JURASSIC GEOLOGY
OF THE WORLD

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PLATE I.—Precipice of Purbeckian and Upper Portlandian limestones, with undercliff of Lower Portlandian sands and Kimeridge Clay, Gad Cliff, Purbeck, Dorset.

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JURASSIC GEOLOGY OF THE WORLD

BY

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To

WILLIAM SMITH
1769-1839
father of historical geology
and

ALBERT OPPEL
1831-1865
founder of zonal stratigraphy

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The comprehensive Treatise of Geology has had its day. No man can hope any longer to assimilate and summarize the whole known geological history of the world. It has become almost a whole-time occupation to keep track of the literature of a single geological system.

This book represents the first attempt at a synthesis of one system on the basis of marine faunas in all parts of the world. Its object is twofold: first, to present a unified description as a reference work, and second, to enquire what can be deduced as to faunal realms, climate, palaeogeography, volcanic and plutonic activity and earth-movements, and especially the distribution of these in space and time, during one reasonably circumscribed period of geological history. The prerequisite of all such investigations is faunal correlation over the whole world, and no small part of the object of this attempt has been to test the principles and performance of palaeontological correlation on the world scale, to establish its capabilities and limitations.

In the Jurassic system ammonites are by far the most important fossils for correlation and consequently they are emphasized in this work, often to the exclusion of other fossils. As originally planned, the book was to have included a systematic review of Jurassic ammonite genera and classification, but this has been detached for publication in the international Treatise of Paleontology, edited by Professor R. C. Moore. The ammonite volume of the Treatise and the present book are therefore to some extent complementary.

The emphasis upon ammonites, regarded by the author as essential, may seem to specialists in other branches of palaeontology to give a lop-sided picture. A review of all the different kinds of life in the Jurassic, from plants and foraminifera to reptiles and mammals, might lend a greater air of completeness and perhaps of balance; but it would greatly increase the length and cost and would add nothing that cannot be found in elementary text-books of geology and palaeontology. Instead, space has been devoted to bringing together evidence on matters less well known, such as faunal realms, permanence of oceans and the chronology of tectonics.

In order to keep as nearly as possible to facts and avoid repeating dubious or erroneous concepts, few palaeogeographical maps are provided. When all the stratigraphical data are sifted it is surprising how often modern information contradicts palaeogeographical maps that have been repeated in book after book for decades. Originally such maps were stimulating and the defence often heard is that they are fertile and suggestive, but it seems to me that we have reached the stage when they often act as an opiate and may do more harm than good. For instance, I am convinced
that the palaeogeographical map of the region surrounding the British Isles which I myself accepted twenty years ago (Jurassic System in Great Britain, 1933, pp. 595, 597) and which still appears in the latest books, is fundamentally wrong and needs to be scrapped. Deep borings in northern Jutland, where land had been assumed, have proved an almost complete suite of Jurassic rocks corresponding palaeontologically, stage by stage, with those in England, and in particular a thick Middle Jurassic Deltaic Series like that in Yorkshire and Scotland. The area must have formed part of the same basin as that in which the Yorkshire rocks were laid down and could not have been cut off from it by the hypothetical 'Cimbria'. On the west the changes required are still more drastic. Here evidence is less uncompromising, but several facts (discussed below) indicate that in place of the hypothetical North Atlantic Continent there rolled the North Atlantic Ocean, much as at present; in fact, Wales was merely an island.

This being the position in respect of the area surrounding the British Isles, I have insufficient temerity to attempt to construct maps for less well-known regions farther afield. The few that are here offered are for the purpose of helping the reader to understand the geology and are to be taken as in the highest degree approximate. Usually, instead of such hypothetical maps, I have attempted to supply sketch-maps of the actual Jurassic outcrops. These enable the text to be followed without any serious departure from the aim of the descriptive chapters to be primarily a factual record.

It has been my personal experience that anyone seeking to understand a single geological system, or even merely to determine collections of fossils from various parts of the world, must flounder in the literature for some twenty years before he can hope to discover all the essential published works, and that when he has specialized for thirty years he will still be surprised from time to time by finding overlooked papers containing some vital pearl of information. Users of this book will be saved some twenty years of work. It is intended for two-way use: as a guide either to the whole Jurassic of a particular area, or to a particular stage over the whole world. Thus anyone confronted with a Bajocian fauna for determination can turn up all the known outcrops of the Bajocian; or, confronted with a collection of doubtful age, he can find the important references to all parts of the Jurassic published for that and neighbouring areas.

While writing the book (1950-4) I have been sent for determination collections of ammonites from England, Scotland, France, Germany, Switzerland, Sicily, Turkey, Morocco, Algeria, Sinai, Kenya, Tanganyika, Madagascar, Arabia, Persia, Baluchistan, Cutch, Tibet, Japan, Australia and New Zealand. In addition I have been loaned or given by friends and correspondents types or other specimens or casts from Canada, Peru, Argentina and Somaliland, and have worked through small collections in the Sedgwick Museum from Bavaria (Solnhofen Slates) and

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Nepal (Spiti Shales). While my judgments may be wrong, therefore, at least they are largely first-hand.

Powerful stimuli to progress and eventual completion were provided by collecting-tours of the Jurassic outcrops of Central Arabia in January 1951 and Algeria in January 1952. For these unforgettable experiences I am profoundly indebted to my friends Dr R. A. Bramkamp, Chief Geologist of the Arabian-American Oil Company, and Professor H. Laffitte and Monsieur Gabriel Lucas, of the Laboratoire de Géologie Appliquée, University of Algiers. In September 1953 I was also privileged to participate as a guest in excursions of the German Geological Society, under the leadership of Dr Helmut Hölder, in the classic regions of the Swabian Alb. To these and other friends and correspondents who have kept me supplied with reprints and with a stream of ammonites from all over the world, this book largely owes its existence.

A few words of explanation on arrangement and lay-out are necessary. The guiding principle has been a purely geographical treatment by continents, for ready reference. The only serious departure from this is the splitting of Europe so that NE. Europe is described with northern Asia. By this means all parts of the Boreal realm are described consecutively; northern Asia leading on directly to Greenland and Arctic America. If Europe were treated as an inviolate continental unit, a large part of the Boreal realm (European Arctic and Russia) would have to be sandwiched between parts of the Tethys. The arrangement adopted leads to a logical sequence through Mediterranean Europe and from Spain across the Straits of Gibraltar to North Africa, and unites the whole Tethys except for a not-too-serious digression to East Africa. The book begins with Britain, not from national prejudice, but because it is the type-area for most of the stages and because it lies at the western edge of Europe and thus provides a logical starting-point.

The boundaries between some of the continents are not so rigidly defined by geographers as might be imagined, and I may therefore be excused for taking some liberties: for instance, I have described Arabia (excepting Oman) with Africa in accordance with geological practice, and both slopes of the Caucasus with Asia. The arrangement by chapters and sections follows natural regions with minimum reliance on political boundaries and names, so often liable to change. Many states are not mentioned by name, but when their geology is described they are indexed.

All tabulated and semi-tabulated stratigraphical matter is arranged right-way-up, with youngest beds at top. The contrary practice, which still prevails in some quarters, seems to be designed for nothing but greater confusion.

Hundreds of ammonites of stratigraphical importance are quoted from published figures. Many of these are redetermined from the figures, and in such cases the revised name is given, followed by the plate and figure reference to the work in question, without further explanation.

Thicknesses are given in metres. These have been converted where
necessary on the basis of 30 m. to 100 ft., so that thicknesses originally published in feet as round numbers retain their essentially approximate character in metres. Heights of mountains, however, are given in feet, and distances in miles, such figures only appearing as part of the English text, not the tabulated matter, and therefore not being suitable for concessions to international convenience.

With increasing mechanical facilities for travel, it may before long become easier to visit and study an outcrop in any part of the world than to discover, procure, translate and interpret the local published description. In that event ‘literature’, that great bugbear, will become largely redundant. Meanwhile I have to thank friends and librarians in the United States, and especially Professor Maxim K. Elias of Nebraska, for procuring me photostats and microfilms of several important Russian papers not in this country and unobtainable, and Professor A. S. Besicovitch, F.R.S., of Trinity College, for time spent in translating orally from the Russian. Other Cambridge colleagues have kindly supplied me with written translations from Russian, Serbo-Croat and Japanese.

Mr A. G. Brighton, Librarian and Curator of the Sedgwick Museum; Miss A. Barber, Librarian of the Geological Society, and her staff; Mr H. B. Rowbotham, Geological Librarian of the British Museum (Natural History); and the photostat service at the Science Library, London, have all shown much patience and resourcefulness. Without them the literature barrier could never have been broken down.

Certain chapters and sections have been kindly read by Mr G. C. Band, Dr D. T. Donovan, Mr P. Evans, Dr H. Frebold, Mr W. B. Harland, Mr N. F. Hughes, Dr G. M. Lees, Dr J. Marwick, Prof. T. Matsumoto, Mr T. G. Miller, Prof. H. Stille, Mr P. C. Sylvester-Bradley, Mr H. R. Warman and Mr C. W. Wright, and I am most grateful for their criticisms and corrections, as also for those of Professor P. Allen, who generously gave up much time to reading the page proofs. Many errors and omissions no doubt remain in the book, but they are my responsibility.

First and last my gratitude is due, and most deeply felt, to the Master and Fellows of Trinity College, Cambridge, who by electing me to a Research Fellowship enabled me to follow lines of thought on which my heart was set, and to Professor W. B. R. King, F.R.S., through whose hospitality I have enjoyed the facilities of the Sedgwick Museum.

W. J. A.

SEDGWICK MUSEUM
CAMBRIDGE
July 1954
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PART I
INTRODUCTION
CHAPTER I

CLASSIFICATION AND CORRELATION

THE JURASSIC AMONG THE SYSTEMS

As the middle system of the middle (Mesozoic) group of fossiliferous rocks, the Jurassic is as good a sample as any that could be chosen to find out what light can be thrown on geological problems by study of a single system all over the world.

In the popular imagination the Jurassic is the period of great marine reptiles and flying dragons. To the average palaeontologist it is perhaps primarily the period of the diminutive proto-mammals and toothed birds, of the first known fully-elaborated freshwater molluscan faunules, and of a bewildering host of ammonites. To the palaeobotanist it is a period of somewhat monotonous world-wide floras composed mainly of conifers, ferns and cycads, but also of the first possible indications of angiosperms. To the palaeoclimatologist it is characterized by uniformity of climate and lack of evidence for glaciation. The igneous petrologist and volcanologist find relatively little that is not displayed much better in other systems, and to the structural geologist the Jurassic was the most passive of the geological periods.

For the stratigrapher, however, the Jurassic is the very well and fountain of his subject. It was on the Jurassic rocks that William Smith, Father of Historical Geology, founded the science of stratigraphy, enunciated the law of superposition, identified fossils with particular strata, and named the classic formations. It was on Jurassic rocks that Oppel founded modern zonal stratigraphy and named the classic zones. It was for Jurassic rocks that d’Orbigny introduced the first scheme of stages. All these concepts became part of the fabric of stratigraphical geology the world over.

Although the approximately 25 million years of the Jurassic period (from about 152 to 127 million years ago according to Holmes, 1947) were on the whole tectonically quiet, they nevertheless witnessed extensive changes. It was a period of preparation for the mountain-building revolutions to come—for the most part in the Cretaceous or Tertiary, but in North America, the Caucasus and Crimea shortly before the end of the Jurassic. The preparations consisted of long-continued subsidence of geosynclines and the filling of them with sediments, several thousands of metres thick, which implies massive denudation of uplands. There were also more widespread, less localized, subsidences and upheavals, of epeirogenic type. These were less spectacular than the orogenic and pre-orogenic movements but they were more important for organic evolution. By opening and closing seaways, controlling ocean currents

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and thereby migrations, and by isolating faunas, the epeirogenic move­m ents had a profound effect on evolution. It has often been claimed that orogenic revolutions were the prime cause of evolution; but if this were true, the ferment of evolutionary activity in so many forms of life during the Jurassic would be inexplicable.

However, we must not be tempted at this stage to anticipate the substance of later chapters.

Before we set off to test the theories of geology along the great Jurassic escarpments of Bavaria and central Arabia, through the sunbaked lime­stone uplands of Andalusia and Dalmatia, the scorching coastlands of Africa, the jungles of Indonesia and Burma, the peaks of Himalaya and the American cordilleras, and among the polar ice, we must acquire the discipline of a classification.

The Units of Classification

In order to be able to begin to describe or discuss a geological system it is necessary to have a classification. For all fossiliferous sedimentary systems three separate classifications have grown up, based on different concepts and requirements and built up of different kinds of units. Each has its place and all three are interdependent, but they should not be mixed. On the first system the rocks are divided into Formations, on the second into Zones, on the third into Stages. It is essential to have a clear understanding of the nature, advantages and limitations of each kind of unit.

Formations. A formation is a convenient lithological rock unit in a particular area and the basis of geological mapping. It is essentially defined by lithology, but that in turn may be sometimes influenced by abundance of certain kinds of fossils to such an extent that the fossils determine the formation; for example, corals, sponges, or oysters may build a large part of the rock. Typical formations in the English Jurassic are the Lias, Inferior Oolite, Forest Marble, Oxford Clay, Coral Rag, Portland Stone, Purbeck Beds; in France the Calcaire de Caen, Oolithe Miliaire and Choin; in Germany the Einbeckhäuser Plattenkalk and Serpulite. The size and scope of the formations are as varied as the names. This is not surprising, since most of them go back to the beginnings of geology: in England most of them were named by William Smith between 1799 and 1815. They are still, however, the basis of all classification and the ultimate court of appeal for settling problems of zonal succession and correlation. Any attempt to standardize them, or modify them in any way, would be disastrous; and such attempts would be futile, for units of classification for modern purposes are provided by the zones and stages.

Groupings into units of higher rank in this same scale are equally arbitrary, inconsistent and heterogeneous, having arisen at different times as a convenience. They too have their uses and historical claims to
freedom from 'reform'. But they grade into formations and like them are strictly limited geographically. In the other direction, formations can be subdivided to any extent required.

In Britain and other European countries the formation names in geological literature have historical associations and antiquity and a consequent individuality which makes them useful and easy to remember. It is not so with many formations recently introduced in some other parts of the world. A superabundance of formation names (which by themselves convey nothing) can choke the literature and build a formidable barrier between writer and reader.

ZONES. Palaeontologically the old formations are often too comprehensive and also inconsistent in content from place to place. The need for time-planes independent of lithology and geography, so that rocks may be correlated more satisfactorily, led to the concept of the Zone.

The hallmark of a zone is the assemblage of guide fossils, of which one is selected as index species and gives its name to the zone. These are supposed to have lived, for practical purposes, contemporaneously, wherever they occur.

Like so many fundamental concepts, the zone is a subject of unending controversy. There are many kinds of zone: faunizones based on assemblages of fossils, biozones based on the evolutionary duration of a species, teilzones based on the local presence of a species, and so on. (For a full exposition see Arkell, 1933.) But over and above these considerations there is uncertainty as to the basic concept of the zone: whether as originally conceived by Oppel it was a stratum or bed, or a time-interval, or an abstract combination of the two,—a hypothetical column of sediment (probably nowhere actually existing) representing the time of duration of the index species on the assumption of continuous sedimentation at some unknown average rate.

British geologists have always envisaged a zone as a bed or stratum, a tangible object accessible to the hammer, though differing lithologically from place to place. Consequently some have thought it necessary to construct a parallel terminology to express the time units to which the various kinds of zones correspond. The need to keep time and rock distinct in our thoughts is obvious, and to the extent that this elaborate terminology has led to clarification of thought it has served a useful purpose. But beyond that it is unnecessary. No one uses it, nor ever will.

That Oppel himself fully appreciated the time element cannot be doubted (Schindewolf, 1950). The fact that he nowhere defined a zone, nor made it clear whether his zones were strata or time intervals, may be taken to mean that he visualized zones from both aspects at once. The argument that a zone must be one or the other is sterile. A zone is much more than a mere bed or stratum, or a formation, because it is an abstraction and a generalization: it is in theory any bed, stratum, or formation deposited in any part of the world during the period in which the index fossils lived. To mention a concrete example: the Mariae Zone

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is part of the Oxford Clay in the south of England and part of the Lower Calcareous Grit in the north of England and the marls of Mount Hermon in Syria, but we do not know whether it exists in Japan, because no comparable fauna has been found there. Wherever it is, the Mariae Zone is a bed or part of a formation, but this does not express its whole entity: it transcends all local occurrences, and the factor which enables it to do this is the time element in the concept. Anything deposited during the critical period of time is part of the zone.

In practice zones have their limitations because for various reasons no fossils fulfil perfectly all the requirements of zonal indices, namely, ease of identification, combined with short vertical and universally wide horizontal range. The best zone fossils are often the most difficult to identify, because their short vertical range depends on subtle characters undergoing rapid evolution, and, owing to the existence of ecological and palaeogeographical barriers and provinces, no fossils are evenly distributed over the whole earth. It is therefore necessary to construct a separate zonal column for each faunal province.

The degree of refinement of the zonal scale that may be possible depends on a number of local factors, not the least of them the lithological. Given ideal lithology and abundance of suitable fossils, a high degree of refinement may be achieved in a restricted area, but the more the area is enlarged the more the refinements break down. This has obvious explanations, which have been discussed elsewhere (Arkell, 1933, pp. 30-35). For correlations from one part of Europe to another the smallest units of practical value are astonishingly near the first set of zones promulgated by Oppel. His pioneer studies of western Europe led him to a remarkably just appraisal of the possibilities. The few last attempts to apply Buckman’s ‘polyhemeral’ chronology across Europe (e.g. Roché, 1939) have been conspicuously unsuccessful, and the only justification put forward for these attempts is a repetition of Buckman’s claim that in relation to the slow speed of evolution and deposition the time required for the universal spread of a species is negligible—like the flight of an aeroplane in relation to the process of bricklaying, as he put it. The argument is fallacious, since many different lineages were evolving and migrating simultaneously and so the succession is bound to vary in different places: all did not wait their turn while each species completed its migrations (Arkell, 1933, p. 33, fig. 1).*

Experience has now shown that minute subdivisions, such as those made by Buckman in the English Lias, are not recognizable even in other European countries, but that over wide areas only the general faunal succession such as is expressed by Oppel’s zones and a few subzones can be recognized. This, moreover, is true even for the Lias, which is by far the most favourable part of the Jurassic for zonal subdivision and

* Roché assumes that Buckman carefully chose as hemeral indices ammonite species which were short-lived and spread rapidly. He did not. His polyhemeral tables comprise a completely random selection of ammonites and only a very small fraction was based on any field experience such as could enable such a choice to be made.

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correlation over long distances. For the Upper Jurassic even Oppel’s zones are often too small to be recognized outside Europe.

STAGES. Just as it is convenient to group together formations into Series, so it is convenient to group like zones together and reduce the numbers for practical purposes, and above all to have a grouping which enables several zones to be correlated in a general way over long distances when the zones individually are too precise. Such groupings of zones are Stages. They transcend zones horizontally as well as vertically and provide a stratigraphical unit of wider use, adapted to inter-continental comparisons and correlations. Whereas the individual zone cannot be recognized beyond the area of occurrence of its index species or typical fauna, a stage can be followed all over the world by a series of overlapping correlations and by the general grade of evolution of its critical fauna.

The hallmarks of a stage-name are that it is based on the (modern or ancient) name of a place or district and has the termination -ian (in French -ien). Names in this form began to be coined for formations in France during the second quarter of the nineteenth century by Brongniart, Marcou and d’Orbigny, but it was not until 1850 that d’Orbigny introduced for the Jurassic and Cretaceous his standard set of stages which are still used to this day. To attempt to unravel and revert to the ancient terms and meanings of before 1850 would produce chaos, for before that date knowledge of stratigraphy was so primitive that no clear definition of a stage-name was possible, nor was there any clear conception of the requirements of the future. (For example Brongniart’s Oxfordien, 1829, also used by Marcou before 1850, covered the whole Middle Jurassic, and Bathonien was first used in 1843 as synonymous with the German Dogger.)

D’Orbigny’s scheme of 1850 was based on the classical areas of northwest and central Europe, and with a few modifications it has stood the test of a century and is now used, with those few essential modifications, as the framework for this book. It contains a convenient number of stages, neither too many nor too few, and is by far the best scheme yet devised for classification on a world scale.

**Standard Scheme of Stages**

**Upper Jurassic**
- Purbeckian (Purbeck, Dorset, England)
- Portlandian (Portland, Dorset, England)
- Kimeridgian (Kimeridge, Dorset, England)
- Oxfordian (Oxford, England)

**Middle Jurassic**
- Callovian (Callovium = Kellaways, Wiltshire, England)
- Bathonian (Bath, Somerset, England)
- Bajocian (Bajoce = Bayeux, Normandy, France)

**Lower Jurassic**
- Toarcian (Toarcium — Thouars, Deux-Sèvres, France)
- Pliensbachian (Pliensbach, near Boll, Württemberg, Germany)
- Sinemurian (Sinemurium = Semur, Côte d’Or, France)
- Hettangian (Hettange, Lorraine, France)

From the Hettangian up to the Middle Kimeridgian these stages can be recognized all over the world, but after that the scheme breaks down owing to regional differentiation of faunas. The terms Portlandian and Purbeckian are applicable only to NW. Europe, except that Purbeckian faunas extend to Savoy and Portlandian to Greenland and perhaps central Russia. In Russia and the Arctic there is otherwise a completely separate ammonite fauna, for which the stage-name Volgian has to be used. Over all the rest of the world the presumed equivalents of these late Jurassic stages have nothing in common with either NW. Europe or Russia and are known as the Tithonian.

Vast numbers of other stages have been proposed by different authors but their very numbers proclaim their futility.* Some synonyms die harder than others, because locally they may seem more reasonable and more practical than the universal terms. Examples are the Aalenian and Domerian (on which I have conducted a lengthy correspondence with colleagues in my own and other countries before deciding not to use them); but on a world view these are no more necessary than the hundred or more other stage names available.

The principles, or rules, on which the names now used have been chosen have been explained at length elsewhere (Arkell, 1946). They are a compromise between priority, suitability and usage. On the whole these self-imposed rules have been adhered to, but a few decisions then made have had to be reconsidered in the light of seven years' further experience. Purbeckian has been reinstated as a separate stage instead of merging it in the Portlandian as advocated by Haug, a procedure likely to cause confusion; and Berriasian has been adopted for the lowest stage of the Cretaceous, in conformity with almost universal modern usage. Although Oppel's Tithonian is not named after a place, it is too late to abolish it after a hundred years of continuous use.

In the above table the Lower, Middle and Upper Jurassic are constituted as nearly as practicable in accordance with von Buch's original arrangement in his classic paper (1839). Von Buch's scheme has priority and produces a better balance than the more usual French and English custom of regarding the Callovian as Upper Jurassic. Even this arrangement is not quite the same as von Buch's, for he included in the Middle Jurassic the condensed Lower Oxfordian of the Swabian Jura, which is often a mere nodule bed (Oppel's Biarmatum Zone) at the top of the Brown Jura (Zeta); and he was followed by Quenstedt. However, it is undesirable to split the Oxfordian stage between the Middle and Upper Jurassic, and since it is always regarded as Upper Jurassic in regions where it is more fully developed, a small departure from von Buch's pioneer scheme seems necessary.

* To the 120 listed by me in 1933 (p. 617) can be added: Alpinian (de Gregorio, 1885), Ardescian (Toucan, 1899), Dubisian (Gardet, 1942), Nevisian (Rozycki, 1948), Suebian (Hennig, 1943), Wetlianian (Ilovaisky & Florensky, 1941). We have even reached the stage of unconscious homonyms: for Dubisian Gardet, 1942, is applied to quite a different part of the stratigraphical column from Dubisian Desor, 1859.
CLASSIFICATION AND CORRELATION

INTERPRETATION OF THE STAGES

As units of the single world scale of classification Stages must be based on zones. As now used they are essentially groupings of zones, but they transcend zones both vertically and horizontally.

At the time d'Orbigny promulgated his scheme of stages, however, although he was the first to use the term zone, the zonal concept current to-day had not been born. It derives essentially from Oppel (1856-63). D'Orbigny listed certain ammonites supposed to be characteristic of each stage, but at that early date the specific names he used (all referred to the single genus *Ammonites*) so often had quite different meanings from those attaching to them to-day, and so many were wrongly used, or ambiguous, or assigned to two stages, or included as the result of incorrect stratigraphical information, that any attempt to interpret the stages primarily by means of these lists of ammonites leads to chaotic results.

The formations, on the contrary, had been defined all over western Europe and were especially well known in the areas after which d'Orbigny named the stages. It was essentially on formations that the stages were based.

A process akin to translation is therefore necessary to render the stages as defined by d'Orbigny on the basis of formations into the stages as used in modern stratigraphy, which must be defined on the basis of zones. Fortunately d'Orbigny gave a more or less clear definition of each stage in terms of formations at some type locality or type area. It is generally a simple matter now to establish the zones represented in those formations at the type locality, and thus to arrive at a satisfactory definition of the contents of each stage.

D'Orbigny's type localities, however, are not always precisely those from which the stage-name was derived. For instance, he defined the Callovian and Oxfordian stages, not in accordance with successions at Kellaways and Oxford, where no comprehensive exposures existed, but on the cliffs of the Yorkshire coast, which had been fully described stratigraphically and palaeontologically by Phillips. The terms Kellaways (or Kelloway) Rock and Oxford Clay have since been proved to have been wrongly applied in Yorkshire, but nevertheless it is better at this late date to accept d'Orbigny's definitions although based on Phillips' errors.* Solutions of the various problems that arise in attempting to redefine d'Orbigny's stages have already been proposed, and all this will not be repeated here. (See Arkell, 1946; 1951, pp. 16-19.)

When a new fauna is found elsewhere, not present or not detected at the type locality, it falls readily into place if it comes between two zones already in the same stage, but if it falls at the boundary between two stages it has to be classed according to its nearest palaeontological affinities. In practice, surprisingly few difficulties have arisen on this score.

* One reason in this case is that owing to lack of exposures the faunal succession in the Kellaways district is still uncertain.
<table>
<thead>
<tr>
<th>Stages</th>
<th>Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Jurassic—</td>
<td></td>
</tr>
<tr>
<td>Purbeckian</td>
<td>[No ammonites]</td>
</tr>
<tr>
<td>Portlandian</td>
<td>Titanites giganteus</td>
</tr>
<tr>
<td></td>
<td>Glauconithites gorei</td>
</tr>
<tr>
<td></td>
<td>Zaraiskites albani</td>
</tr>
<tr>
<td>Kimeridgian</td>
<td>Pavlovia pallasioides</td>
</tr>
<tr>
<td></td>
<td>Pavlovia rotunda</td>
</tr>
<tr>
<td></td>
<td>Pectinatites pectinatus</td>
</tr>
<tr>
<td></td>
<td>Subplanites wheatleyensis</td>
</tr>
<tr>
<td></td>
<td>Subplanites spp.</td>
</tr>
<tr>
<td></td>
<td>Gravesia gigas</td>
</tr>
<tr>
<td></td>
<td>Gravesia gravesiana</td>
</tr>
<tr>
<td></td>
<td>Aulacostephanus pseudomutabilis</td>
</tr>
<tr>
<td></td>
<td>Rasenia mutabilis</td>
</tr>
<tr>
<td></td>
<td>Rasenia cymodoce</td>
</tr>
<tr>
<td></td>
<td>Pictonia baylei</td>
</tr>
<tr>
<td>Oxfordian</td>
<td>Ringsteadia pseudocordata</td>
</tr>
<tr>
<td></td>
<td>Decipia decipiens</td>
</tr>
<tr>
<td></td>
<td>Perisphinctes cautisnigrae</td>
</tr>
<tr>
<td></td>
<td>Perisphinctes plicatilis</td>
</tr>
<tr>
<td></td>
<td>Cardioceras cordatum</td>
</tr>
<tr>
<td></td>
<td>Quenstedtoceras mariae</td>
</tr>
<tr>
<td>Middle Jurassic—</td>
<td></td>
</tr>
<tr>
<td>Callovian</td>
<td>Quenstedtoceras lamberti</td>
</tr>
<tr>
<td></td>
<td>Peltoceras athleta</td>
</tr>
<tr>
<td></td>
<td>Erymnoceras coronatum</td>
</tr>
<tr>
<td></td>
<td>Kosmoceras jason</td>
</tr>
<tr>
<td></td>
<td>Sigaloceras calloviense</td>
</tr>
<tr>
<td></td>
<td>Proplanulites koenigi</td>
</tr>
<tr>
<td></td>
<td>Macrocephalites macrocephalus</td>
</tr>
<tr>
<td>Bathonian</td>
<td>Clydoniceras discus</td>
</tr>
<tr>
<td></td>
<td>Oppelia aspidoides</td>
</tr>
<tr>
<td></td>
<td>Tulites subcontractus</td>
</tr>
<tr>
<td></td>
<td>Gracilisphinctes progracilis</td>
</tr>
<tr>
<td></td>
<td>Zigzagiceras zigzag</td>
</tr>
<tr>
<td>Bajocian</td>
<td>Parkinsonia parkinsoni</td>
</tr>
<tr>
<td></td>
<td>Garantiara garantiara</td>
</tr>
<tr>
<td></td>
<td>Strenoceras subfurcatum</td>
</tr>
<tr>
<td></td>
<td>Stephanoceras humphriesianum</td>
</tr>
<tr>
<td></td>
<td>Otoites sauzei</td>
</tr>
<tr>
<td></td>
<td>Sonninia sowerbyi</td>
</tr>
<tr>
<td></td>
<td>Ludwigia murchisonae</td>
</tr>
<tr>
<td></td>
<td>Tmetoceras scissum</td>
</tr>
<tr>
<td></td>
<td>Leioceras opalinum</td>
</tr>
</tbody>
</table>
The possibility of describing and analysing a geological system as a whole, all over the world, depends primarily on availability of a single universal language for use in classification. This language the stages provide. Their great value for this purpose is impaired if different countries introduce their own scheme of stages. Those recently proposed, for instance, for New Zealand, are not true stages, since they are not definable in terms of zones and are not applicable outside New Zealand. They are in reality Series, or groups of formations. An independent scale of classification for the Jurassic rocks of New Zealand was a necessity and these names will no doubt be invaluable as a basis for further work in that country; but in this book the terminations -ian, -an will be reserved for stages in the old sense, which can be defined palaeontologically and used virtually in any part of the world.

Those geologists who like to keep time terms separate from rock terms consider a stage a rock term and an age its equivalent time-term. The term age, however, has also been used (especially by Buckman) for the time of dominance of a particular ammonite genus or family. These latter ages are smaller subdivisions than stages and are in fact more nearly equivalent to zones. The old classical species of the mid-nineteenth century, which were selected by Oppel as index fossils for his zones, have for the most part now become genera, with the result that the dominant species of Oppel’s day is much the same as the dominant genus of to-day. It results that Buckman’s ammonite ‘ages’ (tabulated in Arkell, 1933, p. 24) are more or less reflections of Oppel’s zones. They suffer from all

### Table 1—continued

<table>
<thead>
<tr>
<th>Stages</th>
<th>Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lower Jurassic—</strong></td>
<td></td>
</tr>
<tr>
<td>Toarcian</td>
<td>Lytoceras jurene</td>
</tr>
<tr>
<td></td>
<td>Hildoceras bifrons</td>
</tr>
<tr>
<td></td>
<td>Harpoceras falcifer</td>
</tr>
<tr>
<td></td>
<td>Dactylioceras tenuicostatum</td>
</tr>
<tr>
<td></td>
<td>Pleuroceras spinatum</td>
</tr>
<tr>
<td></td>
<td>Amaltheus margaritatus</td>
</tr>
<tr>
<td></td>
<td>Prodactylioceras davoei</td>
</tr>
<tr>
<td></td>
<td>Tragophylloceras ibex</td>
</tr>
<tr>
<td></td>
<td>Uptonia jamesoni</td>
</tr>
<tr>
<td></td>
<td>Echioceras raricostatum</td>
</tr>
<tr>
<td></td>
<td>Oxynoticeras oxynotum</td>
</tr>
<tr>
<td></td>
<td>Asteroceras obtusum</td>
</tr>
<tr>
<td></td>
<td>Euasteroceras turneri</td>
</tr>
<tr>
<td></td>
<td>Arnioceras semicostatum</td>
</tr>
<tr>
<td>Hettangian</td>
<td>Schlotheimia angulata</td>
</tr>
<tr>
<td></td>
<td>Psiloceras planorbis</td>
</tr>
</tbody>
</table>
the limitations of zones, for they do not apply universally. For instance, no one can recognize the rocks belonging to Kosmoceratan, Quenstedtoceratan or Cardioceratan ‘ages’ in the southern hemisphere, where these genera do not exist. It is, however, possible to recognize the Callovian and Oxfordian stages, because those are abstractions, not dependent on occurrence or absence of any particular index species or index genera,

### Table 2.—Upper Jurassic Ammonite Zones of the Western Tethys (Central and Southern Europe)

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upper Tithonian</strong></td>
<td>Virgatosphinctes transitorius (Berriasella chaperi and B. delphinensis)</td>
</tr>
<tr>
<td><strong>Middle Tithonian</strong></td>
<td>Semiformiceras semiforme</td>
</tr>
<tr>
<td><strong>Lower Tithonian</strong></td>
<td>Berriasella ciliata and Anavirgatites palmatus Subplanites vimineus</td>
</tr>
<tr>
<td></td>
<td>Taramelliceras lithographicum and Hybonoticeras hybonotum</td>
</tr>
<tr>
<td><strong>Middle and Lower Kimmeridgian</strong></td>
<td>Hybonoticeras beckeri Aulacostephanus pseudomutabilis Streblites tenuilobatus</td>
</tr>
<tr>
<td><strong>Oxfordian</strong></td>
<td>Epipeltoceras bimammatum Gregoryceras transversarium Cardioceras cordatum Quenstedtoceras mariae</td>
</tr>
</tbody>
</table>

but recognized by the general grade of evolution of the ammonite fauna as a whole and by a chain of overlapping correlations carried link by link round the world.

### The Guide Fossils of the Jurassic

It is a commonplace that for the three Mesozoic systems ammonites provide incomparably the best zonal index fossils. For the four requirements of the ideal index fossil—short vertical range, wide horizontal range, independence of facies, and ease of recognition—the ammonites score heavily over all other fossils, except perhaps for ease of recognition.

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On the first two requirements (the most important) they have no serious rivals. Marine pelecypods have been found in recent years to have much longer ranges than had sometimes been supposed: single species in Europe alone often range through four or five stages and many ammonite zones. This makes them of little value for correlation in spite of the great geographical extension of some of them, which may exceed that of many ammonites. It is illuminating (to name an instance personally brought home to me) to find the limestone escarpment of Jebel Tuwaiq in central Arabia strewn with some of the same species of pelecypods as may be picked up in the English Cotswolds—Pholadomya, Homomya, Mactromya, Ceromyopsis, etc.; but whereas in the Cotswolds the limestones enclosing them are Bajocian, in the Jebel Tuwaiq they are Upper Bathonian and Callovian.

Gastropods are sometimes useful locally, where ammonites are rare or non-existent, but they too have long ranges, some species occurring through four stages.

Brachiopods are also helpful locally, but over wider areas they are disqualified because of their colonial habits, heavy dependence on facies and frequent homoeomorphy.

On the third requirement, independence of facies, most groups of fossils take low marks and even ammonites are not entirely successful here. The types of facies in which ammonites are seldom found are coral reef and current-bedded rocks. This is not the place to enter into the wide fields of speculation concerning the mode of life of ammonites, but there is much to be said for the hypothesis of Termier & Termier (1951) that many bred in loose mud among marine vegetation, which on decaying could have produced the iron and sulphur that went to make the iron pyrites in which large numbers of ammonites in clays and shales are so often preserved.

The clay milieu which was so favourable to many ammonites seems to have been inimical to others, such as Stephanocerataceae, which are usually linked with limestone deposits (Arkell, 1952, pp. 83-4). The great variety of forms and apertural modifications among ammonites strongly suggests that there were adaptations to almost every kind of niche, excepting always coral reefs and the distributaries of deltas. In addition their floating shells were probably carried far and wide after death, like Nautilus shells at the present day, by winds and currents. Drifted specimens therefore may come to the rescue of stratigraphers in unlikely places.

As to the fourth requirement of a zonal index fossil, ease of recognition, ammonites have lately been gaining ground since the introduction of statistical methods of classification in pelecypods and brachiopods.

Therefore, wherever ammonites are present they take pride of place. Where they are absent other fossils are brought in for local correlation of Jurassic rocks just as for the Chalk; but at the best of times such schemes of classification and correlation are make-shifts and liable to be overthrown by the discovery of a single ammonite.

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This was already perceived by both d’Orbigny and Oppel in the middle of the nineteenth century: d’Orbigny gave lists of ammonites to help identify each of his stages, but he listed no other fossils; and Oppel used an ammonite species wherever he knew of a suitable one, as index for each of his zones.

Accordingly the emphasis throughout this book is overwhelmingly on ammonites. The zonal index species for NW. Europe, the Tethys, Russia and the Arctic (tables 1-3) will be found illustrated on plates 31-46 at the end of the book.

It remains only to mention that for freshwater beds ostracods provide the most promising means of subdivision and correlation. References to the excellent research done on this subject will be found under the Purbeckian of England, Lower Saxony and the Jura Mountains (pp. 19, 90, 134).
PART II
WESTERN AND SOUTHERN EUROPE
CHAPTER 2
THE BRITISH ISLES

The British Jurassic having been summarized already (Arkell, 1933), the present account is reduced to essentials for understanding the ammonite succession as a basis for correlation elsewhere. The list of references (p. 643) contains only items published since 1933 and consequently is fuller than the lists for other regions of Europe, which are selections of

the most important sources published in the last hundred years. (For British Jurassic bibliography before 1933, see Arkell, 1933.)

The British Jurassic rocks comprise a highly variable series of formations laid down as shelf and trough deposits upon the Upper Triassic Keuper lake beds and thin marine Rhaetic Beds. They reach a maximum thickness of about 1000 m. in the south of England and in Yorkshire,
seldom a little more (Portsdown boring 1294 m.). Where normally
developed, they show a marked tendency to cyclic lithology; the tri-
partite sequence, clay, sand, limestone is repeated many times. Yorkshire
and Scotland differ by having a deltaic development of most of the Middle
Jurassic, but otherwise are essentially similar. The sand/sandstone
member of the various cycles is always more or less diachronic, sometimes
markedly so. The highest Upper Jurassic stages, the Upper Kimeridgian,
Portlandian and Purbeckian, are present only in the south of England.
They are perfectly conformable with one another and the Purbeckian
passes up imperceptibly into the Wealden. In Lincolnshire and York­
shire marine Neocomian rests transgressively on Kimeridge Clay
(Swinnerton, 1935), and farther south, in places where the Wealden lake
beds are absent, marine Aptian or even Albian rests transgressively or (as
in Dorset) unconformably on various formations of the Upper Jurassic.
Volcanic rocks are absent from the British Jurassic. Conglomerates
are few, thin and altogether inconspicuous, except in the Lower
Kimeridgian of East Scotland, close to an Old Red Sandstone shoreline
(Bailey & Weir, 1932; Waterston, 1951). Internal unconformities are
seldom so marked that they can be detected without mapping, but very
gentle ones do exist, especially in the Bajocian of the Cotswolds. Dis­
conformities are frequent. Besides the Middle Jurassic deltaic beds in
Scotland and Yorkshire there are beds of partly 'estuarine' facies in the
Bathonian of the Midlands and a thin brackish or freshwater bed with
*Viviparus* in the Bathonian of Oxfordshire. The Purbeckian is largely
brackish and partly lacustrine. Liassic shorelines exist in South Wales
and round the Mendips and neighbouring hills, which were an archipelago
in the Lower Jurassic sea.

Summaries and revisions of many areas have been published since
1933. The principal ones are as follows:—

General lie of the Jurassic of England: Lees & Taitt, 1946; Kent,

Dorset: Kellaway & Wilson, 1941; Chatwin, 1948; Arkell, 1947,
1951a, 1951b.

Cotswolds: Gardiner & others, 1934; Richardson, 1933; Cox, 1941,
1950; Kellaway & Welch, 1948; Channon, 1950.

Oxford district: Arkell, Richardson & Pringle, 1933; Richardson &
others, 1946; Arkell, 1939b, 1943, 1944, 1947a.

East Midlands: Richardson, 1938-40; Hollingworth & others, 1944;
Hollingworth & Taylor, 1946, 1951; Edmunds & Oakley,
1947; Kent, 1947; Wilson, 1948; Whitehead & others, 1952.

Lincolnshire: Richardson, 1938-40; Kent, 1941; Swinnerton & Kent,
1949; Wilson, 1948a; Evans, 1952.

Yorkshire: Wilson, Hemingway & Black, 1934; Rastall &
Hemingway, 1940-49; Smithson, 1934, 1942; Wilson, 1936, 1938,
1948a; Arkell, 1945; Sylvester-Bradley, 1953.

Scotland: Macgregor, 1934; Waterston, 1951.
PURBECKIAN (Purbeck Beds, max. c. 120 m.) (Plate 36)

A thin-bedded sequence of marine, brackish and lacustrine strata with a varied and rich fauna. The commonest fossils are pelecypods (Corbula, ‘Cyrena’, Unio) and gastropods (Viviparus, Hydrobia, Valvata, Physa), but there are some purely marine bands with Pecten, etc., and an oyster lumachelle (Cinder Bed) with Trigonia and Hemicidaris. Some horizons are rich in fish, insects, isopods, or ostracods, and there are one or more dirt beds with coniferous trees and cycads in position of growth. Characea are abundant in some of the lacustrine beds. For full descriptions of the Dorset type-sections, see Arkell, 1947, ch. vii, and Sylvester-Bradley, 1949. The Swindon exposures and those in the Oxford district are described by Sylvester-Bradley, 1940; Arkell, 1947a, ch. viii, and Arkell, 1948. For studies of the ostracods and other fossils see Anderson, 1939, 1940, 1940a; Sylvester-Bradley, 1949; Arkell, 1941; Harris, 1939. The Dorset succession is as follows, with ostracod zones according to Sylvester-Bradley, 1949.

UPPER (22 m. +)—
Viviparus clays
Marble beds and ostracod shales
Unio beds
Broken shell limestone

Zone of Pseudocypridina setina

MIDDLE (47 m.)—
Chief beef beds
Corbula beds
Upper building stones (Scallop and Intermarine beds)
Cinder bed
Lower building stones (Cherty and Marly Freshwater beds)
Mammal bed

Zone of Cypridea granulosa

LOWER (50 m.)—
Marls with gypsum and insect beds, and cockle beds
Broken beds and Cypris freestone
Caps and dirt beds (tufa, etc.)

Zone of Cypris purbeckensis

PORTLANDIAN (Portland Beds, max. c. 72 m.) (Plates 1, 2, 3)

Where most fully developed, in Purbeck and Portland and north of Weymouth, the Portland Beds consist of the Portland Stone above and the highly variable Portland Sand below. The latter consists largely of marls, loams, cementstones and stinkstones, often glauconitic, and inland it is represented by glauconitic sandy limestones, locally quarried for building. The Portland Stone (34-35 m. in Purbeck, 27 m. in Portland) contains giant Perisphinctids throughout; until these have been monographed (an arduous task owing to the great size and weight of the material and the difficulty of extracting it from rock not quarried), it is best to consider the whole as belonging to one zone of Titanites giganteus Sowerby sp. (House, 1955). (For statement of the position, see also Arkell, 1947, pp. 90-95.) There is a rich fauna of large pelecypods, and at the top in

http://jurassic.ru/
Portland the Roach bed is full of the turreted gastropod Aptyxiella portlandica (Sowerby). The succession is:—

Zone of Titanites giganteus (up to 35 m.). Portland Freestone Beds above, Cherty Beds below. Inland the Freestone Beds are represented by rubbly creamy limestones, the Cherty Beds by sands and sandstones (Swindon Sands and Stone) with rubbly limestones (Cockly bed) at base, the latter with abundant Titanites and Kerberites.

Zone of Glaucolithites gorei (Salfeld). These evolute Pavlovia-like ammonites occur in the upper part of the Portland Sand in Dorset, in the glauconitic Tisbury Stone in the Vale of Wardour (of which Salisbury Cathedral is mainly built) and in thin glauconitic beds (1-3 m.) at Swindon and near Oxford and Aylesbury, at all of which places there is a basal lydite bed (Upper Lydite Bed).

Zone of Zaraiskites albani (Arkell) (1935, p. 339, pl. 26, fig. 2). So far found only in Purbeck, in the lowest 11 m. of the Portland Sand (Emmit Hill Marls and basal Massive Bed). With the Zaraiskites are poorly-preserved Pavloviae.

KIMERIDGIAN (Kimeridge Clay*, max. 495 m.) (Plates 1, 2)

In Dorset the whole formation consists of clays and shales, with some cementstone bands and septarian nodules, but inland, at Swindon and about Oxford and Aylesbury, the Pectinatus Zone in the Upper Kimeridgian is developed as sands with sandstone doggers. The maximum thickness is reached in Purbeck, around the type locality of Kimeridge. Twenty miles farther west, in the Weymouth district, the thickness is nearly halved. Inland it is reduced to 90 m. at Swindon and about 30-45 m. at Oxford, although Lower, Middle and Upper Kimeridgian are all represented. The highest Jurassic in Yorkshire probably belongs to the Wheatleyensis Zone. The ammonite zones recognized are as follows:

UPPER KIMERIDGIAN

Zone of Pavlovia pallasioides (Neaverson). In Dorset c. 21 m. of marls and clays with badly-preserved crushed Pavloviae. The type locality is Hartwell, near Aylesbury, where the Hartwell Clay yields P. pallasioides, P. hartwellensis and other species (Neaverson, 1925, pl. ii, figs. 3-5, pl. iii, figs. 5, 6) and also Dorsoplanites ultimum (Neaverson, pl. i, fig. 11).

Zone of Pavlovia rotunda (Sowerby). In Dorset 80 m. of clays and shales with Pavlovia spp., mostly crushed, except in a line of nodules near the middle, which dips to the beach at Chapmans Pool and yields perfect specimens of P. rotunda and Buchia spp. Inland, phosphatized fragments of Pavloviae from these two zones are common in lydite beds

* The neologism 'Kimmeridge', with two 'm's' has unfortunately come to be widely adopted of late. From Domesday Book (1085) to 1892 only one 'm' was generally used. See Arkell, 1947, p. 68, footnote.
PLATE 2a.—Portland Stone cliffs at Portland Bill, Dorset.

PLATE 2b.—Kimeridge Bay from Broad Bench. Kimeridgian shales and cementstone ledges (Pseudomutabilis and Gravesia Zones). Portlandian escarpment behind, on left.
PLATE 3a.—Lower and Upper Portlandian and basal Purbeckian, west coast of Portland Island.

Photo W. J. A

PLATE 3b.—Purbeck Beds, Stair Hole, Lulworth, Dorset.

Photo Dr. O. Haas, Amer. Mus. Nat. Hist.
at the base of the Portlandian at Swindon and about Oxford, at the base of the Neocomian in Lincolnshire, and at the base of the Aptian at Faringdon and in Cambridgeshire.

**Zone of Pectinatites pectinatus** (Phillips). In Dorset 36 m. of clays and shales down to a conspicuous white paper-shale stone band (lowest of the Three White Stone Bands); inland Shotover Grit Sands with doggers at Swindon and about Oxford and Thame. Abundant large ammonites of the genera Pectinatites, Wheatleyites (with coarse-ribbed body-chamber), Keratinites (with rostrate aperture), Paravirgatites. (Many figures in Buckman, *Type Ammonites*).

### Middle Kimeridgian

- **Zone of Subplanites wheatleyensis** (Neaverson). In Dorset, the Dicey Clays, 34 m., including cuboidal cementstone. Inland 3±4.5 m. of clay with cementstone septaria containing *S. wheatleyensis*.
- **Zone of Subplanites grandis** (Neaverson). In Dorset, the Bituminous Shales, 27 m. Various *Subplanites* common in the lower part. Absent inland?
- **Zone of Subplanites spp. (vimineus Schneid?)**. In Dorset, the Cattle Ledge Shales 24 m. The numerous crushed *Subplanites* still remain to be worked out. Absent inland?
- **Zone of Gravesia gigas** (Zieten). **Zone of Gravesia gravesiana** (d'Orb.). In Dorset, the Hen Cliff Shales, 21 m., with crushed Lithacoceras and *Gravesia*. Salfeld recognized species of the group of *G. irius* (d'Orb.) in the upper part, and of the group of *G. gravesiana* (d'Orb.) in the lower part. Present in Scotland.

### Lower Kimeridgian

- **Zone of Aulacostephanus pseudomutabilis** (de Loriol). In Dorset, the Kimeridge Bay Shales, 70 m.+. These are the lowest beds exposed in Purbeck, but a boring at Broad Bench, Kimeridge, proved a further 174 m. of Kimeridge Clay below sea-level. Species of *Aulacostephanus* are common throughout the zone. *A. pseudomutabilis* and *A. eudoxus* occur together and no subdivisions have been established. In the lower part *Aspidoceras longispinum* (Sow.) and *Aptychus latus* Parkinson abound, and some bedding-planes are whitened with crushed *Amoeboceras krausei* (Salfeld) and *A. anglicum* (Salfeld). At Ringstead Bay and Black Head these occur perfect in a cementstone band (Arkell, 1947, pl. iv). Well-preserved *Aulacostephanus* spp. also occur at Speeton in Yorkshire (Pavlow and Lamplugh, 1892, pp. 88-9, pl. iv, figs. 7, 8).
- **Zone of Rasenia mutabilis** (Sowerby). Shales with crushed, iridescent, fine-ribbed *Raseniae* of the group of *R. mutabilis* (Sow.) extend from Dorset to Yorkshire and Scotland (see Arkell, 1933, pl. xxxix, 5; 1947, pl. iv, 4).
- **Zone of Rasenia cymodoce** (d'Orbigny). The wonderfully-preserved
ammonite fauna of Market Rasen, Lincolnshire, is characterised by stout-whorled *Raseniae* s.s. with strong, forward-swung ribs, such as *R. involuta* and *R. evoluta* (Salfeld MS.) Spath and the form usually known as *R. uralensis* (d'Orb.), together with *Amoeboceras kitchini* (Salfeld) and *A. cricki* (Salfeld). To this zone belong the Abbotsbury Iron Ore in Dorset and beds on the east coast of Scotland (Arkell, 1947, p. 87; Waterston, 1951).

**Zone of Pictonia baylei** Salfeld. At the base of the Kimeridge Clay in England are a few feet of clay and mudstone nodules, yielding a well-preserved assemblage of *Pictonia* spp., *Triozites* and *Prorasenia*. They form a thin but well-characterized zone, which has produced good material especially at Ringstead Bay, Dorset, at Wootton Bassett and Stratton, Wiltshire, and at Malton and Hildenley, Yorkshire. (Arkell, 1945, pp. 351-2; 1947, pl. iv, fig. 1).

**UPPER OXFORDIAN** (Corallian Beds—upper and middle part—max. 65-70 m.)

**Zone of Epipeltoceras bimammatum** (Quenst.). The ammonite horizons or zones within the uppermost 'Corallian Beds'—mainly clays—are still so uncertain that it is advisable to use Oppel’s Bimammatum Zone for the whole and to indicate the probable order of the local zones or sub-zones. Although the index species has never been found in Britain there is no doubt that the rocks as a whole correspond to this zone as developed in continental Europe.

In Dorset and Wiltshire the succession is:

- Ringstead Coral Bed (0-33 m.) and Westbury Ironstone (4 m.) with *Ringsteadia pseudocordata* (Blake & Hudleston), *R. anglica* Salfeld and many other species; also rare *Pictoniae*?
- Ringstead Waxy Clay (3-4-5 m.); rare *Ringsteadia*.
- Sandsfoot Grit (6-6-7-5 m.) with *Amoeboceras* (*Prionodoceras*) *prionodes* Buckman and rare large smooth ammonites believed to be *Ringsteadiae*.
- Sandsfoot Clay (4·5-12 m.); no ammonites.
- *Trigonia clavellata* Beds (6-7 m.), including massed shell beds, with *Perisphinctes cautisnigrae* Arkell and numerous other *Perisphinctids*; also *Decipia lintonensis* Arkell, *Amoeboceras* (*Prionodoceras*) *glosensis* (Bigot & Brasil) and allied species (described and figured Arkell, 1935-37).

In the south, therefore, three zones can be recognized, from below up *cautisnigrae, prionodes, pseudocordata*.

North and east of Wiltshire, *Ringsteadiae* have not been found but other faunas come in. In the Ampthill Clay of Cambridgeshire (max. perhaps 30 m.) no continuous sections exist and the succession is still uncertain. Near the base in thin impersistent limestone bands, one of which is the Boxworth Rock, *Decipia decipiens* occurs with *D. lintonensis* and some of the *Perisphinctids* of the Cautisnigrae Zone (Hancock, 1954). Higher up, *D. decipiens* occurs with other species not found in the south, associated with numerous small *Amoeboceras pseudocaelatum* Spath (Long
Stanton fauna), which also is not known in the south (Arkell, 1937a). A third assemblage, not yet definitely fixed in relation to the others, is characterized by *Amoeboceras (Prionodoceras) prionodes* Buckman, *A. (P.) serratum* (Sowerby), and *Perisphinctes variocostatus* (Buckland); this is especially well developed in Lincolnshire and the Fenland, whence its ammonites have been strewn over wide areas in the Boulder Clay, as far as London, Kettering, and the coast of Suffolk. At Upware, near Cambridge, and at Steeple Ashton, Wiltshire, coral rags occur which are probably on the horizon of the Trigonia clavellata Beds of Dorset.

In Yorkshire there is also coral rag probably of this age, followed by Upper Calcareous Grit which contains *Prionodoceras, Decipia* and Perisphinctids, denoting an age no later than the Sandsfoot Clay.

The probable order of succession as a whole therefore is:

1. *Perisphinctes cautisnigrae* (Zone of *Perisphinctes plicatilis* (Sowerby). To this zone, so called in Britain for more than three-quarters of a century, belong the main mass of the coral rags and coralline oolites of England and some of the 'calcareous grits'. In general the zone correlates with the Transversarium Zone of continental Europe, but *Gregoryceras transversarium* has not been found, nor does any other species of *Gregoryceras* occur. The outstanding feature of the fauna is the wealth of large Perisphinctids, especially *P. plicatilis* (Sow.), *P. pickeringius* (Y. & B.), *P. cotovui* Simionescu, *P. antecedens* Salfeld, *P. parandieri* de Loriol, *P. chloroolithicus* (Gümbel) and their allies, with numerous Cardioceratidae and large Goliathiceras; also *Euaspidoceras perarmatum* (Sowerby) and its allies, but no Pelto- ceratidae. The succession in the south of England (Arkell, 1947a, 1951) is:

<table>
<thead>
<tr>
<th>WILTS, BERKS, OXON</th>
<th>DORSET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Coral Rag and Wheatley Limestones</td>
<td>Osmington</td>
</tr>
<tr>
<td>Urchin marls and Faringdon Oolite</td>
<td>Oolite Series</td>
</tr>
<tr>
<td>Upper Trigonia bed</td>
<td>Bencliff Grit</td>
</tr>
<tr>
<td>Upper pebble bed</td>
<td>Nothe Clay</td>
</tr>
<tr>
<td>Highworth Grit</td>
<td></td>
</tr>
<tr>
<td>Highworth Clay</td>
<td>Trigonia hudlestoni bed</td>
</tr>
<tr>
<td>Pusey Flags, Highworth Limestones and lower Coral Rag</td>
<td>(top of Nothe Grit)</td>
</tr>
<tr>
<td>Lower pebble bed</td>
<td></td>
</tr>
<tr>
<td><em>Catena</em> and <em>Natica</em> grits</td>
<td></td>
</tr>
</tbody>
</table>

The Arngrove Stone near Oxford belongs at or near the base of the zone. In Yorkshire the Plicatilis Zone is represented by the Coral Rag, Coralline Oolite and Middle Calcareous Grit, of which the last two yield abundant ammonites of the same species as are found in the south. In Scotland the zone is also represented in the Ardassie Limestones of Brora and their equivalents in Skye and Eigg. (For the ammonites, see Arkell,
1935-48; for the stratigraphy in the south, various papers by Arkell, and for the north, various papers by Wilson.)

LOWER OXFORDIAN (Lower Corallian Beds and Upper Oxford Clay)

Zone of Cardioceras cordatum (Sowerby). The thickest development of this zone is in Yorkshire, where it comprises the Ball Beds, Passage Beds and (probably) Lower Limestone (Hambleton Oolite). In all other parts of England the lower part of the zone is in Oxford Clay facies, while the upper part consists of sands (often current-bedded) with bands and dogger of calcareous sandstone—the Lower Calcareous Grit. Three ammonite subzones are recognizable: the true *C. cordatum* occurs only in the highest, and the three faunas are in reality just as worthy of promotion to true zones as some of the zones of the Kimeridgian, and have sometimes been so used (Arkell, 1941c; 1945, p. 346).

Subzone of Cardioceras cordatum (Sow.), with *C. persecans* (Buckman), *Euaspidoceras acuticostatum* (Y. & B.), *E. nikitini* (Borissjak), etc. Nothe Grits of Dorset (9-10 m.); Lower Calcareous Grit of Wiltshire and Berkshire (up to 20 m.), especially Seend and Calne; Lower Elsworth Series of Cambridge (pars); Hambleton Oolite of Yorkshire?

Subzone of Cardioceras costicardia Buckman, with *C. costellatum* Buckman, *Peltoceratoides williamsoni* (Phillips), etc. Red Nodule Beds at top of Oxford Clay in Dorset and Wiltshire, Oxford Clay of Oxford (pars); Lower Elsworth Series of Cambridge (pars); Passage Beds of Yorkshire.

Subzone of Cardioceras bukowskii Maire, with many other species of *Scarburgiceras*, *Goliathiceras anacanthum*, etc. Oxford Clay (pars) of Dorset and Wiltshire; Ball Beds of Yorkshire.

There is a considerable development of late-Lower and early-Upper Oxfordian in Scotland, but the ammonites require redetermination in the light of work done in England during the last twenty years; in particular there is confusion due to ambiguity in the use of the name *Cardioceras cordatum*, by which was often meant *Card.* (*Subvertebriceras*) *densiplicatum* Boden (figured Arkell, 1933, pl. xxxviii, fig. 5), characteristic of the Plicatilis Zone. The type specimen of *C. cordatum* is shown on pl. 38, fig. 1.

Zone of Quenstedtoceras mariae (d'Orb.). This zone comprises the whole Oxford Clay in Yorkshire, and also the Lower Calcareous Grit; in Scotland it is represented by at least part of the Brora arenaceous series. The Oxford Clay of this zone in the south contains a rich fauna of pyritized ammonites of many families, best known from Woodham brick-pit, Buckinghamshire. Commonest are *Cardioceras* (*Scarburgiceras*) *praecordatum* R. Douville (upper and middle parts of zone), *C. (S.)* *scarburgense* (Y. & B.) (middle and lower parts), *Quenstedtoceras* (*Pavloviceras*) *mariae* (d'Orb. sp.), *Euaspidoceras babeanum* (d'Orb.), *Creniceras renggeri* (Oppel), *Taramelliceras* (*Proscaphites*) *richei* (de Loriol), and many small *Hecticoceras*, *Perisphinctes*, etc. Between this assemblage
and that of the Upper Callovian there is a conspicuous change of the ammonite fauna. In particular, no Kosmoceras crosses the boundary.

**UPPER CALLOVIAN (Middle Oxford Clay, Hackness Rock)**

Zone of *Quenstedtoceras lamberti* (Sowerby). Where best known, at Tidmoor Point, Dorset, the clays contain great numbers of pyritized ammonites of at least forty species (Arkell, 1947, p. 31). Among the commonest are *Quenstedtoceras* (*Lambertioceras*) *lamberti* (Sow.), *Q.* (*Q.*) *leachi* (Sow.), *Q.* (*Eboraciceras*) *ordinarium* (Leckenby), *Distichoceras bicostatum* (Stahl), *Kosmoceras* (*K.*) *spinosum* (Sow.), *Hecticoceras* (*Putealiceras*) *puteale* (Leckenby), *H.* (*P.*) *punctatum* (Stahl), *H.* (*P.*) *pseudopunctatum* (Lahusen), but *Peltoceras athleta* (Phillips) also occurs, with several other Peltoceratidae. The same fauna occurs in Oxford Clay at Oxford (New Bodleian Library, Arkell, 1938), but at Woodham brick-pit it is condensed in a band of argillaceous limestone or mudstone, 1 foot thick, packed with ammonites. On the Yorkshire coast the fauna occurs in the Hackness Rock, and in east Scotland some elements are found in the Fascally Sandstone of Brora. The Lamberti Zone could be classed as a subzone of the Athleta Zone.

Zone of *Peltoceras athleta* (Phillips). In the south of England the *Quenstedtoceras* assemblage is confined to the top of the Upper Callovian, and although *Peltoceras athleta* and its allies range up into the same beds they are more characteristic of some 12 m. of clays below the range of *Quenstedtoceras*. In these lower beds the characteristic Kosmoceratids are *K. proniae* Teisseyre and its allies, but *K. spinosum* occurs also, as do some of the Hecticoceratids and other ammonites. From the Athleta beds in Dorset come *Pseudopeltoceras chauvinianum* (d'Orb.) and *Reinckeia* (*Reineckeites*) *stuebeli* Steinmann, *R.* (*Kellawaysites*) *multicostata* Petitclerc; but some giant Reinkekeids of the genus *Collovia* occur in the Lamberti Zone at Woodham and also in the Athleta Zone of Dorset and Oxford. In Yorkshire the two zones or subzones are represented in the condensed Hackness Rock. In Scotland the Athleta Zone is represented by the Fascally Shale.

**MIDDLE CALLOVIAN**

Zone of *Erymnoceras coronatum* (d'Orb.). To this zone belongs the bulk of the Lower Oxford Clay, the bituminous shales used in the modern brick-making techniques at Peterborough, Bletchley, and Stewartby, where there are many huge sections. The shales are crowded with crushed shells of *Kosmoceras* spp., chiefly *K. castor* and *K. pollux* with (especially in the lower part) *K. stutchburii* and *K. obductum*. *Erymnoceras* spp. are usually scarcer, but are sometimes preserved uncrushed in septaria: many such have been obtained at Chickerell near Weymouth. The zone is present in the same facies in Yorkshire (inland, at Peckondale Hill, not on the coast), and in Scotland, where it is worked as the Brora brick clays and shales. Callomon (1955) recognizes an upper subzone
of *K. grossouvrei* Douville and a lower subzone of *K. obductum* (Buckman).

Zone of *Kosmoceras jason* (Reinecke). The lowest 2-5 m. of the Oxford Clay shales are characterized from Dorset to Peterborough by *Kosmoceras (Gulielmites) jason* and its allies (including *K. conlaxatum*). In these beds at Peterborough occur *Kosmoceras gulielmi* (Sow.) and *Reineckeia rehmanni* (Oppel).

**LOWER CALLOVIAN** (Kellaways Beds, 8-20 m., and Upper Cornbrash, 0-7-8 m.)

Zone of *Sigaloceras calloviense* (Sowerby). The zonal index (proposed by Oppel for the Kellaways Rock) occurs only in Wiltshire and perhaps adjacent counties, not in Yorkshire (contrary to some published statements). The Kellaways Rock of South Cave, Yorkshire (inland) belongs to a higher horizon, which Callomon (1955) regards as a separate subzone of *Catasigaloceras planicerclus* Buckman. It is characterized by great numbers of this species and its varieties or allied species, with *Kosmoceras aff. gulielmi* (Sow.), *Pseudocadoceras cf. grewingki* (Pompeck), *Cadoceras sublaeve* (Sow.), *C. durum* (Buck.), *C. milascheviki* (Nikitin), *C. tchefkini* (d’Orb.), *Proplanulites* spp., *Choffatia difficilis* (Buckman), etc.

The Kellaways Rock of Wiltshire, subzone of *Sigaloceras calloviense*, likewise contains many *Cadoceras* spp. and *Proplanulites* spp., together with *Kepplerites* spp., especially the *gowerianus* group, but no *Catasigaloceras*. The type-locality for *Kepplerites gowerianus* (Sow.) is the Brora Roof Bed in east Scotland. This fauna is well represented on the Yorkshire coast in the Kellaways Rock.

The Kellaways Clay, under the Rock, in the south of England consists of two parts belonging to different zones. The typical fauna in the type area, Wiltshire, belongs to the upper part and is the same as that found in Rock facies in Oxfordshire, Yorkshire and Kent (Callomon, 1955). Owing chiefly to the different preservation in Wiltshire, Buckman (1913) introduced for this fauna a separate zone of *Proplanulites koenigi* (Sow.), but Callomon has shown that there is no noteworthy difference from the fauna of the Wiltshire Kellaways Rock and he considers that the Koenigi Zone is at most a subzone of the Calloviense Zone.

Zone of *Macrocephalites macrocephalus* (Schloth.) (=*M. verus* Buckman; see pl. 37, fig. 6).

An upper subzone of *Macrocephalites kamptus* (Buckman) is adopted by Callomon from Buckman for the Upper Cornbrash of Yorkshire, which was already considered later than the southern Cornbrash by Lycett (1877, Mon. Brit. Foss. Trigoniae, Pal. Soc., p. 172). Its ammonites comprise an assemblage of *Macrocephalites s.s., Dolikephalites* and, above all, *Kamptokephalites* (*herveyi-kamptus* group). The same forms are found in Upper Cornbrash at least as far south as Peterborough and Bedford, but already in this area the subzone begins to be replaced.
by clay, and in the south it is represented by the lower part of the Kellaways Clay only, as Buckman perceived in 1927.

The lower subzone of *M. macrocephalus* comprises the southern Upper Cornbrash, which in addition to various Macrocephalitids yields *Choffatia* spp. and, very rarely, *Kepplerites cerealis* (Buckman) and *Paracadoceras breve* (Blake), which confirm its essentially Callovian age. The upper part of the subzone is often characterized by *Ornithella* (*Microthyridina*) *lagenalis* and *O. (M.) calloviensis*, the lower part by *Ornithella siddingtonensis* and *O. arenaria*. Pebble beds occur locally (Douglas & Arkell, 1932, 1935).

**BATHONIAN** (Great Oolite Series including Lower Cornbrash, plus Crackneck Limestone, up to 150 m.)

The last stage of the English Jurassic to yield to ammonite ‘zoning’, the Bathonian has only lately been reduced to order, chiefly by mapping. The Fuller’s Earth Rock, which in the South Cotswolds underlies ‘The Great Oolite’, has proved to pass northwards into the part of the Great Oolite which at Minchinhampton yields the same ammonite fauna as the lower part of the Fuller’s Earth Rock in Somerset. This result vindicates a correlation published by Buckman in 1901, which seemed impossible. (Arkell & Donovan, 1952; ammonites monographed, Arkell, 1951- (in progress); other mollusca revised by Cox & Arkell, 1948-50; brachiopods by Muir-Wood, 1936 and McKerrow, 1953.) The Bathonian of the Cotswolds comprises four sedimentary cycles of clay, sand or false-bedded oolite, and shelly compact limestone, as follows (Arkell & Donovan, 1952, p. 251). The middle parts of the third and fourth cycles together comprise the Forest Marble of Wychwood Forest and the Oxford district.

**Formations and Ammonites**

**Cycle 4—**

3. Lower Cornbrash .... Clydoniceras discus
   2. Wychwood Beds and Hinton Sands
   1. Bradford Clay .... Clydoniceras hollandi

**Cycle 3—**

3. Petty France White Limestone .... Oppelia aspidoides
   2. Kemble Beds, Bath Stone, Lower Rags
   1. Lansdown Clay (Upper F.E. Clay) .... Bullatimorphites bullatimorphus

**Cycle 2—**

3. Tresham Rock and White Limestone
   2. Hens’ Cliff Oolite
   1. Hawkesbury Clay (Middle F.E. Clay) .... Tulites subcontracts

**Cycle 1—**

3. Minchinhampton White Limestone .... Gracilisphinctes progradilis
   2. Minchinhampton Weatherstones and Stonesfield Slates
   1. Stroud Clay (Lower F.E. Clay) .... Zigzagiceras zigzag

Top of Inferior Oolite: rubbly beds

North-east of the Cotswolds the Bathonian becomes much thinner, most of these subdivisions disappear, and ammonites become scarce. In Yorkshire the stage is represented by deltaic beds, the Upper Estuarine

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Series (up to 60 m.), and in the Hebrides by the Great Estuarine Series (120 m.), containing *Viviparus scoticus* and pelecypods.

**Upper Bathonian**

*Zone of Clydoniceras discus* (Sowerby). Lower Cornbrash (up to 3 m.). This comprises a variety of rubbly and flaggy limestones and marls, sometimes only a line of small nodules; sometimes shelly, with masses of *Trigonia angulata*, *Astarte hilpertoniensis*, *Meleagrinella echinata*, etc., sometimes almost barren. The brachiopods *Ornithella obovata* (above) and *Cererithyris intermedia* (below), abound and are useful as subzonal indices. The only ammonites known are *Clydoniceras discus* (Sow.), *C. thrapstonense* (Arkell) and other spp., *Delecticeras delectum* Arkell and spp., *Choffatia subbakeriae* (d'Orb.), *C. homoeomorpha* (Buckman) and spp.

Below the Cornbrash is the Upper Forest Marble (Wychwood Beds), a shallow-water formation (up to 42 m.) comprising oolitic flaggy and shaly limestones, with ripple-marks and current-bedding and subordinate clay lenticles. Locally there are sands and doggers (Hinton Sands). The only ammonites ever found in these beds are two specimens of *Clydoniceras hollandi* (Buckman) from the Bradford Clay, and two small *Siemiradzka* sp.

*Zone of Oppelia aspidoides* (Oppel). Next below the Bradford Clay come the Kemble Beds, which are developed in Forest Marble facies in Oxfordshire and include there the typical development in Wychwood Forest, but southward pass laterally into the Bath Stone and Lower Rags. Near Bath the Lower Rags contain a ferruginous oolite (Twinhoe Ironshot) with *Oppelia aspidoides*, *Wagnericeras arbustigerum* (d'Orb.) and other *Procerites*-like Perispinctids. Below is Upper Fuller's Earth clay, which reaches a thickness of 27 m. at Lansdown near Bath (Lansdown Clay) but has not yielded ammonites and soon wedges out northwards.

**Middle Bathonian**

*Zone of Tulites subcontractus* (Morris & Lycett). (Fuller's Earth Rock and main Great Oolite, up to 38 m.). The Fuller's Earth Rock of Somerset (6-10 m.) splits north of Bath into two, divided in the South Cotswolds by the Hawkesbury Clay (9 m.). Each half passes northward into Great Oolite, comprising a 'White Limestone' facies above and a shelly, flaggy oolite facies below. The only ammonite known from the upper division (Tresham Rock) is *Bullatimorphites bullatimorphus* Buckman, from Tiltups End, near Nailsworth. The lower division (Cross Hands Rock and Minchinhampton Beds) contains a rich ammonite fauna, both in the Great Oolite of Minchinhampton and in the lower Fuller's Earth Rock of Somerset. The principal ammonites are *Tulites subcontractus* (M. & L.), *T. cadus* (Buck.) and spp., *T. (Rugiferites) rugifer* (Buck.), *Morrisiceras morrisi* (Oppel) and spp., *Lycetticeras lycetti* Arkell, *Krumbeckia reuteri* Ark., *Berbericeras schwandorfense* Ark., *B. sekkense* Roman and occasional *Wagnericeras* and *Siemiradzka*.

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Fig. 2.—Diagrammatic horizontal section of the Bathonian from Lansdown, near Bath, to near Stow-on-the-Wold, to show the lateral passage of the Fuller's Earth facies into Great Oolite facies. From Arkell & Donovan, 1952.
To the same zone belong higher rock bands in the lower part of the Upper Fuller’s Earth in Dorset, the Wattonensis Beds (Kellaway & Wilson, 1941, p. 160), chiefly characterized by brachiopods but containing rare Morrisiceras and Perisphinctids.

Zone of Gracilisphinctes progracilis (Cox & Arkell). The ammonites in the Minchinhampton quarries are believed all to have come from beds above the basal Weatherstones (false-bedded shelly oolites) to which they were for long attributed. The Weatherstones either become sandy northwards and pass into, or wedge out and are replaced from below by, the sandy Stonesfield Slate Beds, which in turn pass down into the Lower Fuller’s Earth clay. In Oxfordshire the Stonesfield Slate Beds (0-2 m.) have yielded a peculiar assemblage of fossils, including small primitive mammals, pterosaurs, Megalosaurus, insects and plants, associated with the common marine mollusca and brachiopods, saurians, chelonians and fish (Arkell, 1947a, 1947b). The commonest ammonites are Gracilisphinctes progracilis (Cox & Arkell) and Micromphalites micromphalus (Phil.), with which occur rarely Tulites sp. indet., Clydoniceras tegularum Arkell, Oppelia cf. limosa (Buckman) and Oecotraustes formosus Arkell. On account of the Tulites and Clydoniceras, this thin formation is classed with the Middle Bathonian.

LOWER BATHONIAN

Beneath the Stonesfield Slate Beds, which locally form the base of the Great Oolite in the North and Mid Cotswolds, is the Lower Fuller’s Earth clay (up to 33 m.), from which no identifiable ammonites have been obtained except at the very base. At the top are up to 10 m. of beds with lumachelles of Ostrea acuminata Sowerby and some brachiopods. In Dorset the clay is even thicker and equally little known. In north Oxfordshire part of it is represented by the Sharp’s Hill Beds (up to 4-8 m.), in which locally is a 6-inch marl band containing Viviparus langtonensis Hudleston, a gastropod presumed to have lived in fresh water (Watson, 1950).

Zone of Zigzagiceras zigzag (d’Orbigny). The base of the Lower Fuller’s Earth has yielded Oppelia fallax (Guéranger) and O. limosa (Buckman). Under it in south Dorset is the Zigzag Bed, a 6-inch limestone forming the top of the Inferior Oolite, but crowded with fossils of the Lower Bathonian. The chief ammonites are Oppelia fallax, O. limosa, Oecotraustes spp., Zigzagiceras spp., Procerites subprocerus and spp., Morphoceras multiforme and spp., Parkinsonia convergens (Buck.) and P. pachypleura Buck. In north Dorset the Zigzag Zone is less condensed, most of the same ammonites being found in 4-5 m. of white limestone (Crackment Limestone) which locally forms the upper part of the Inferior Oolite. Some of the same ammonites occur in the topmost Inferior Oolite around Bath and at Stroud, and in the Hook Norton Limestone in the North Cotswolds and Oxfordshire.
Bajocian (Inferior Oolite Series, less Crackneck Limestone; up to 240 m.)

For the most part richly-fossiliferous limestones, except in Yorkshire where largely replaced by deltaic sandstones and shales.

Upper Bajocian (up to c. 15 m.)

In the south of England the Upper Bajocian is the most constant part of the stage in distribution and thickness. It constitutes the 'Top Beds', which are disconformable on the Middle and Lower Bajocian and Lias in different parts of Dorset, Somerset, the Cotswolds and Oxfordshire, and transgressive on Carboniferous Limestone in the planed Variscan structures of the Mendips. It consists of varying combinations of rubbly and bedded limestones, of which the most characteristic is the Clypeus Grit, full of Clypeus ploti, brachiopods and myacean casts. In the Lincolnshire-Rutland basin of deposition it probably contains some of the best Jurassic building-stones in Britain, the Barnack, Weldon, Ketton and Clipsham stones in the Upper Lincolnshire Limestone. In Yorkshire it is probably represented by the upper argillaceous part of the Scarborough Beds; but no ammonites of definitely Upper Bajocian age are known from either area. In western Scotland and the Inner Hebrides are up to 9 m. of shale, clay and sandstone with ammonites of the two lowest zones. The zonal sequence is as follows:

Zone of Parkinsonia parkinsoni (Sow.). To this zone belong the Clypeus Grit and, farther south, the equivalent Doulting Stone, Anabacia Limestones, Upper Coral Bed, Microzoa and Sponge Beds, and Truellei Bed. The commonest ammonites are Parkinsonia parkinsoni (Sow.) and P. dorsetensis (Wright). The former abounds from the Dorset coast to the Evenlode valley in Oxfordshire, but has not been found beyond. A common form in the upper part of the zone was figured by Buckman as P. schloenbachi and made index of a special zone; but it was not correctly named, and the true P. parkinsoni occurs with it (see Arkell, 1951, Mon. Engl. Bathonian Am., p. 9). At the base in south Dorset is often (but not always distinguishable) a bed 1 to 2 ft. thick, containing Strigoceras truellei (d'Orb.), which Buckman regarded as another separate zone. The ammonite is not known anywhere else in Britain and its distribution abroad does not warrant recognition of a separate truellei zone. For purely local work in Dorset, however, the truellei bed is a useful datum. Various Cadomites and Oppellidae (Oxycerites, etc.) occur.

Zone of Garantiana garantiana (d'Orb.). This zone is never more than 1 ft. thick in south Dorset, and usually a mere seam with average thickness of 4 inches. In north Dorset it expands into the Sherborne building-stone and Hadspen Stone. Farther north it forms the Dundry Freestone and Upper Trigonia Grit, which are conspicuously transgressive beds in the Mendips and Cotswolds, sometimes with a thin basal conglomerate (e.g. Maes Knoll conglomerate of Dundry Hill).

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Besides *Garantiana*, forms of *Spiroceras* are characteristic of the zone. Various *Prorsisphinctes*, *Bigotites*, etc. also occur.

Zone of *Strenoceras subfurcatum* (Schlotheim). This is the Niortensis Zone of Buckman, but *S. niortensis* (d'Orb.) is a junior synonym of *S. bajocense* (Defr.) and *S. subfurcatum* has many years' priority as zonal index. The zone has a limited distribution in Dorset but has yielded a rich fauna of *Strenoceras* spp. and many other ammonites, especially *Leptosphinctes*, *Prorsisphinctes*, *Cleistosphinctes* and *Cadomites* spp., with *Cadomoceras*, *Oecotraustes*, *Strigoceras*, *Sphaeroceras*, etc.

**MIDDLE BAJOCLIAN** (up to 24 m. in S. England, to 150 m. in Scotland)

In Dorset and Somerset the Middle Bajocian is highly condensed, often only 1 m. thick, but contains representatives of all the zones. In the Cotswolds it expands into the Ragstones, up to 24 m. thick, but the highest zone of *Stephanoceras humphriesianum* is missing. In the Lower Lincolnshire Limestone ammonites of the lowest subzone of the Sowerbyi Zone occur 8 ft. above the base (Kent & Baker, 1938; Kent, 1941; Swinnerton & Kent, 1949; Muir-Wood, 1952). In Yorkshire the Humphriesianum Zone is developed in marine facies as the Scarborough Beds, with ammonites; the rest of the substage is presumed to be represented by the Middle Estuarine Series* (30 m.) and Millepore Bed and Whitwell Oolite (0-15 m.). In the Inner Hebrides sandstones up to perhaps 150 m. thick correspond to the Middle Bajocian and yield large Stephanoceratidae of the Humphriesianum Zone, closely resembling species found in Dorset. There are also condensed beds with ammonites of the Sowerbyi Zone. The zones and subzones are as follows, with the formations as developed in the Cotswolds:

<table>
<thead>
<tr>
<th>Zones</th>
<th>Subzones</th>
<th>Cotswold Formations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stephanoceras humphriesianum (Sow.)</td>
<td>Teloceras blagdeni (Sow.)</td>
<td>Absent from Cotswolds</td>
</tr>
<tr>
<td></td>
<td>S. humphriesianum (Sow.)</td>
<td></td>
</tr>
<tr>
<td>Otoites sauzei (d'Orb.)</td>
<td>...</td>
<td>Phillipsiana Beds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bourguetia Beds</td>
</tr>
<tr>
<td>Soninia sowerbyi (Sow.)</td>
<td>Witchellia laeviuscula (Sow.)</td>
<td>Witchellia Grit</td>
</tr>
<tr>
<td></td>
<td>Shirbuirnia trigonalis (Buck.)</td>
<td>Notgrove Freestone</td>
</tr>
<tr>
<td></td>
<td>Hyperlioceras discites (Waagen)</td>
<td>Gryphite Grit</td>
</tr>
<tr>
<td></td>
<td>(Waagen)</td>
<td>Buckmani Grit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower Trigonia Grit</td>
</tr>
</tbody>
</table>

* My suggestion (1933, p. 312) that the 'Estuarine Series' might appropriately be renamed Deltaic Series seems to be finding favour (Hemingway, 1949; Harris, 1953) but it involves difficulties (see Sylvester-Bradley, 1949a) and a break with the literature of a century.

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Zone of *Stephanoceras humphriesianum* (Sowerby). (The Blagdeni Zone in Buckman’s and Richardson’s papers and in Arkell, 1933). Characterized by *Stephanoceras* spp., *Teloceras* spp., *Phaulostephanus*, *Normannites orbignyi* Buck., *N. formosus* (Buck.), *N. densus* (Buck.), *N. latansatus* (Buck.), *Chondroceras gervillii* (Sow.) and other species figured by Buckman, and the Sonninids *Dorsetensia* and *Poeciloceramus* spp.

Zone of *Otoites sauzei* (d’Orb.). Besides *Otoites* spp., many other *Stephanoceratidae*: *Normannites braikenridgei* (Sow.), *Skitroceras macrum* (Quenst.), *S. leptogyrale* Buck., *Emileia brochii* (Sow.), *E. (Frogdenites) profectus* Buck. and *spiniger* Buck., *Labyrinthoceras* spp., *Sonninia alsatica* (Haug), *S. corrugata* (Sow.), *S. propinquans* (Bayle), *S. micracantha* (Buck.) and other spp., with Oppeliidae and *Cadomoceras* spp.

Zone of *Sonninia sowerbyi* (Sow.). In this zone Sonniniidae predominate, with *Witchellia laeviuscula* (Sow.) and many other spp. in the upper subzone especially. Also *Emileia crater* Buck., *E. catamorpha* Buck., *Docidoceras* spp., *Trilobiticeras* spp., *Otoites delicatus* Buck., *Hyperlioceras* spp. and many Oppeliidae, including *Hebetoxyites* spp., *Strigoceratidae*, *Bradfordia* and *Lissoceras*. The best source of figures for all the Middle and Upper Bajocian zones is Buckman’s *Type Ammonites*. The exact horizon of *Sonninia sowerbyi* remains to be determined: it is possible that it belongs to the Sauzei Zone, in which case the Sauzei Zone must be considered a subzone of the Sowerbyi Zone (an arrangement logical on general palaeontological grounds). The Discites Subzone contains *Eudmetoceras*, *Hyperlioceras* spp., and the latest *Graphoceras* (*G. scriptitatum* Buck., etc.). Large *Sonninia* abound in the Discites Subzone and were figured in Buckman’s *Inferior Oolite Ammonites* monograph (sub ‘Concavum-zone’).

**Lower Bajocian** (up to 84 m.)

Like the Middle Bajocian, the Lower is condensed and ammonitiferous in Dorset (Bomford, 1948), but expands in the Cotswolds (to 84 m.) and ammonites become scarce. In the Midlands and Lincolnshire it is represented by the Northamptonshire Ironstone and Lower Estuarine Series, in Yorkshire by the Dogger (up to 6 m.) with ammonites of the Murchisonae Zone, resting on an eroded surface of the Toarcian (Rastall & Hemingway, 1939, 1939a, 1940-49; Macmillan, 1932), overlain by the Lower Estuarine Series (up to 85 m.) with a marine horizon, the Eller Beck Bed. In Scotland it is condensed once more and rich in ammonites (Skye is type locality of *Ludwigia murchisonae*).

Many plates of the ammonites will be found in Buckman’s *Inferior Oolite* monograph, but the nomenclature is in great confusion. In particular, Buckman figured as from the Concavum Zone many *Sonninia* which came in fact from what he later called the Discites Zone, the lowest subzone of the Sowerbyi Zone.

Recent work in the northern Jura summarized below (p. 102) has enabled the zones and subzones of the Lower Bajocian to be grouped c.
much more satisfactorily than in the past, for in the Jura the ammonite faunas of the Saxon and English basins meet and are combined in one succession. A gap in the English sequence exists between the Scissum and Murchisonae Zones, but it has turned out to be not so great as was supposed from the Hanover succession, where six subzones were intercalated between *opalinum* and *murchisonae* by Hoffmann (1913) (see below, p. 144), and it is probably bridged to some extent by the *Ancolioceras* beds of Buckman, which represent some of the lower parts of the Murchisonae Zone. There are visible signs of pre-Murchisonae Zone erosion in Yorkshire.

<table>
<thead>
<tr>
<th>Zones</th>
<th>Subzones</th>
<th>Cotswold Formations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphoceras concavum</td>
<td>Graphoceras concavum (Sow.)</td>
<td>{ Tilestone Snowshill Clay Newbury Sands</td>
</tr>
<tr>
<td>Ludwigia murchisonae</td>
<td>Brasilia bradfordensis Buckman</td>
<td>Upper Freestone Oolite Marl</td>
</tr>
<tr>
<td>Ludwigia murchisonae</td>
<td>Ludwigia murchisonae (Sow.)</td>
<td>{ Lower Freestone Pea Grit</td>
</tr>
<tr>
<td>‘Ancolioceras spp.’</td>
<td>‘Ancolioceras spp.’</td>
<td>? Lower Limestones</td>
</tr>
<tr>
<td>Tmetoceras scissum</td>
<td>Tmetoceras scissum (Benecke)</td>
<td>Scissum Beds</td>
</tr>
<tr>
<td>Leioceras opalinum</td>
<td>Leioceras opalinum (Reinecke)</td>
<td>(absent)</td>
</tr>
</tbody>
</table>

The Scissum Zone is upheld as a separate zone because it is distinct in the Jura (where it is found to be contemporaneous with the German subzone of *Costileioceras sinon* Bayle sp.) and has been recognized in Canada and Argentina. It therefore has wide stratigraphical significance, despite the isolated rare occurrence of a minute *Tmetoceras* in the condensed Bradfordsens and Concavum Bed in Dorset (Bomford, 1948). Buckman and Richardson traced the Scissum Zone as a distinct formation over most of the outcrops of southern England. Its discrimination as a separate zone between those of Opalinum and Murchisonae is due to Buckman (1898), but *Tmetoceras scissum* had already been proposed as index species for a Mediterranean zone, supposed to be equivalent to these two northern zones, by Neumayr (1871, *Der Penninische Klippenzug*, p. 509).

The Scissum and Opalinum Zones acquire great economic importance in the English Midlands, where they are developed as the Northampton Sand, with its valuable low-grade ironstone. The ammonites of this include *Leioceras opalinum* and *Tmetoceras scissum*, with *Bredyia* and Lytoceratids (Hollingworth & Taylor, 1946, 1951).

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TOARCIAN (Upper Lias, up to 135 m. in Yorkshire)

The Toarcian in the definition here accepted corresponds to the Upper Lias with the Cotswold and Bridport Sands and at the top the Cephalopod Bed of the South Cotswolds. The Upper Lias clay of the Northants-Lincoln area reaches 60 m. in thickness but represents only the lower half of the stage. Sands began to form at the time of the Bifrons Zone in the Cotswolds, but not until the Moorei Subzone on the Dorset coast, where the Bridport Sands, of Moorei and Aalensis date, with the Opalinum bed, reach 42 m.* The limestone Junction Bed on the Dorset coast (1-2 m.) at the base of the Upper Lias overlaps in date with the Cephalopod Bed at the top of the formation in the Cotswolds. The most complete development at any one place is found in Yorkshire (Dean, 1954). In Raasay, western Scotland, the bulk (21 m.) of the Upper Lias, the Dun Caan Shales, is Upper Toarcian; below is the Raasay Ironstone (2-4 m.) of the Subcarinata Subzone.

The zonal sequence is as follows:—

<table>
<thead>
<tr>
<th>Zones</th>
<th>Subzones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lytoceras jurens (Zieten) .</td>
<td>Pleydellia aalensis</td>
</tr>
<tr>
<td></td>
<td>Dumortieria moorei</td>
</tr>
<tr>
<td></td>
<td>Dumortieria levesquei</td>
</tr>
<tr>
<td></td>
<td>Phlyseogrammoceras dispansum</td>
</tr>
<tr>
<td></td>
<td>Grammoceras strickmanni</td>
</tr>
<tr>
<td></td>
<td>Grammoceras striatulum</td>
</tr>
<tr>
<td></td>
<td>Haugia variabilis</td>
</tr>
<tr>
<td></td>
<td>Phylmatoceras lilli</td>
</tr>
<tr>
<td>Hildoceras bifrons (Brug.) .</td>
<td>Dactylioceras braunianum</td>
</tr>
<tr>
<td></td>
<td>Peronoceras fibulatum</td>
</tr>
<tr>
<td></td>
<td>Frechiella subcarinata</td>
</tr>
<tr>
<td>Harpoceras falcer (Sow.) †</td>
<td>Ovaticeras pseudovatum</td>
</tr>
<tr>
<td></td>
<td>Harpoceras falcer</td>
</tr>
<tr>
<td></td>
<td>Harpoceras exaratum</td>
</tr>
<tr>
<td>Dactylioceras tenuicostatum (Y. &amp; B.)</td>
<td>Dactylioceras tenuicostatum</td>
</tr>
<tr>
<td></td>
<td>Tiltoniceras acutum</td>
</tr>
</tbody>
</table>

With these and the other zones of the Lias, the succession of ammonite faunas is sufficiently well illustrated by the list of subzones.

UPPER PLIENSACHIAN (Middle Lias or Domerian, up to 125 m. in Dorset)

In its typical development the Middle Lias consists of relatively thin ironstone or marly limestone at top, corresponding to the Zone of

* On p. 165 of my *Jurassic System* (1933) the thickness was misprinted, 40 ft. for 140 ft.
† Although prior as zonal index, *Hildoceras (?) serpentinum* (Schloth.) is too doubtful for it to be used: see *Bull. Zool. Nomencl.*, 1931, vol. ii, parts 6-8, p. 192.
**THE BRITISH ISLES**

*Pleuroceras spinatum*, and thicker sands and micaceous shales below, corresponding to the Zone of *Amaltheus margaritatus*, with some early Hildoceratids, *Paltarpites* and *Arieticeras* (Buckman, Type Am. ii, 1913, pl. LXXIV, iv, 1923, pls. CCCLXII-III, vi, 1927, pl. DCXCVIII). M. K. Howarth (1955), as the result of a thorough restudy of the cliff-sections in Dorset, Yorkshire and the Hebrides, has established the following subzones:

<table>
<thead>
<tr>
<th>Zones</th>
<th>Subzones</th>
</tr>
</thead>
</table>
| Pleuroceras spinatum (Brug.) | *Pleuroceras spinatum* (and *P. hawskerense*)  
| Amaltheus margaritatus Montfort | *Amaltheus margaritatus* (and *A. gibbosus*)  
| | *Amaltheus subnodosus*  
| | *Amaltheus stokesi* |

For monographic treatment of the ironstones, see Whitehead & others, 1952. Some of the brachiopods have been revised by Ager (1954).

**LOWER PLIENSCHIAN** (upper part of Lower Lias, or Carixian, up to 54 m. in Dorset)

In Dorset this substage is represented by the Green Ammonite Beds and Stonebarrow Beds or Belemnite Marls (Lang, Spath & others, 1928, 1936). Spath (1938) has monographed the Liparoceratid ammonites and (1942) recognizes the following subzones:

<table>
<thead>
<tr>
<th>Zones</th>
<th>Subzones</th>
</tr>
</thead>
</table>
| Prodactylioceras davoei (Sow.)  
(*= Capricornus Zone auct.*) | *Oistoceras figulinum*  
| | *Androgynoceras lataecosta*  
| | *Androgynoceras maculatum*  
| Tragophylloceras ibex (d'Orb.)  
(*= Henleyi Zone auct.*) | *Beaniceras centaurus*  
| | *Acanthopleuroceras valdani*  
| Uptonia jamesoni (Sow.) | *Uptonia jamesoni* (with *U. bronni*)  
| | *Platypleuroceras brevispina*  
| | *Phricodoceras taylori* |

**SINETURIAN** (middle part of Lower Lias, 104 m. in Yorkshire)

Almost everywhere in England the Sinemurian is well developed as shales, with numerous local ammonite horizons. In Dorset the stage corresponds to the Black Ven Marls, Shales-with-Beef and top of the Blue Lias Limestones (Lang, Spath & others, 1923, 1926). In Somerset and Glamorgan a littoral facies is developed and there is slight

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unconformity with the Hettangian. The ammonites of the Blue Lias of the Bristol area have been revised by Donovan (1952), who has also revised Wright’s monograph nomenclaturally (1954). In Lincolnshire the Frodingham Ironstone (10 m.) is a notable development in the Semi-costatum and Obtusum Zones and a condensed representative of 45 m. of limestones and clays in the south of the same county (Kent in Swinnerton & Kent, 1949, p. 43). In Scotland there are shales in the upper part of the stage and limestones in the lower, as elsewhere, but in Morvan a sandy shale passing to sandstone, 0-48 m. thick, represents the Obtusum Zone. The Sinemurian is the highest Jurassic in Ireland. The numerous local epiboles recorded by observers in different parts of the country (collected together in Arkell, 1933, p. 28) have been reduced to the following subzones by Spath (1942). (A few nomenclatural revisions have been introduced.)

<table>
<thead>
<tr>
<th>Zones</th>
<th>Subzones</th>
</tr>
</thead>
</table>
| Echioceras raricostatum (Zieten) | Paltechioceras aplanatum  
Leptechioceras macdonnelli  
Echioceras raricostatoides  
Eoderoceras bispinigerum |
| Oxynoticeras oxynotum (Quenst.) | Oxynoticeras lymense  
Bifericeras bifer  
Oxynoticeras simpsoni |
| Asteroceras obtusum (Sow.) | Eparietites denotatus  
Asteroceras stellare  
Asteroceras obtusum |
| Euasteroceras turneri (Sow.) | Microderoceras birchi  
Euasteroceras brooki  
Parrnicioceras alcinoë |
| Arnioceras semicostatum (Y. & B.) | Euagassiceras sauzeanum  
Agassiceras scipionianum  
Coroniceras gmuendense |
| Arietites bucklandi (Sow.) | Arietites bucklandi  
Coroniceras rotiforme  
Coroniceras conybeari |

Hettangian (Blue Lias limestones, lower part, and Pre-Planorbis Beds; up to about 43 m. in Glamorgan)

The Hettangian, which reaches its maximum thickness in the littoral facies of Glamorgan, consists predominantly of limestones, with subordinate shales. In the Hebrides and Glamorgan some of the limestones contain corals. The characteristic ammonites have been revised by Donovan (1952). Spath (1942) recognizes four subzones:

<table>
<thead>
<tr>
<th>Zones</th>
<th>Subzones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schlotheimia angulata (Schlotheim)</td>
<td>Schlotheimia angulata Alsatites laqueus</td>
</tr>
<tr>
<td>Psiloceras planorbis (Sow.)</td>
<td>Psiloceras johnstoni Psiloceras planorbis</td>
</tr>
</tbody>
</table>

Both zonal indices have been dealt with by the International Commission on Zoological Nomenclature (Bull. Zool. Nom., 1951, vol. ii, parts 6-8, pp. 204, 228-9, 233). The principal revisions of stratigraphy have been in Nottinghamshire (Kent, 1937), Lincolnshire (Dudley, 1942) and Skye (Trueman, 1942). Hettangian also occurs in Northern Ireland (Antrim). A non-sequence between Hettangian and Rhaetian is believed to exist in Gloucestershire (Richardson, 1948).

[Rhaetian]

The ammonites of the Rhaetian are palaeontologically Triassic (see p. 172) and consequently the Rhaetic Beds are here regarded as belonging to the Triassic System. (For sections and faunas and floras see Donovan, 1947; Johnson, 1950; Kellaway, 1936; Kellaway and Oakley, 1933; Kent, 1953; Kühne, 1949.)
CHAPTER 3

THE PARIS BASIN AND BORDERS OF THE MASSIF CENTRAL

The Jurassic rocks of France can be arranged and described from two different points of view: either as three basins of deposition, the Paris Basin, the basin of Aquitaine, and the basin of the Lower Rhone; or as deposits fringing three ancient Palaeozoic horsts, Armorica, the Massif Central, and the Ardennes-Eifel massif. A compromise is here adopted. The Paris Basin is a unit that cannot be ignored, although all the central part is blanketed by Cretaceous and Tertiary rocks and only a rim of Jurassic crops out. On the other hand, the southern rim of the basin of Aquitaine belongs to the Pyrenees and will be described with the Iberian Peninsula, while the eastern rim of the Lower Rhone basin belongs to and will be described with the Alps. This leaves the outcrops fringing the eastern and southern sides of the Massif Central, in the Mâconnais, Vivarais, Languedoc and Aveyron, to be described after those on the north and west sides of the Massif Central, which form part of the Paris Basin.

The Jurassic rocks of the Paris Basin join up south-westwards with those of the basin of Aquitaine through the Poitou portal or 'Straits of Poitiers', and south-eastwards with those of the Jura and Rhone basin by a second portal which has been called the 'Straits of Langres', between Morvan and the Vosges.

The three great Palaeozoic horsts or massifs and perhaps also the Vosges-Black Forest on the west (separated by the Rhine rift) were above water throughout the Jurassic, as is proved by the repeated overlaps and oversteps of various stages around their edges (Bonte, 1941; Mouterde, 1953). The Vosges are a more debatable case, but the existence of Upper Bajocian drifted land-plants and dinosaur bones on their west side, and of quartz sand which can only have come from the east, strongly suggests that this massif formed an island in the Middle as well as Upper Jurassic sea (Maubeuge, 1949b). The mere thinning and condensation of beds offers no proof of the proximity of land, as Gignoux (1950, p. 358) has pointed out, for such beds are common in the Jurassic in nearly all parts of Europe and may extend all over a wide basin of deposition.

The Langres portal was originally much wider than appears from the geological map, for both the Vosges and the north-eastern spur of the Massif Central, the Morvan massif, were probably submerged until at least the Bajocian (Mouterde, 1953). In Liassic times, also, a narrow strait extended northward through Luxemburg to join up with the North German sea, cutting off the Ardennes from the German slate-mountains (Hunsrück and Taunus).
All the French Jurassic rocks here described are in essentials the same as the English; generalities therefore need not be repeated. The following account begins in the north and follows round the basin anti-clockwise.

**Fig. 3.**—The Jurassic outcrops of the Paris Basin and adjoining lands.
Based on the *Atlas de France*, sheet 6, 1952.

**The Boulonnais**

The small Jurassic area of the Bas-Boulonnais, ringed around on its landward side by Chalk hills, is structurally the south-eastern end of the pericline of the Weald. Pliensbachian and Toarcian rocks have been proved in borings near the coast between Gris-Nez and Wimereux,
the thickness of the Lias varying from 35 m. to 70 m. or more (Pruvost, 1922). At outcrop, however, the earliest marine Jurassic rock is a sand (Sables d'Hydrequent) with a pelecypod fauna similar to that of the Hook Norton Beds and probably therefore of Bathonian date, which is transgressive on Palaeozoics. From there upwards quarries, cuttings and clear cliff-sections expose a complete succession of the Jurassic up to Purbeck and Wealden (Pellat, 1878, 1879-80; Rigaux, 1865, 1892; Pringle & Pruvost, 1924; Pruvost & Pringle, 1924).

The total thickness of marine Jurassic is about 400 m. Although the outcrop is so small in area, it is of great importance, owing to the good cliff exposures and abundance of ammonites at many levels. The succession in some respects amplifies the English record and serves as a bridge to the more distant French outcrops. The Upper Oxfordian succession is of special interest; the ammonites of the Calcaire du Mont des Boucards represent an assemblage unknown in England and, with those of the Calcaire de Bruquedale, help to correlate with the Jura province. The Kimeridgian-Portlandian succession is also highly important and has received more attention, but would richly repay monographic treatment of the ammonites. The late A. P. Dutertre, who had intended to do this, was killed in action at Dunkirk in 1940. A remarkable feature is a conglomerate of purely local pebbles in the Upper Portlandian, well shown in the cliffs at La Rochette and Pointe aux Oies. The Upper Kimeridgian contains three phosphatic nodule beds indicative of condensation. 

The following tabulated section incorporates and interprets numerous observations on the ammonites by Pruvost (1925) and Dutertre (1924-28), as well as my own examination of the sections and of the Oxfordian and Callovian ammonites in the Boulogne Museum and at Paris.

[WEALDEN (20-30 m.). Clay believed to be the Weald Clay; without ostracods.]

PURBECKIAN (0-3 m.)

Concretionary limestone with *Anisoccardia socialis* and *Candona bononiensis*, presumed to represent the Lower Purbeck.

PORTLANDIAN (22 m.)

Sands and sandstones with *Protocardia dissimilis* and *Trigonia gibbosa*, 4 m.

Sands and sandstones with *Ampullina ceras*, *Trigonia gibbosa*, *Titanites giganteus* (Sow.), *T. bononiensis* (de Lor.), 4 m.

Sands, sandstones, conglomerate and sandy clay with glauconite: various large Perisphinctids, including *Titanites* spp. (*Behemoth* Buckman, and inner whorls figured, Sauvage, 1911, pl. ix, 4, 5), also *Glaucolithites gorei* Salfeld sp. (type specimen, de Loriol, 1874, pl. ii, fig. 1, probably from here: Pruvost, 1925, p. 193).
Nodular limestones and glauconitic sandy clays with *Ostrea expansa, 'Perisphinctes pseudobiplex'* Pruvost, etc. (Portland Sands?).

**KIMERICIAN (123 m.)**

Tour Croi Nodule Bed, with phosphatic examples of *Pavlovia rotunda* (Sow.), *P. leblondi* Dutertre sp. (type, Sauvage, 1911, pl. ix, 3) and other spp., *Keratinites devillei* (de Lor.), *K. boidini* (de Lor.), *Wheatleyites rarescens* Buck., *W. opulentus* Buck., etc. (Dutertre, 1927).

Clay with *Exogyra dubiensis*, *K. devillei*, *K. boidini*, *Pectinatites* (see Spath, 1936, p. 153) and *Pavlovia lydianites* Buck. (8 m.).

Clay with phosphatic nodule bed at top (2 m.).

La Rochette Nodule Bed, with *Subplanites* (*Virgatosphinctoides*) *pringlei* Pruvost sp. (1925, pl. ii, fig. 1, lectotype desig. Buckman, 1926, TA vi, p. 24) and other spp. (Pruvost, figs. 3-7).

Clays with *Subplanites* spp. (8 m.).

Grès de la Crèche, upper part, with *Subplanites* (5 m.).

Grès de la Crèche, lower part, with *Gravesia portlandica* (de Loriol) and *Exogyra virgula* (10 m.).

Marnes et Grès de Châtillon, with *Aulacostephanus pseudomutabilis* (de Lor.), *A. subeudoxus* Pavlow (de Loriol, 1874, pl. v, 2, 3), *Aspidoceras longispinum*, etc. (34 m.).

Calcaires du Moulin-Wibert with *Aspidoceras caletanum* (Oppel) (21 m.).

Argiles du Moulin-Wibert with *Aspidoceras orthocera* (d'Orb.) (28 m.).

Calcaire de Brecquereque (7 m.).

**KIMERICIAN-OXFORDIAN**

Grès de Questrecques with *Pictonia 'cymodoce' auct.*, *Rasenia moeschi* (Oppel), *R. quehenensis* (de Lor.), *Ringsteadia anglica* Salfeld and *Decipia achilles* auct. (Dutertre, 1925a, p. 225) (0-4 m.).

**OXFORDIAN (116 m.)**

Calcaires à *Cerithium pellati*, *Decipia achilles* auct. (3-5 m.).

Oolithe d'Hesdin l'Abbé, with *Ringsteadia anglica* Salfeld, *R. frequens* Salf., *R. brandesi* Salf. (9-11 m.).

Grès de Brunembert with *Decipia decipiens* (Sow.) (2-12 m.).

Clays with a 0-6 m. lenticle of coral limestone (Calcaire de Bruquedale) in which are recorded *Amoeboceras ovale* (Quenst.) and *Perisphinctes vartae* Buk. (Dutertre, 1925a, p. 236), also 20 species of corals and a rich fauna of molluscs (20-27 m.).

Calcaire du Mont des Boucards, with *Orthospinctes colubrinus* (Reinecke), *Divisosphinctes aff. divisus* (Quenst.), *Decipia cf. tranchandi* (Bigot & Brasil), *Decipia* spp., nuclei (Arkell, 1937, p. 56) (13-14 m.).

Argile de Selles (25-35 m.).

Calcaire d'Houllefort, with *Perisphinctes antecedens* Salf., *P. gresslyi*
de Lor., *P. chloroolithicus* (Gümbel), *P. cotovui* Sim., *Cardioceras densiplicatum* Boden, *C. cf. tenuiserratum* (Oppel) (Arkell, 1948, p. 389). (1.5 m.).

Marne à *Millericrinus* of La Liégette railway-cutting; *Cardioceras cordatum* is recorded, but the ammonites of this bed have yet to be reinvestigated. (5 m.).

Argile du Coquillot, upper part. Abundant small pyritized ammonites of the Mariae Zone, including *Q. mariae* and its allies, *Scarburgiceras scarburgense* and *Creniceras renggeri* (listed Arkell, 1939, pp. 208-9). (6-10 m.).

**CALLOVIAN (115 m.)**

Argile du Coquillot, lower part, with pyritised *Quenstedtoceras lamberti* (Sow.) and its allies, *Distichoceras bicostatum* (Stahl) and a 30 cm. band of marly limestone (2 m.).

Argile de Montaubert, worked for bricks near le Wast, with *Kosmoceras* spp. recorded as *K. duncani* and *K. jason*, and *Erymnoceras coronatum* (6-25 m.).

Marne ferrugineuse de Belle, from which *Sigaloceras calloviense* is recorded (0-6 m.). At base derived Cornbrash fossils.

Calcaire des Pichottes, upper part: Upper Cornbrash with *Macrocephalites herveyi* (Sow.), *M. typicus* Blake, *M. tumidus* auct. (Dutertre, 1926, p. 48) (1-2 m.).

**BATHONIAN (26 m.)**

Calcaire des Pichottes, lower part: Lower Cornbrash with *Clydoniceras discus* (Sow.), *Delecticeras legayi* (Rig. & Sauv.), *Choffatia* cf. *subbakeriae* (d'Orb.) and *Cererithyris intermedia* (Sow.) (Dutertre, 1928, p. 59) (0-33-2 m.).

Calcaire marneux à *Rhynchonella elegantula*. A large *Clydoniceras* cf. *discus* (Sow.) recorded (Dutertre, 1926, p. 48) (3 m.).

Oolithe de Marquise, with *Rhynchonella hopkinsi* (8 m.).

Calcaire oolitique de Rinxent, with abundant *Rh. concinna* and obscure Perisphinctids compared to *Siemiradzkia* and *Procerites* (Dutertre, 1926, p. 48) (12-13 m.).

Sables d'Hydrequent, without ammonites (1-3 m.).

[**CARBONIFEROUS LIMESTONE** below, containing solution pipes filled with sands and clays with Rhaetic plants and shells of large Unionids (Corsin, 1951).]

**PAYS DE BRAY**

About midway between the Boulonnais and Normandy a small inlier of Kimeridgian and Portlandian rocks is brought to the surface in the core of the Pays de Bray pericline. The lowest beds exposed are in the Pseudomutabilis Zone, consisting of clays and lumachelles of *Exogyra*
virgula, with Aulacostephanus cf. eudoxus d'Orb. sp. (more than 50 m.). Above this is 4 m. of lithographic limestone with Gravesia gigas (auct.) and Perisphinctids, but this is followed by further lumachelles of Exogyra virgula and a succession of marls, limestones and calcareous sandstones 40-60 m. thick, which probably include parts at least of the Upper Kimeridgian and Lower Portlandian. At the top are 8-10 m. of sands with large doggers of calcareous sandstone containing ammonites recorded as Glaucolithites gorei (Salf.) and Titanites lapideus (Buck.), associated with abundant Trigonia gibbosa, T. incurva, Ampullina ceres and other typical Portlandian fossils. The overlying Wealden continental sands, sandstones and clays (40-50 m.) have at their base pebbly beds attributed to the Purbeckian (Lemoine, 1911a; Laffitte, 1939).

The Pays de Bray is more famous for the deep boring at Ferrières-en-Bray, which started at or near the top of the Portlandian and passed from the base of the Hettangian into Permo-Trias at a depth of 1128 m. and into the ancient basement at 1150 m. The outstanding result of this boring was the proof it afforded that all the stages above the Sinemurian are thickly developed, but in essentially the same shallow-water facies here in the middle of the basin of deposition as at outcrop near the edges (Pruvost, 1928, 1930; Bonte, 1941, pp. 243-251). Only the Hettangian and Sinemurian are reduced, fragmentary, and in peculiar facies; the Hettangian is represented by oolite, which is overlain by plant-bearing sandstone, as at outcrop in the Ardennes, directly followed by marine Upper Sinemurian.

**NORTH-WEST OF THE PARIS BASIN: NORMANDY AND SARTHE**

The cliffs of Normandy and the Boulonnais are complementary. The Middle and Upper Kimeridgian and Portlandian so well displayed on the coast of the Boulonnais are absent on the west side of the Paris Basin, where the Lower Cretaceous rests on Lower Kimeridgian at the first appearance of Jurassic rocks at the mouth of the Seine. Thence westward for fifty miles there is a splendid line of Jurassic cliffs which take the section, with few interruptions, down to the Bajocian (complete profile sections in Eudes-Deslongchamps, 1864). It begins with 11 miles of cliffs from Villerville, past Hennequeville, Trouville, Deauville and Villers to the mouth of the River Dives, providing one of the best and most important sections of the Oxfordian and Upper Callovian in the world. The Bathonian and Bajocian are magnificently displayed in quarries along the valley of the River Orne and about Bayeux, type locality of the Bajocian, and in cliffs at Lion-sur-Mer, Luc, Langrune and Port-en-Bessin. Finally the Lias, consisting of reduced representatives of the Toarcian and Pliensbachian, oversteps against the Armorican massif in quarries at May and other places in Calvados, Orne, and Sarthe. The Sinemurian and Hettangian are often absent at outcrop, overlapped by the later stages up to Bajocian.

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A conspectus of the relation of these marginal outcrops to the Paris Basin as a whole and its tectonic development during the Jurassic is given in two brilliant essays by Lemoine (1930) and Pruvost (1930), already discussed in my *Jurassic System in Great Britain* (1933). There is an excellent summary of the geology of Normandy, with bibliographies, by Dangeard (1951).

Owing to the importance and continuity of the exposures and the wealth of ammonite faunas in the Bajocian to Oxfordian stages, greater space is given to the detailed succession in Normandy than is possible for most other areas. Many ammonite determinations have been made as the result of my own studies on the cliffs on several occasions during the 1930's and of the unsurpassed collections in the University of Caen, destroyed during the war in 1944; also of the collections in Paris, and of the Guillaume collection.

**LOWER KIMERIDGIAN** (about 30 m.)

Under the Cretaceous at the foot of the cliffs and on the shore at Cap de la Hève, Le Havre, are obscure sections of clays and limestones with ammonites of the Mutabilis, Cymodoce and Baylei Zones, and interesting Saurian and other vertebrate remains (Dollfus, 1863; Lennier, 1888-89, and in H. Douville, 1881, p. 450). The highest beds are 18 m. of clay alternating with calcareous bands full of *Exogyra virgula* and probably belonging to the Pseudomutabilis Zone. Below this are 'Marnes a Pterocères' (0-9-1-5 m.) with *Raseniae* and *Pictoniae*. Some *Pictoniae* in Le Havre Museum are labelled as from the underlying 'Calcaires coquillers', in which thin division (overlain by clays full of *Ostrea delta* as at Ringstead) the junction between Kimeridgian and Oxfordian falls (Arkell, 1937, p. 55).

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**Fig. 4.**—The principal Jurassic localities of Normandy.
UPPER OXFORDIAN (40-56 m.)

Zone of *Ringsteadia anglica*. From the ‘Calcaires coquillers’ at Cap de la Hève there are in Le Havre Museum four species of *Ringsteadia*, several in an ironshot mudstone exactly like that in which they are commonest on the Dorset coast and at Westbury (Arkell, 1937, p. 55). Below these beds at la Hève are sometimes seen up to 5 m. of clay with *Ostrea delta*, devoid of recognizable ammonites; probably the Sandsfoot Clay.

Zone of *Decipia decipiens*. The same clay is exposed on the south side of the Seine estuary, the Argile (or Marne) de Villerville (13-17 m.), which is the highest bed clearly seen in the long line of Jurassic cliffs on the south coast of the Baie de la Seine. Inland, near Lisieux, the Argile de Villerville seems to pass laterally into the Sables de Glos (35 m.), famous for their marvellously preserved gastropod and pelecypod fauna, still retaining colour-banding (Bigot & Brasil, 1904; Bigot, 1950). The only ammonites known are *Prionodoceras glosensis* and *Decipia tranchandi* Bigot & Brasil sp. (1904, pl. iv); the former occurs in the Dorset Red Beds, the latter in the later Calcaire du Mont des Boucards in the Boulonnais (above, p. 42).

Zone of *Perisphinctes cautisnigrae*. Calcaire (or Grès) d’Hennequeville (4-2 m.). Sandy limestones, partly silicified and cherty, some bands packed with *Trigonia clavellata* (Sow.) and *T. bronni* Ag. Formerly in Caen University Museum were specimens of *Perisphinctes durnovariae* Arkell, *P. boweni* Arkell, and *P. cf. variocostatus* (Buckland) from these beds, which accordingly correlate with the Red Beds of Dorset (Arkell, 1937, p. 53). At Trouville a thin coral rag develops on this horizon. Probably of much the same age is a coral-and-*Diceras* reef at Bellème, Orne (Dangeard, 1951a).

Zone of *Perisphinctes plicatilis*. Oolithe de Trouville (beds H 17-33) (17-25 m.). The upper part consists of white and grey oolites and oolitic marls resembling the Osmington Oolite; the lowest 4-8 m. is an ironshot oolite marl like Elsworth Rock. The Dorset, Wiltshire and Cambridgeshire facies of the Plicatilis Zone are here combined. The ammonite fauna is almost identical with that of England, except that Cardioceratidae are scarcer. The dominant species are large Perisphinctids such as *P. chlorolithicus*, *P. maximus*, *P. cotowui*, *P. plicatilis*, *P. antecedens*, with *Euaspidoceras perarmatum*, *E. catena*, *E. crebricostis*; also *Cardioceras excavatum* and a solitary *C. densiplicatum* (Arkell, 1948, pp. 386-9). Inland the oolites pass laterally into coral rag with coral reefs and *Diceras* reefs up to 40 m. thick (Dangeard, 1950, pp. 143-4) inseparable from those just mentioned.

LOWER OXFORDIAN (34 m.)

Zone of *Cardioceras cordatum*. Oolithe ferrugineuse (7-78 m.). Bands in clay and ironshot marly limestone with abundant ammonites, especially of the lowest 2-2 m. (bed H15). In this the dominant forms are

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Cardioceratids of the Costicardia Subzone, with *Goliathiceras goliathum* d’Orb. sp. (the type), *Peltoceratoides constantii* d’Orb. sp. (the type) and *Euaspidoceras faustum* Bayle sp. (the type) (Arkell, 1944-48, figs. pp. 291, 324, 345, 387; 1939a, p. 200; for stratigraphical details, Raspail, 1901).

Zone of *Quenstedtoceras mariae*. Marnes de Villers (26-55 m.). Beds H5-14 yield the typical fauna of this zone, including, in the lowest beds (H5-7) *Q. mariae*, *Scarburgiceras scarburgense*, *Hecticoceras bonarellii* de Lor., *Taramelliceras richei* (de Lor.), *T. episcopale* (de Lor.), etc. (Raspail, 1901; R. Douville, 1904, 1912, 1912a, 1913, 1914; Arkell, 1939a, p. 202). *Creniceras renggeri* occurs near the top, in bed H13 (Mercier, 1936).

**Upper Callovian**

Zone of *Quenstedtoceras lamberti*. Marnes de Dives (c. 10 m.). Beds H1-4 and Bed Ho contain a rich fauna of this zone (revised and listed in Arkell, 1939a, p. 203; for figures see the references given under the *Mariae* Zone, plus R. Douville, 1915). The highest metre of bed H3 is a marlstone packed with ammonites, largely identical with those in the *lamberti* limestone of Woodham pit, Buckinghamshire, but in better preservation and yielding many superlative *Quenstedtoceras*, *Kosmoceras*, etc. with complete body-chambers. At Jauzé, inland, the zone is represented by sands (Dangeard, 1951, p. 136).

Zone of *Peltoceras athleta*. Clays said to belong to this zone were formerly exposed at the ‘Mauvais pas’ at the mouth of the River Dive, but the old records of ammonites are not reliable (see Douville, 1912, p. 9; Arkell, 1939a, pp. 200-201). Various *Peltoceras*, *Kosmoceras*, *Pachyceras* (pl. x, figs. 1, 2), *Grossouvria* (pl. ix, 4), *Distichoceras*, etc. of this zone have been figured from limestones at Carreaux, Orne (Bizet, 1895).

**Middle Callovian**

The Athleta Zone ends the eleven miles of cliff-sections in the Oxfordian which stretch from Villerville to Dives. The Middle Callovian is much less well-known, but in inland sections both *Erymnoceras coronatum* and *Kosmoceras jason* have been recorded (Bizet, 1895, p. 89; Parent, 1939c, p. 162). Inland in the depts. of Orne and Sarthe the Middle Callovian becomes ferruginous and yields *Reineckeia anceps* associated with these ammonites (Dangeard, 1951, p. 132).

**Lower Callovian**

Zones of *Sigaloceras calloviense* and *Proplanulites koenigi*. Both index fossils occur in clays in a brickyard at Argences, with *Kepplerites goweri-anum* (Sow.), *Cadoceras sublaeve* (Sow.), *Cadoceras* sp., *Proplanulites teisseyrei* Tornquist, and many brachiopods (R. Douville, 1910; Bigot, 1938; Cardinet, 1944).

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Zone of *Macrocephalites macrocephalus*. At Argences are clays with *Macrocephalites herveyi*. Upper Cornbrash with *Macrocephalitidae* occurs at Lion-sur-Mer and Bréville-Bavent with the typical brachiopods as in Dorset (Mercier, 1927, 1928; Parent, 1939a, 1939e). At Argences the Cornbrash brachiopods occur in clay under the *herveyi* clay (Dangeard, 1951, p. 131).

**UPPER BATHONIAN (up to c. 60 m.)**

Zone of *Clydoniceras discus*. Typical Lower Cornbrash with *Clydoniceras discus, Choffatia subbakeriae, Cererithyris intermedia* and *Ornithella obovata* also occurs at Lion-sur-Mer and Bréville-Bavent and along the Orne valley (Mercier, 1927, 1928; Parent, 1939a, 1939d). Beneath this come the following representatives of the English Forest Marble and Bradford Clay (Guillaume, 1925, 1928):

- Pierre Blanche de Langrune (up to 30 m.)
- Marne à *Ornithella digona* (c. 1 m.)
- Caillasse à *Rhynchonella boueti* (1-5 m.)

The last bed is an expansion of the condensed *boueti* bed of the Dorset coast (Guillaume, 1928; Mercier, 1935, 1939).

Zone of *Oppelia aspidoides*. This zone is comparably represented by the Great Oolite at and south of Bath:

- Caillasse infr. à céphalopodes de Ranville: a lenticular bed with *Wagnericeras wagneri* (Oppel), *W. arbustigerum* (d’Orb.), *Clydoniceras* sp., *Oppelia aspidoides* (Oppel) and *Oecotraustes serrigerus* Waagen (Guillaume, 1925, p. 50), with *Dictyothyris coerectata, Eudesia cardium, Eligmus polytypus*, etc. (Eudes-Deslongchamps, 1864, p. 147)
- Pierre de Taille de Ranville (10 m.)
- Caillasses de Blainville et du Maresquet, with *Oppelia aspidoides, Oecotraustes serrigerus, Wagnericeras spp.* and ‘Zeilleria’ circumdata (1 m.)
- Pierre de Taille de Blainville and Colombelles with coral and stromatoporoid beds which, despite their names, are hardly true reefs (Bigot, 1934, 1949; Dangeard, 1948). (Judging by ammonites figured (Bigot, 1934, pl. xli) at least some of these beds are Upper Bajocian).
- Caillasse de Fontaine-Henry, with *Siemiradszkia aurigera* (Oppel), *Prohecticoceras retrocostatum* (de Grossouvre) and large ammonites described (Parent, 1939b) as *Parkinsonia württembergica*, but which presumably are large discoidal *Gracilisphinctes* (3 m.).

**MIDDLE BATHONIAN (11-20 m.)**

- Pierre de Taille de Creully and Grès du Planet (3-10 m.)
- Caillasses de Longues et de Marigny (Guillaume, 1927), with *Tulites subcontractus, Morrisceras morrisi, Bullatimorphites cf. ymir, Cadomites sp., Siemiradszkia* and other Perisphinctids, and *Ebrayiceras gignouxi* (Guillaume, 1928a).
LOWER BATHONIAN (up to c. 60 m.)

As in England, the stratigraphy of all but the basal beds of the Lower Bathonian is uncertain owing to scarcity of ammonites. Guillaume (1927) established the following succession on and near the coast at Port-en-Bessin:

Calcaires de Maisy (8-10 m.) (perhaps Middle Bathonian)
Calcaires de Cricqueville (10-15 m.)
Calcaires de Vierville (4.5-12 m.) with Posidonia alpina
Marnes de Port-en-Bessin (c. 40 m.) with Posidonia alpina.

Inland the marls (Lower Fuller’s Earth pro parte) are believed to pass laterally into the Calcaire de Caen (30-55 m.), famous building-stone of the Normans; but the Calcaire de Caen may be in part also equivalent to the Calcaires de Vierville & Cricqueville (Parent, 1945), sometimes united as the Oolithe Miliaire but not corresponding to that group around Caen, where the true Oolithe Miliaire is Middle and early-Upper Bathonian. Ammonite records are insufficient for a decisive answer (discussed Wetzel, 1924, pp. 217-8). Eudes-Deslongchamps (1864, pp. 121-8) recorded ammonites nearly a metre in diameter which seemed to him to be giant Am. parkinsoni; this and the vertebrates recall the Hook Norton Limestone and indicate the Zigzag Zone.

The ammonites of this zone abound in three thin beds of limestone, altogether 40-50 centimetres thick, which crop out on the shore east of Port-en-Bessin (Guillaume, 1927b):

Bed C: abundant Oppelia (Oxycerites) fallax (Guéranger), O. limosa (Buck.), O. nivernensis de Gross., with Morphoceras, Ebrayiceras, Zigzagiceras, Oecotraustes, etc.

Bed B: same fauna but Zigzagiceras and Morphoceras more abundant, Oppeliids less common.

Bed A: still has O. fallax and other Oppeliids, Morphoceras and Ebrayiceras, but also abundant Parkinsonia convergens (Buckman), P. pachypleura Buck., and P. ?postera (Seebach), with large Procerites cf. schloenbachi de Gross. (I was able to confirm and correct some of these identifications, especially the Parkinsoniidae, when the late Louis Guillaume showed me his collection in Paris in 1951).

UPPER BAJOCIAN (up to 15 m.)

In the cliffs of Bessin the Zigzag Zone rests on a thick white compact limestone with abundant sponge-remains (‘Oolithe Blanche’, but it is not a true oolite), from which rare Parkinsonia and Oppeliids have been obtained but not determined. This corresponds to the ‘schloenbachi beds’ and sponge limestone in the same position in Dorset, at the top of the Parkinsoni Zone.

Under the white sponge limestone about Bayeux is the Ironshot Oolite, famous as the source of so many perfect ammonites in the quarry at Sully, about 3 miles NW. of Bayeux. It is only up to 2 m. thick, but
in it four beds with distinct ammonite assemblages are recognized (Brasil, 1895, 1895b; Bigot, 1930, p. 383); the highest three comprise the rest of the Upper Bajocian. A revision of the ammonites in accordance with modern systematics is badly needed notwithstanding an attempt by Wetzel (1924). From the records the following may be deduced:

Layer d, very thin and transitional lithologically to the overlying white limestone: *Polyplectites linguiferus* (d'Orb.) dominant, with *Morphoceras defrancei* (d'Orb.), *M. sp.*, *Parkinsonia parkinsoni* (Sow.), *Caumontisphinctes caumonti* (d'Orb.), *Strigoceras truellei* (d'Orb.), *Cadamoceras cadomense* (Defr.) (v. common), *Oecotraustes genicularis* Waagen, *Oppelia subradiata* (Sow.), etc.

Layer c, with *Parkinsonia parkinsoni*, *P. sp.*, *C. caumonti*, and all the other species as in layer d, but also abundant *Lytoceras eudesianum* (d'Orb.) and *Calliphyliceras heterophylloides* (Oppel) (type locality).

Layer b, with *Garantiana garantiana* (d'Orb.), *G. sp.*, *Strenoceras subfurcatum* (Ziet.), *S. bigoti* Brasil, *Strigoceras truellei* (d'Orb.), *Oppelia subradiata* (Sow.), *Oecotraustes genicularis* Waag., *O. skrodskyi* Brasil, *Leptosphinctes davidsoni* Buck., *Cadomites deslongchampi* (d'Orb.), *Sphaeroceras brongniarti* (Sow.), *Bigotites* sp. (Nicolesco, 1917), and *Spiroceras*.

It is obvious that layers c and d fall in the Parkinsoni Zone, while layer b represents a condensed mixture of the Garantiana and Subfurcatum Zones. (See also de Grossouvre, 1919, p. 347, for commentary on this sequence.)

Judging by some small ammonites figured (Bigot, 1934, pl. xli), shelly beds transgressive on the Gres de May and described as Bathonian ('Bradfordian') are Upper Bajocian; but see also p. 76.

**Middle Bajocian (1-3 m.)**

Layer a of the Oolithe ferrugineuse is conglomeratic and contains two distinct faunas. The contemporary ammonites are those proper to the Humphriesianum Zone, namely *Dorsetensia complanata* Buck., *D. eduardiana* (d'Orb.), *D. regrediens* Haug, *D. lennieri* Brasil, *Skirroceras bayleanum* (Oppel), *Teloceras blagdeni* (Sow.), *Stemmatoceras subcoronatum* (Oppel), *Chondroceras gervillei* (Sow.), *Poecilomorphus cycloides* (d'Orb.), *Bajocia farci* Brasil, *Cadamoceras sullyense* Brasil, *Strigoceras bessinum* Brasil, etc.

Inside the blocks of the conglomerate (which are often large) is a derived fauna, among which Brasil enumerates *Sonninia propinquans* Bayle, *S. corrugata* Buck., *Zurcheria zurcheri* Douvillé, *Otoites sauzei* (d'Orb.), *Emileia polymera* (Waag.) and *Bradfordia praeradiata* (Douv.): clearly an assemblage derived from the Sauzei Zone. An analogue of this layer is the 'Red Conglomerate' at Burton Bradstock, an impersistent seam occupying pockets in the top of the Red Bed.

The Sowerbyi Zone is greatly reduced and impersistent, but two levels have been recognized, an upper with *Witchellia laeviuscula* (Sow.) and a
lower with *Hyperlioceras walkeri* (Buck.) (Discites Subzone); the beds are thin, partly phosphatized and conglomeratic (Brasil, 1895b, p. 2; Bigot, 1930, p. 382).

**LOWER BAJOCIAN** (up to 6 m.)

Zone of *Ludwigia murchisonae*. Although thin and sometimes im-


persistent, all three subzones of *murchisonae, bradfordensis* and *concaum* have long been recognized and assigned to the Lower Bajocian (Munier-Chalmas, 1892; Brasil, 1895, 1895a). Many interesting ammonites were figured and assigned to their proper subzones by Brasil (1895); among them *Planammatoceras vaceki* (Brasil), *P. megacanthum* (Brasil), *Erycites cestiferus* Brasil, *Zurcheria pugnax* Vacek, *Z. boutillieri* Brasil, and three new species of Lytoceratids. In May quarries the various subzones overlap earlier beds and transgress on the Palaeozoic platform (see fig. 5).

![Diagram of the plateau of May-sur-Orne](http://jurassic.ru/)

**Fig. 5.—**The plateau of May-sur-Orne; diagrammatic section, after Bigot.

Bajocian: 18, White oolite; 17, Oolithe ferrugineuse; 14, 13, Witchellia and Sonninia beds; 10, Brasilia bradfordensis beds; 9, Ludwigia murchisonae beds; 8, Leioceras opalinum beds (Le Diguet).

Toarcian: 5, Grammoceras toarcense beds with zone of *Haugia variabilis* at base; 4, Hildoceras bifrons beds; 3, Harpoceras falcifer beds (crinoidal limestone and Leptaena bed).

Pliensbachian: 2, Amaltheus margaritatus beds (conglomerate and pockets of gastropods); 1, Acanthopleuroceras valdani beds (Butte de Laize).

**Zones of Tmetoceras scissum and Leioceras opalinum.** A bed containing *L. opalinum* commonly occurs at Le Diguet quarry (Munier-Chalmas, 1892, p. cxiii). The zone was later found at other localities, and studied by Brasil (1893), who found close affinity between its fauna and that of the Murchisonae Zone, justifying its inclusion in the Bajocian. He figured from it *Ludwigia* sp., *Eudmetoceras actinomphalum* (Brasil) and *E. feuguerollense* (Brasil), and recorded *Tmetoceras scissum* and *Erycites cf. fallax*. He stated that *Tmetoceras scissum* also ranges up into the Murchisonae Zone. The base of the Opalinum Zone locally contains rolled ammonites derived from the Upper Toarcian (Brasil, 1896, p. 150).
TOARCIAN (up to 10 m.)

In the condensed succession of clays and shales all the main zones and subzones are represented. The following sequence has been recognized (Brasil, 1895a, 1896; Munier-Chalmas, 1892):

- Niveau de Pleydellia aalensis
- Niveau de Dumortieria pseudoradiosa
- Niveau de Grammoceras thouarsense & G. fallaciosum
- Niveau de Haugia variabilis
- Niveau de Hildoceras bifrons & Dact. commune
- Niveau de Harpoceras falcifer & H. levisoni

A list of ammonites from each level of the Upper Toarcian is given by Brasil (1895a) and of the Lower Toarcian by Munier-Chalmas (1892). At May the various zones and subzones overlap one another on to the Palaeozoic platform and are overlapped by the Bajocian.

PLIENS Bachian

Thin remnants and wisps of deposits, limestone, sand and conglomerate with various Upper and Lower Pliensbachian ammonite faunas, occur at a number of places upon the Palaeozoics and sometimes contain blocks of Ordovician Grès de May (Bigot, 1930, p. 380). A remarkable ammonite, Canavaria mazetieri (Dubar sp., 1927), seems to be a link with Mediterranean faunas; it was found in situ at Tilly in the limestone band which contains Amaltheus and Pleuroceras and forms the top of the stage. At this locality the thickness reaches 7 m. and three horizons are separable (Dangeard, 1951, p. 97).

SINEMURIAN AND HETTANGIAN

Remnants of these stages also occur, but ammonites are rare; Psiloceras johnstoni and Arietites bisulcatus are recorded (Bigot, 1930, p. 378). Locally the Sinemurian reaches 30-35 m., consisting of clays and thin argillaceous limestones with Gryphaea arcuata.

SOUTH-WEST OF THE PARIS BASIN, WITH POITOU AND NORTHERN AQUITAINE

South of the Loire the Jurassic ring that encircles the Paris Basin sends out an extension south-westward, between the crystalline rocks of Armorica and the Plateau Central, to join up with Jurassic outcrops that flank the northern rim of the basin of Aquitaine. The narrows between the two crystalline massifs are known in geological literature as the Straits of Poitiers. The Jurassic forms a low plateau, faulted and gently folded in Tertiary times on lines parallel to the Armorican structures in the basement.

In this south-western area the Lias is greatly reduced and incomplete.

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and, as in Normandy, the various stages overlap the crystalline rocks, sometimes with basal conglomerates. The Toarcian is thin but complete. Not far south of the Loire is its type-locality of Thouars. The Bajocian and Bathonian are thicker and highly variable in facies. The Callovian is in most places greatly reduced in thickness but complete and extremely rich in ammonites. The Oxfordian is also fully represented. This is usually the highest stage present, but in the south-west there is some Lower Kimeridgian left beneath the transgressive Cenomanian. Excellent detailed general accounts are given by Welsch (1903), Couffon & Dolfuss (1928), and Glangeaud (1895).

KIMERIDGIAN (0-50 m.)

A broad band of limestones with marls and coral rags, up to 100 m. thick, extends from the coast between La Rochelle and Marans inland through Charente Inférieure and Charente, in which it is often difficult to draw the line between Lower Kimeridgian and Upper Oxfordian. The upper part, when in suitable cephalopod facies, yields *Streblites tenuilobatus* (Oppel), *Rasenioides thermaurus* (Oppel), *Aspidoceras*, *Taramellinoceras*, *Lithacoceras*, etc. To this period belong the fine coral reefs exposed on the coast near La Rochelle and figured by Haug (1910, Traité, pls. 107, 108). (Glangeaud, 1895, pp. 215-33).

OXFORDIAN (up to 90 m.)

*Zone of Epipeltoceras bimammatum.* The lower part of the formations just described, where in suitable facies, yields the zone fossil and *Ocheto-ceras marantianum* d’Orb. sp., used as alternative index by Oppel and others, of which the type locality is Marans on this coast, together with other Oppeliidae and Perispinctidae (Glangeaud, 1895, pp. 222-3; Welsch, 1903, p. 850; Gérard, 1937, with some new species of *Epipeltoceras*).

*Zone of Gregoryceras transversarium.* This zone also exhibits rapid changes of facies, from marls and marly limestones with cephalopods to coral rags and lithographic limestones with pelecypods. In places where the facies is suitable all the characteristic ammonites occur. The beds have variously been called the *transversarium, perarmatum, martelli* and *canaliculatum* zone (Glangeaud, 1895, pp. 195-213; Welsch, 1903, pp. 847 ff.; Gérard, 1937, pls. xi-xiv, with new species).

*Zone of Cardioceras cordatum.* The ammonite fauna of this zone is mostly pyritized (Glangeaud, 1895, p. 198). The small *Cardioceras* spp. figured by de Grossouvre (1922, pl. xv) certainly belong to this zone and seem to include *C. costicardia* Buckman (fig. i) and other English species. With them are *Creniceras crenatum* and a number of *Taramellinoceras* (*Proscaphites*), *Trimarginites*, *Euaspidoeceras*, etc., including interesting new species figured by de Grossouvre (1922) and Gérard (1937).

The Zone of *Quenstedtoceras mariae* seems to be missing.
Callovian (up to 60 m.)

The Callovian is especially celebrated for its wealth of well-preserved ammonites and appears to be complete with all its zones. The ammonites and their stratigraphy, especially those from the famous locality Montreuil-Bellay (30 miles SE. of Angers) have been the subject of studies by Hébert & Deslongchamps (1860), de Grossouvre (1891), Couffon (1917-19, 1934), Petitclerc (1915, 1918, 1921, 1924) and Gérard & Contaut (1936). These works provide a wealth of excellent figures. The stratigraphy is also well summarized by Glangeaud (1895), Welsch (1903) and Couffon & Dolfuss (1928).

The Lower Callovian contains Bullatimorphites spp. as well as all the usual genera, but it is doubtful whether the true Macrocephalus Zone is represented, despite many records of this species and M. herveyi; if the index species does occur it seems to be associated with Kepplerites, Reineckeia, etc., of the Koenigi and later zones. The age of the celebrated ironstone fauna of the Chalet quarry, Montreuil-Bellay, is substantially Middle Callovian, with late-Lower Callovian, as can be seen from Couffon’s splendid plates. The Upper Callovian contains a remarkable fauna of the Athleta Zone (monographed by Gérard & Contaut, 1936) and locally admits of the separation of a distinct Lamberti Zone (de Grossouvre, 1891, p. 252).

Bathonian (about 12 m.)

Typically, the Bathonian consists of 8-10 m. of poorly-fossiliferous cherty limestones with thin ammonite beds above and below. At the top is a variable series of limestones with Oxycerites aspidoides, Bullatimorphites bullatus, etc., assigned to the Aspidoides Zone (Welsch, 1903, pp. 841, 974, 994). At the base is a well-marked horizon (0.5-1.5 m.) with a rich fauna of the Zigzag Zone, yielding all the characteristic ammonites, such as Zigzagiceras in great variety, Morphoceras, Ebrayiceras, Procercites schloenbachi and other spp., Parkinsonia spp., and Oxycerites spp. (Welsch, 1894). At Luçon, Vendée, are limestones with Cadomites which de Grossouvre (1930, p. 363) regarded as Middle Bathonian. Although the Bathonian along the western border of the Massif Central is often called brackish, the fauna is overwhelmingly normal marine (Glangeaud, 1895, p. 168).

Bajocian (up to 50 m.)

The Bajocian, though often thin, seems to be zonally complete. All the zones from Opalinum to Parkinsoni have been recognized and distinguished by their ammonite faunas (Glangeaud, 1895, 1896; Welsch, 1903, pp. 828, 986; 1928a; Couffon & Dolfuss, 1928, p. 34). Especially valuable for world correlation is a succession of ammonite horizons, each with a distinctive assemblage agreeing with its Dorset counterpart, representing the Discites, Trigonalis and Laeviuscula Subzones of the Sowerbyi Zone, and overlain by the Sauzei Zone (Welsch, 1928a).
collections were determined by S. S. Buckman and are in the museum of the Faculté des Sciences at Poitiers.

TOARCIAN (8-10 m.)

In its type region the Toarcian consists uniformly of blue marl with blue marly limestone bands and pyritized ammonites. Although the stage is so thin, the following ammonite zones are distinguishable at Thouars (Welsch, 1903, p. 821; 1928; for farther east, in Indre, see Mouterde, 1948). Locally the stage transgresses on to the crystalline basement.

- Zone of *Pleydellia aalensis*
- Zone of *Dumortieria radians*
- Zone of *Hammatoceras insigne*, with *Polyplectus discoides*
- Zone of *Grammoceras thouarsense*, with *G. striatum*
- Zone of *Haugia variabilis*, with *Pseudolioceras compactile*
- Zone of *Hildoceras bifrons*, with *H. levisoni* and *Dactyliloceras commune*
- Zone of *Harpoceras falcifer*, with *Dactyliloceras annulatum* and *Frechiella*

PLIENSCHIAN (5-15 m.)

Limestones and sandy limestones of this stage yield *Pleuroceras spinatum*, *Amaltheus margaritatus*, *Prodactylioceras davoii*, *Androgynoceras capricornum*, *Protoprogrammoceras normannianum*, etc. (Welsch, 1903, pp. 815-21, 945; Couffon & Dolfuss, 1928, p. 32). Locally the stage transgresses on to the crystallines.

SINEMURIAN AND HETTANGIAN (up to 20 m.)

Where not cut out by Pliensbachian or Toarcian overlaps, there are limestones assigned to the Lower Lias but containing a meagre fauna. An *Arietites* is recorded (Welsch, 1903, pp. 812-5; Glangeaud, 1895, pp. 22 ff.).

EAST OF THE PARIS BASIN

From the departments of Indre and Nièvre in the south, a continuous broad band of Jurassic,—the most extensive outcrop in Europe,—encircles the Chalk of the Paris Basin on the east as far north as the Ardennes. South-eastwards it spreads over continuously by way of the Plateau of Langres and the department of Doubs to join up with the Jura chain, and it is continued eastward in south Belgium, Luxemburg and Alsace. In this great Jurassic area are Hettange and Semur, type localities of the Hettangian and Sinemurian stages.

Against the Palæozoic horsts of the Massif Central, Morvan, Vosges and Ardennes, various members of the Jurassic change facies or wedge out, overlapped by higher members or by the Cretaceous. For instance, in the Ardennes area the Cretaceous usually rests on the Oxfordian, though occasionally there is some Lower Kimeridge left below the unconformity; parts of the Lower Lias are sometimes missing; and the

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Callovian and Lower Oxfordian are often condensed and represented by thin ironstones.

For the most part the area is one of limestone plateaux, sparsely wooded. The chief plateau-building limestones are the Bajocian-Bathonian, the Upper Oxfordian (coralline oolites and coral rag) and the Middle and Upper Kimeridgian (Calcaire du Barrois). The only extensive lowland is the marshy Woëvre, where the Callovian and Lower Oxfordian are developed as in England and Normandy as ‘Oxford Clay’. The chief sections are along the valleys of the Rivers Loire, Yonne, Seine, Meuse, Saône, and Doubs, where regional monographs have long given an excellent picture of chosen parts of the Jurassic (for instance Buvignier, 1852; de Loriol & Cotteau, 1868; de Loriol, Royer & Tombeck, 1872). Modern syntheses of remarkable breadth and detail now exist or are in preparation for the north (Bonte, 1941), centre (Joly, 1908, Corroy, 1934; Maubeuge, 1955, in the press*) and south (Mouterde, 1953, Lias and Bajocian only). Briefer syntheses of the whole area, or most of it, are given by Lemoine (1911), Corroy (1927) and Gignoux (1950, 4th ed., p. 351) who in his great book on stratigraphical geology takes the east of the Paris Basin as a type series to illustrate the Jurassic System. Exhaustive bibliographies are given by Bonte (1941) and Mouterde (1953). The following is an attempt to collate the most important chronological evidence, as distinct from the almost boundless wealth of detail in the domains of facies and palaeontology.

PORTLANDIAN ? (0-12 m.)

The ‘Zone à Cyrena rugosa’ (up to 12 m.) consists of greenish-grey sandy limestones enclosing the freestone of Savonnieres (3-7 m.), from which are recorded Trigonia gibbosa and ‘Perisphinctes giganteus’ (Lemoine, 1911, p. 124). Quantities of Corbula inflexa and Cyrena rugosa indicate a shallow and brackish sea. (Mollusca figured by de Loriol, Royer & Tombeck, 1872.) The Lower Cretaceous overlaps more or less unconformably.

UPPER KIMERIDGIAN ? (100 m.)

The following succession of the upper Calcaires du Barrois has not yet been satisfactorily dated (see de Loriol, Royer & Tombeck, 1872; Salin, 1935).

Calcaires tubuleux, 2 m., with Serpulae
Calcaires tachetés
Calcaires cariés c. 100 m. about Bar-le-Duc

Together these beds are known as the Zone à Cyprina brongniarti. There is a rich pelecypod fauna, but the only ammonites mentioned are uncertain Perisphinctids (? Katroliceras suprajurense d’Orb. sp.).

* Unfortunately I have not had the advantage of this work, publication of which has been delayed. Dr Maubeuge, however, has sent me several hundred ammonites during the period 1948-53 and showed me some of the sections in 1954.
MIDDLE KIMERIDGIAN (60-70 m.)

The lower part of the Calcaires du Barrois (Salin, 1935) consists largely of lithographic limestone, but contains a marl with *Hemicidaris purbeckensis* and at top shelly limestones. Both above and below the marl occur rather commonly *Gravesia irius* (d’Orb.), *G. portlandica* (de Loriol) and *G. gravesiana* (d’Orb.). Other ammonites are *Aulacostephanus autissiodorensis* (Cotteau) and *Aspidoceras catalaunicum* (de Loriol). (Figures in de Loriol & Cotteau, 1868; de Loriol, Royer & Tombeck, 1872.)

LOWER KIMERIDGIAN (up to c. 150 m.)

The Lower Kimeridgian is difficult to correlate, owing to a high proportion of oolites and other facies unfavourable to ammonites. Under the Gigas Zone in the Haute Marne are 90-100 m. of limestones and marls divided by de Loriol, Royer & Tombeck (1872) between their zones of *Aspicoderas caletanum* (Öppel) above and *Orthaspidoceras orthocerum* (d’Orb.) below. The upper zone (45 m.) contains *A. caletanum*, *Aulacostephanus cf. pseudomutabilis* (de Loriol), *Involuciceras erinum* (d’Orb.) and *Enosphinctes eumelus* (d’Orb.). The lower zone contains *O. orthocerum* (d’Orb.), *Physodoceras laillierianum* (d’Orb.), *Rasenia decipiens* (d’Orb. non Sow.), *Aulacostephanus quenstedti* Durand and *Ataxioceras lorioli* Durand. It appears to have been from a conglomerate at the base of this series that *Rasenia cf. evoluta* Salfeld was collected by Maubeuge (1953). In that case these two Aspidoceratid zones represent the three zones of Pseudomutabilis, Mutabilis, and Cymodoce.

Underneath come the following beds:—

Calcaire à Astartes, 25-30 m., the type formation of Marcou’s Sequanien stage; from this level ‘*Pictonia cymodoce*’ has repeatedly been recorded (Abrard, 1929).

Oolithe de la Mothe, 7 m.

Lithographic limestones, 30-40 m., with the Oolithe de Saucourt in the middle (‘Corallien compacte’, upper part).

From all these beds de Loriol, Royer & Tombeck recorded no ammonites except the doubtful ‘*Perisphinctes achilles*’, but that at least the Calcaire à Astartes is Lower Kimeridgian in Haute-Saône is confirmed by its yielding *Katroliceras aff. crussoliense* (Font.) and *Rasenia aff. trifurcata* (Rein.) (Petitclerc, 1916-17, pl. vii, 1, 2, pl. viii, 1-5). For the underlying beds evidence is still needed. According to Corroy (1927, p. 110), *Ataxioceras lothari* (Oppel) is ‘characteristic’ of this group of beds, without distinction of level, and if it is true that they are on the same horizon as clays at Dompecevin, Meuse, with *A. lothari*, *Katroliceras crussoliense* (Font.), *Progeronia ernesti* (de Lor.), and *P. lictor* (Font.), they must be still Kimeridgian, equivalent to the Lothari and Platynota subzones of the Tenuilobatus Zone in SW. Germany. In NW. Europe it appears that these *Ataxioceras* and *Progeronia* beds are missing; the extremely thin Baylei Zone is no adequate equivalent.
Upper Oxfordian (up to 150 m. or more)

Zone of *Epipeltoceras bimammatum*. To this zone certainly belongs the lower half (30-40 m.) of the 'Corallien compacte', from which de Loriol, Royer & Tombeck (1872) figured *E. bimammatum* Quenst. sp. (pl. v, fig. 3), *Ochetoceras marantianum* d'Orb. sp. (pl. v, fig. 4), *Decipia* sp. (pl. iv, fig. 3), and *Ringsteadia frequens* Salfeld (pl. iv, fig. 2). The first two guide-fossils are found in various places on the east and south-east of the Paris Basin (Lemoine, 1911, pp. 113-117). The basal part of the zone, corresponding to the Cautinsigrae Subzone of England, is represented in at least the upper part of the Calcaire de Creué, Meuse (or in similar beds taken for it), with *Perisphinctes mosensis* Bayle, *P. aff. damoni* Arkell, etc. (Maubeuge, 1953, p. 1909).

Zone of *Gregoryceras transversarium*. The species of *Gregoryceras* have been revised and figured by de Grossouvre (1917). To this zone belong the thick coral rags and coralline oolites, such as those of St Mihiel, Meuse (Buvignier, 1852), with wonderfully rich faunas of pelecypods, gastropods, echinoids, etc. in which ammonites are either very scarce or wanting. In the chalky Calcaire de Creué ammonites are commoner but crushed; most are certainly of Transversarium Zone age (Dechaseaux, 1931, p. 354; Bonte, 1938; Maubeuge, 1953, p. 1909). The sorting-out of the ammonite succession in these coralline facies, mainly from isolated marly lenticles, remains one of the major problems in the stratigraphy of the Paris Basin. The most promising attempt was made by de Grossouvre (1897), who sought to establish a number of ammonite zones, but it is difficult to relate these to the stratigraphy. His conclusions seem to indicate a more gradual passage into both Cordatum Zone faunas below and Bimammatum Zone faunas above, the fauna of the Transversarium Zone being less distinctly demarcated than in NW. Europe and the Jura ranges, probably as the result of continuity of deposition and environment. The same result emerges from the researches of Maubeuge (1951b) in the Verdun region and on the Etain sheet (1952d). Here, as in the Swiss Jura, the fauna of the Plicatilis Zone occurs below the coralline beds, in the 'Chaïlles'; and in the Ardennes (Arkell, 1948, p. 390) and Côte d'Or (Collot, 1917) the base of the zone, already with *Gregoryceras transversarium* or *G. toucasi* near Dijon, is found in the top of the ironshot oolites which so often underlie the coralline oolites and coral rags. Much time has been wasted in sterile attempts to classify the beds into 'Oxfordian s.s.', 'Argovian', 'Rauracian', and 'Sequanian' (e.g. Reyre, 1944) without regard to ammonites and oblivious of the fact that in the type-area of the Jura Mountains the Rauracian and Argovian have long ago been shown to be the same, and that both are equivalent to d'Orbigny's Upper Oxfordian. In the Nièvre this tendency has been carried to extremes with four substages for each of these stages (Panthier, 1931-35); but a useful set of ammonites has been figured, all belonging to the Upper Oxfordian and typical of the Plicatilis-Transversarium Zone.

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Since most are misidentified, they may be listed here with revised names:

- Cardioceras cf. excavatum (Sow.) (Panthier, pl. iv)
- Ochetoceras canaliculatum var. hispidum (Oppel) and an intermediate variety ('montapinense' Panthier) (pl. v)
- Perisphinctes cuneicostatus Arkell (type, P. martelli Klebelsberg, 1912, pl. xviii, fig. 2) (pl. vi)
- P. chlorolithicus (Gümbel) (pl. vii)
- P. aff. cotovui Simionescu (pl. viii)
- Euaspidoceras perarmatum (Sow.) (pl. ix)
- E. (Paraspidoceras) choffati (de Loriol) (pl. x)
- E. nivernum Panthier (pl. xi) (indet. from figure)

It is to be hoped that the admirable remarks by Maubeuge (1951, p. 21) will be taken to heart by future workers.

LOWER OXFORDIAN (up to 60 m.)

Zone of Cardioceras cordatum. The zone is widely represented, mainly by two facies: Terrain à Chailles, and ironshot oolite. The 'chailles' are chert nodules. The usual thickness is about 8-15 m. Locally, however, these facies pass laterally into normal oolites (as in the Jura: see p. 96) and then there is liable to be confusion with the overlying zone. The fauna of the Cordatum Zone sensu stricto is best represented by the Neuvizy Ironstone in the Ardennes, celebrated for its wealth of ammonites in wonderful preservation (Arkell, 1948, p. 390). An Aspidoceratid fauna mainly of this age has been figured from the ironstone of the Côte d'Or by Collot (1917), and the Cardioceratidae and some Perisphinctidae have been figured from there also (especially from Talent) in several works by Maire (1938, 1940, and see references under Mariae Zone). The typical ammonite assemblage is also recorded from the Terrain à Chailles of the Toul district (Maubeuge, 1950c, p. 82) and the Etain district (Maubeuge, 1952d, tableau), and a number of figures are given by Petitclerc (1916-17).

Zone of Quenstedtoceras mariae. The typical facies is marls with pyritized ammonites in great variety, dominated by Scarburgiceras, Pavloviciaceras and Proscaphites, with Creniceras renggeri, Properisphinctes, Prososphinctes, etc., but the zone also occurs as ironshot oolite as at Talent, and as 'gaize', a siliceous marly sandstone (up to 50 m.). The ammonites have been well illustrated in a number of works by Maire (1908, 1928, 1932, 1932a, 1938, 1938a, 1938b, 1940; lists for the Dijon district also by Poinsot, 1939, under 'Præcordatum Zone'). The assemblage is closely comparable with that in the Renggeri Marls of the Jura and equivalent Upper Oxford Clay in the Boulonnais and England.

_CALLOVIAN (up to 170 m.)_

In the Woëvre the whole Callovian is represented in clay facies which passes up into the Lower Oxfordian, Mariae Zone. The full thickness

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of the Argiles de Woëvre is 215 m., of which the Callovian part is at least 165 m. thick (Maubeuge, 1952a, 1953a). Elsewhere condensed ironshot oolites represent all or any of the subdivisions, while the Lower Callovian passes into crinoidal limestone (Dalle nacrée) and oolites that were long mistaken for Bathonian.

**UPPER CALLOVIAN**

Usually, where condensed, the Athleta and Lamberti Zones cannot be separated, but they remain distinct where in clay facies and have been recognized separately in the Dijon district (Poinsot, 1939) and about Besançon (Bonte, 1945a) (where the Lamberti Zone was mistaken for the Mariae Zone). Extensive series of figures of *Quenstedtoceras* from the Lamberti Zone are given by Maire (1938) and a few also by Petitclerc (1916-17, pl. ii, figs. 1-4). In the Vaux boring (Woëvre), the presence of a good Athleta Zone fauna between 105 and 153 m. and of well-preserved, unmistakable *Kosmoceras arkelli* Makowski at 45 m. (Arkell in Maubeuge, 1953a) suggests that Upper Callovian clays there are at least 108 m. thick.

**MIDDLE CALLOVIAN**

Zone of *Reineckeia anceps*. The stratigraphy and ammonites of the Middle Callovian have been monographed by Corroy (1932, as Callovian supérieur), from whose work it is apparent that Oppel's single zone of *anceps* is here more practical, as in the Jura and Germany, though in some places (e.g. Corroy, 1932, p. 57, fig. 10) a lower level with *Kosmoceras jason* and a higher with *R. anceps* are recognized; but in others a level of *Erynmoceras coronatum* is recognized below a mixed level of *jason* and *anceps* (p. 61, fig. 11). The ammonite fauna is extremely rich, especially where the beds are condensed into a few metres or less of ironshot oolite. It includes a great variety of *Reineckeia*, *Hecticoceras*, *Grossouvria*, *Choñatia*, etc., with subordinate *Kosmoceras* and *Erynnoceras*, thus showing its southern affinities. (See also Bonte, 1945a; Joly, 1914; and figures in Petitclerc, 1916-17.)

**LOWER CALLOVIAN**

Besides the records listed in previous literature, there is evidence for Koenigi and Macrencephalus Zones in the magnificent plates of Corroy's monograph (1932). Unfortunately, however, misidentifications are so general in this work that it requires to be used with discretion. *Sigaloceras calloviense* is recorded but not figured, nor are there figures of any *Sigaloceras* or *Cataspigaloceras*, so that the presence of this zone remains doubtful. The Koenigi Zone is represented by splendid *Proplanulites* spp. (1932, pls. xx-xxii), *Gowericeras* (pl. xxiv, figs. 3, 4), *Cadoceras* (pl. xv, 5, 6), and *Pleurocephalites* (pl. v, 1-6). Species of *Kamptokephalites*, *Macrocephalites* s.s., and *Dolikephalites* (pls. vi-xii) abound and show

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that in some places at least the upper part of the Macrocephalus Zone is represented in the ironshot and condensed ‘Callovian inférieur’ (especially in the Vosges department). Elsewhere, however, probably the Koenigi Zone alone is represented in this, resting on the crinoidal Dalle nacrée, which represents the kamptus beds of the Macrocephalus Zone (see above, p. 26). Finally, the lower division, or Macrocephalus Subzone s.s., is developed, at least about Chaumont, as white oolite, previously regarded as Bathonian, but yielding rarely enormous specimens of Macrocephalites s.s. and an occasional Reineckeia (Maubeuge, 1952e). Between Chaumont and Neufchâteau this basal Macrocephalus Zone rests conformably on the Lower Bathonian. Elsewhere other zones of the Callovian also overlap each other and on to Middle Jurassic; in the Ardennes the Anceps Zone contains derived specimens of Proplanulites and Gowericeras, and elsewhere the Athleta Zone overlaps the Anceps Zone (Bonte, 1939, 1945).

**Upper Bathonian (up to about 50 m.)**

In the north, in the Ardennes, the Upper Bathonian is developed as in the Boulonnais and in England. At the top is Lower Cornbrash, with subzones of Ornithella obovata and Cererithyris intermedia, underlain by oolitic marls and limestone with Rhynchonella elegantula like the Forest Marble of the Boulonnais (le Wast), and brachiopod beds. Beneath this again is typical White Limestone with Nerinea eudesii, overlying chalky limestones with Rhynchonella concinna comparable to the Hampen Marly Beds (Bonte, 1941, pp. 144-5).

Towards the south-east this well-differentiated series is replaced by monotonous limestones, the Dalle d’Etain (20 m.), which may yet prove to be (at least in part) Lower Callovian, but from which Dr Maubeuge (1950, table) has sent me a Choffatia belonging to an English Lower Cornbrash species (unpublished) and a ? Procerites. In central Lorraine a more varied succession of marls, limestones, and oyster lumachelles comes in again, as follows (see Maubeuge, 1950, for correlation; and for details Klüpfel, 1916; Frebold & Mülleried, 1923; Gardet, 1947):

- Calcaires de Rouvres, with Clydoniceras, and beds with Gresslya peregrina and Anisocardia nitida, 15 m.
- Upper Ostrea knorri marls, 10 m.
- Marls with Rhynchonelloidea alemannica Rollier sp. (=Rh. varians auct.; see Gardet, 1947, pl. iv, figs. 1-12) upper part, =Marnes de Conflans, upper part. From these beds I have seen Bullatimorphites bullatus (d’Orb.) (typical), Choffatia cf. recuperoī (Gem.) and Oxycerites sp. indet. (see Maubeuge, 1950); 20 m.

Farther south, at least between Neufchâteau and Chaumont, the Upper and Middle Bathonian are cut out by overlap of the Macrocephalus Zone (Oolithe de Chaumont). Records show that Upper Bathonian comes in again on the south side of the Paris Basin (de Grossouvre, 1885, p. 368).

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MIDDLE BATHONIAN (up to 25 m.)

In the north no deposits definitely identifiable as Middle Bathonian have been described, but it is possible that some of the lower 'Great Oolite' facies in the Ardennes (Oolithe miliaire) is of this age. In Lorraine, however, typical ammonites of the Subcontractus Zone occur in the lower part of the Marls with *Rh. alemannica* and the upper part of the Marnes du Jarnisy with *Ostrea acuminata* and *Ostrea knorri*, called the Zone of *[Procerites] quercinus* by Terquem & Jourdy (1869) and the Beds with *[Tulites] subcontractus* by Schlippe (1888). From these beds Dr Maubeuge has sent me *Procerites quercinus* (T. & J.), *Wagnericeras*, giant sp., *Siemiradzkia pseudo-rjasanensis* (Lissajous), *Procerites cf. schloenbachi* de Gross., *Morrisiceras sphæra* Buckman, *Lycetticeras bulbosum* Arkell, *L. lycetti* Ark., *L. comma* (Buck.), *Tulites schlippei* Arkell and *Oxycerites waterhousei* (M. & L.) (see Maubeuge, 1950). The presence of the same zone at points along the south of the Paris Basin is proved by records of several species of *Tulites* and *Morrisiceras* in the departments of Nièvre, Cher and Yonne, at Clamecy, Blet and Vézelay (de Grossouvre, 1930, p. 376).

LOWER BATHONIAN (10-? 25 m.)

As in the Boulonnais, so along the outcrop flanking the Ardennes, the Lower Bathonian is missing, or possibly represented by sands and oolite (which are, however, probably later). In Lorraine the characteristic ammonite fauna of the Zigzag Zone is well represented in the Caillasses à Anabacia (10 m.), which yield *Oxycerites cf. fallax* (Guéranger) and its allies, with *Procerites subprocerus* (Buck.), *P. schloenbachi* de Gross., *P. aff. fullonicus* (Buck.), *P. tmetolobus* Buck., *Morphoceras multiforme* Arkell, *Parkinsonia convergens* (Buck.), *P. württembergica* (Oppel), *Garantiana cf. bathonica* Liss., etc. (Maubeuge, 1950). These beds thus provide a useful correlation between the Württembergicus Beds of Germany and the Zigzag Zone of the west, confirming the opinions of Thiéry (1922, 1922a) and Wetzel (1924). As in Dorset and Normandy, *Parkinsonia convergens* is commonest in the lower part of the zone (Maubeuge, 1950, p. 12) and may be characteristic of a separate subzone. It is possible, but not proved, that the overlying 15 m. of clays, with the lower *Montlivaltia* horizon at base and levels of *Ostrea knorri* in the lower part and *O. acuminata* at top, correspond to the Lower Fuller's Earth which they so strikingly recall (Frebold & Müllered, 1923, p. 376).

The most celebrated fossiliferous Lower Bathonian, however, occurs on the south of the Paris Basin, beyond the Morvan Massif, in the department of Nièvre. Here are St Benin d’Azy (east of Nevers) and Vandennesse (in the valley of the Aron, 28 miles ESE. of Nevers), from which many ammonites have been figured by de Grossouvre (1919, 1930) and Wetzel (1924, p. 221; 1937). On an eroded surface of the Upper Bajocian with *Garantiana* rests a highly fossiliferous bed of oolitic ironstone only 25-70 cms. thick, crowded with ammonites of the Zigzag.
Zone, including a great range of Parkinsonia, Procerites, Zigzagiceras, Morphoceras, Ebrayiceras, Oxycerites, etc. (Revised list in Mouterde, 1953, p. 170.) Above this bed follow limestones and pale marls, undated. An anomaly requiring investigation is the alleged occurrence in the Zigzag Zone of St Benin d'Azy of the type and sole known European specimen of Micromphalites busqueti (de Grossouvre, 1919, p. 359, pl. xiv, 2), which seems identical with forms common in Arabia in the early-Upper Bathonian.

At St Gaultier, Indre, there occurs at the local base of the Bathonian a celebrated marly bed with freshwater gastropods, Viviparus aurelianus and Valvata benoisti (Cossmann, 1899). The bed is only 0.5 to 1.5 m. thick, and is overlain by 10 m. of Bathonian limestones, with Rhynchonella elegantula in the upper part. It is usually considered Upper Bathonian ('Bradfordien'), but since it rests directly on Upper Bajocian limestone with Parkinsonia it may well be older, more nearly the age of the similar Viviparus and Valvata bed in Oxfordshire (p. 30).

**Bajocian** (up to 220 m.)

The Bajocian has now been elucidated in great detail in many works too numerous to quote, and its complicated variations of facies (oolites, coral reefs, ironshot oolite, crinoidal limestone—'calcaire à entroques'—, marls, oyster lumachelles, etc.) are now so thoroughly sorted out that it is possible to compress the results into a single table (p. 64). This is based on works which cite adequate faunas of ammonites for each zone—especially the detailed monographs on the northern area by Bonte (1941) and Maubeuge (1951a), on the southern by Mouterde (1953), for the central region papers by Thiéry (1922, 1922a) and Maubeuge (1943, 1945, 1945a, 1947, 1947a, 1948b, 1949b, 1951a, 1952b) and for the Rhine valley Guillaume (1927), Gillet (1928) and Theobald & Maubeuge (1949). For the Lower Bajocian older works with many figures of ammonites by Benecke (1905) and Branco (1879) cannot be dispensed with; more modern figures are given by Schneider (1927), Gérard & Bichelonne (1934), Gérard (1937) and Gillet (1937).

The monograph by Mouterde (1953) is an immense mine of information on faunal associations and successions, to which no brief commentary could do justice. Anyone working on Liassic and Bajocian stratigraphy will have to study it. Mouterde establishes that in the region west of the massif of Morvan the ironshot oolite facies and crinoidal limestone facies are interchangeable in all the zones of the Lower and Middle Bajocian, and that the ironshot oolite facies locally continues through the Upper Bajocian, and even into the Lower Bathonian, migrating persistently eastwards, in the direction of the ancient massif, as if following a retreating shoreline (p. 429). In central Lorraine it has been established that species of Teloceras pass up into the Subfurcatum Zone, as in the Jura, Germany and Poland (Maubeuge, 1952c), while the upper part of the Parkinsoni Zone contains a stout-whorled Parkinsonia like that

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### Table 4—The Bajocian on the East of the Paris Basin

<table>
<thead>
<tr>
<th>Zones</th>
<th>Ardennes Meuse and Moselle</th>
<th>Alsace</th>
<th>Central Lorraine and North Burgundy</th>
<th>Nièvre and Cher</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UPPER BAJOCIAN</strong></td>
<td></td>
<td></td>
<td></td>
<td>Marls and marly limestones and ironshot oolites</td>
</tr>
<tr>
<td>Parkinsonia parkinsoni</td>
<td>Marnes de Gravelotte (30-40 m.)</td>
<td>Upper and Middle Hauptrogenstein (28 m.)</td>
<td>Calc. à Rh. decorata, Calc. lithographiques, and oolites</td>
<td></td>
</tr>
<tr>
<td>Garantiana garantiana</td>
<td>Oolithe de Jaumont (12-20 m.)</td>
<td>Lower Hauptrogenstein and Marls with Ostrea acuminata (60 m.)</td>
<td>Oolites and cherty limestones of Villey-St-Etienne, etc. (4-9 m.)</td>
<td></td>
</tr>
<tr>
<td>Strenoceras subfurcatum</td>
<td>Marnes de Longwy (10 m.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MIDDLE BAJOCIAN</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stephanoceras humphriesianum</td>
<td>Calcaires à polypiers (10-40 m.)</td>
<td>Marls with some thin limestones and nodules: Dorsetensia romani beds at top, S. humphriesianum and O. sauzei mixed below (19 m.)</td>
<td>Oolites and coral reefs</td>
<td></td>
</tr>
<tr>
<td>Otoites sauzei</td>
<td>Soninia beds and conglomerate</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Soninia sowerbyi</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LOWER BAJOCIAN</strong></td>
<td></td>
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</tr>
<tr>
<td>Graphoceras concavum</td>
<td>...</td>
<td>Marly limestone full of Gryphaea calceola (3 m.)</td>
<td>Red sandy marl and conglomerate</td>
<td></td>
</tr>
<tr>
<td>Ludwigia murchisonae</td>
<td>...</td>
<td>Ironshot oolite (15 m.) passing laterally into sandy marls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leioceras opalinum</td>
<td>...</td>
<td>Marls with L. opalinum (87 m.)</td>
<td>Ironstone with rich Leioceras fauna (15-25 cms.)</td>
<td></td>
</tr>
</tbody>
</table>

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recognized in the same position in England as a subzonal index by Buckman under the wrong name *P. schloenbachi* Schlippe (Maubeuge, 1950, p. 10). (The type-specimen of *P. schloenbachi*, Schlippe, 1888, pl. iv, fig. 4, designated by Rollier in 1911, came from the Zigzag Zone.)

**Toarcian** (up to c. 100 m.; 140 m. in borings in Lorraine)

In places the Toarcian contains phosphatic and quartz pebble beds and shows other signs of incompleteness; but on the whole it is very fossiliferous and admits of highly refined subzonal division, rivalling anything known in England. The standard succession in Lorraine (Corroy & Gérard, 1933) begins with blue marls of the Falcifer Zone (3-5 m.) followed by *Posidonia* shales, clays with big limestone nodules, and marls with phosphatic nodules (Bifrons Zone, 35-50 m.), and ends with marls passing up into the lower part of the Lorraine ironstone (30-50 m.). In east Lorraine a phosphatic nodule bed marks the contact between Pliensbachian and Toarcian, but in Luxemburg there is a gradual passage between the two, with a relatively thick Tenuicostatum Zone (more than 4 m.) (Maubeuge, 1952). This zone is also present in the south of the Paris Basin, where there is a complete representation of the Toarcian zones and subzones although the deposits are thinner (Mouterde, 1953). The following is a summary of the succession, based on that determined in the south, amplified from work in Lorraine, Luxemburg, and Alsace (Theobald & Maubeuge, 1950, p. 276; Schirardin, 1914).

*Zone of Lytoceras jurense*

Subzone of *Pleydellia aalensis*

Subzone of *Pleydellia mactra*

In the Lorraine ironstone beds Maubeuge (1947, p. 86) recognizes a number of minor subdivisions in these subzones.

Subzone of *Dumortieria moorei* = subzone of *D. levesquei*

Subzone of *Dumortieria radiosa*

Subzone of *Phlyseogrammoceras dispansum*: at this level the maximum development of *Hammatoceras insigne*, *H. speciosum* Jan., *H. semilunatum* Jan., etc. In Lorraine Maubeuge (1947) finds *levesquei* in this bed, rather than above.

Subzone of *Grammoceras fallaciosum* and other spp.

Subzone of *Grammoceras thouarsense*, with *G. striatulum*, *G. doerntense* (Denck.), etc.

Subzone of *Haugia variabilis*

Subzone of *Phymatoceras lilli*. The fauna of this subzone seems to be inseparable, at least in the south, from the *Braunianum* Subzone of the Bifrons Zone (Mouterde, 1953, p. 417).

*Zone of Hildoceras bifrons*. Within this zone the following three horizons are recognizable (Corroy & Gérard, 1933):—

Subzone of *Catacoeloceras crassum* [Braunianum Subzone]

Subzone of *Peronoceras subarmatum* [Fibulatum Subzone]

Subzone of *Dactylioceras commune*

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Zone of *Harpoceras falcifer*, with abundant *Harpoceras*, *Dactylioceras*, etc.; according to Mouterde (1953, p. 417) the typical *H. falcifer*, agreeing with the holotype figured by Buckman, occurs in the Bifrons Zone.

Zone of *Dactylioceras tenuicostatum*, *D. semicelatum* (Simpson), *D. directum* (Buck.), and other finely-ribbed species (Maubeuge, 1952, p. 367).

Many of the ammonites from the Jurense Zone and the overlying zones of the Lower Bajocian have been figured in the classic monographs by Branco (1879), Janensch (1902) and Benecke (1905), as also by Schneider (1927) and Gérard & Bichelonne (1940). Revisions of the plates in the earlier works have been published, with many new figures, by Maubeuge (1946, 1947, 1949, 1950a).

**PLIENSBACHIAN (30-195 m.)**

On the northern border of the basin, in the Ardennes, nearly all the English subzones are recognizable. The Spinaatum Zone is developed as a ferruginous and conglomeratic ironstone up to 5 m. thick; it is absent locally and marks a phase of regression. The rest of the Pliensbachian consists of about 50 m. of marls, with belemnites and *Spiriferina* beds in the Ibex Zone. These marls continue the Upper Sinemurian transgression and near Hirson they overstep on to the Palaeozoic (Dubar, 1923; Bonte, 1941, pp. 61-4). In borings in the extreme north of Lorraine the thickness varies from 30 to 195 m. and there is a widespread thin limestone horizon with *Productylioceras davoei* (Guillaume, 1941). All the zones of the stage have also been identified in Belgium and Luxemburg, and their ammonite faunas revised and listed (Maubeuge, 1948, 1948a, 1951, 1952a). For Meurthe & Moselle the ammonites have been listed by Gérard & Tétry (1938); for Burgundy and the Vosges region by Corroy (1934; and see bibliography); and for the south of the basin, where the thickness is about 60-100 m., by Mouterde (1953). South of Langres the Davoei Bed seems to overlap the rest of the Lower Pliensbachian and rest disconformably on the Calcaire ocreux (Rouyer, 1947, p. 46).

**UPPER SINEMURIAN (LOTHARINGIAN) (25-50 m.)**

This substage, which takes its name Lotharingian from Lorraine (Lothringen), comprises the three zones of Obtusum, Oxynotum and Raricostatum (with Armatum), and is useful locally. It begins, however, with the uppermost *Gryphaea* limestones, usually grouped with the Sinemurian *sensu stricto*, but which contain *Promicroceras planicosta* of the Obtusum Zone. The bulk of the substage is made up by marls with *Promicroceras* and *Xipheroceras dudressieri* (d’Orb.), usually 25-30 m. thick. At the top is a condensed bed, the Calcaire ocreux, sometimes

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known as the Raricostatum limestone, which may be of different ages in different places and as a whole combines the Oxynotum and Rari-
costatum Zones and their various subzones. Its upper surface is eroded and followed by a disconformity and pebble bed (Klüpfel, 1921; Frebold, 1927; Maubeuge, 1949a). Thus, although the poor development of these three zones at the type-locality of Semur (see below) has been adduced as an argument for detaching them from the Sinemurian although d’Orbigny included them in it, the highly condensed form of two-thirds of the beds is against taking Lorraine as type-area for a stage based upon them. (For the development and lists of ammonites from other parts of the eastern rim of the Paris Basin, see the same references as before, plus Gérard & Gardet, 1938.)

LOWER SINEMURIAN (up to 50 m.)
At the type-locality, Semur, Côte d’Or, the Upper Sinemurian is highly condensed and fragmentary, represented by 25 cms. only of phosphatic nodules with ammonites of the Oxynotum and Raricostatum Zones (Mouterde, 1953, p. 404). The Lower Sinemurian also is condensed, but much more complete. It comprises 6 m. of grey, semi-crystalline limestones full of *Gryphaea*, in undulating beds with shaly partings.

The succession of ammonites is somewhat different from that expected from more northerly European and English sections (Mouterde, 1953, p. 396; the standard zones are here given, and nomenclatural corrections have been made):

Zone of *Euasteroceras turneri*. *Gryphaea* limestone with *Microderoceras birchi*, present a short distance to the north of Semur, 1.2 m.

Zone of *Arnioceras semicostatum*:
- Horizon of *Arnioceras semicostatum* (Y. & B.) and *A. miserabile* (Quenst.)
- Horizon of *Arnioceras geometricum* (Oppel) and *Arietites falsani* (Dum.)
- Horizon of *Euagassiceras resupinatum* (Simpson) (=saueeanum d’Orb.) and *Metarnioceras*
- Horizon of *Agassiceras scipionianum* (d’Orb.)
- Horizon of *Arnioceras ceratitoides* (Quenst.)

Zone of *Arietites bucklandi*:
- Horizon of *Arietites bucklandi* (Sow.)
- Horizon of *Coroniceras kridion* (Ziet.) and *Megarietites meridionalis* (Reynès)
- Horizon of *Coroniceras rotiforme* (Sow.)
- Horizon of *Metophioceras cordieri* (Canav.)

Southward from Semur parts of the series are missing and the Semicostatum Zone overlaps. West of the Loire the thickness increases to 25 m. and perhaps 50 m. at first, but in Indre it thins again. North-eastward round the Paris Basin the facies remains constant. The thickness

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is less than 10 m. in most of Lorraine, but in the Thionville trough in the extreme north borings prove it to reach 48 m.; and the lower part passes laterally into the upper part of the Hettange Sandstone in the vicinity of the Luxemburg border (Guillaume, 1941). In Luxemburg and Belgium the Sinemurian passes laterally into the Virton Sandstone, 50 m. thick, the upper part of which locally becomes decalcified and forms the Stockem Sands (Maubeuge, 1948, 1952a, 1954a). In the Ardennes the lower part of the Bucklandi Zone is a calcareous sandstone, the upper part only consisting of Gryphaea limestones; and the Semicostatum Zone is condensed as sandy marls and ironstone, while the Turneri Zone begins the overlying series of sandy marls and marly limestones which mainly represent the Obtusum Zone (Bonte, 1941, Table B, p. 82; Joly, 1936).

HETTANGIAN (up to 70 m.)

The type-locality, Hettange (marked Hettingen on some maps) is a village a few miles on the Lorraine side of the Luxemburg border, 14 miles south of the city of Luxemburg. In this district and in Luxemburg territory the Gryphaea arcuata limestones, with Arietites, overlie the Hettange Sandstone, which corresponds to the Zones of Psiloceras planorbis and Schlotheimia angulata. The area from which the Hettangian stage takes its name, however, is unfavourable for establishing an ammonite succession. The whole stage consists of sandstone, more or less calcareous, resting on Rhaetic Beds in some places, on Keuper Marls in others. The basal part is unfossiliferous except for occasional oysters; higher up are masses of Cardinia and Lima with a well-preserved and large fauna of gastropods. The best works on the subject, and almost the only ones providing adequate illustrations, are the early classics by Terquem (1855), Terquem & Piette (1865), Chapuis & Dewalque (1853), and Chapuis (1858). In parts of Luxemburg and Belgium, the Hettange Sandstone passes laterally into the Jamoigne Marl, which contains Caloceras and Schlotheimia (Chapuis & Dewalque, 1853). The Hettangian was said by Terquem (1855, p. 6) to be usually 25-30 m. thick, but in some places up to 100 m. Borings in the Thionville district proved 57-70 m. for the Hettange Sandstone, but part of this represents the Lower Sinemurian in sandstone facies (Guillaume, 1941). Westwards in the Ardennes department of France the stage thins and becomes conglomeratic, and is eventually overlapped by the Sinemurian (Bonte, 1941, p. 77, table B). Farther south, in Meurthe & Moselle, although thicknesses are much less, the facies is marly and calcareous and a much richer ammonite fauna occurs (Gérard & Gardet, 1938). Against the Massif du Morvan the Hettangian oversteps the Palaeozoic rocks, beginning with an oyster lumachelle of Planorbis Zone age, and features similar to those in the northern rim of the Paris Basin, near the Ardennes, are repeated (Mouterde 1953).
Eastern and Southern Borders of the Massif Central

The Massif Central is bounded on the east by the broad alluvial valley of the Rhone and Saône, which is a tectonic depression comparable to the middle Rhine. The faulting has carried the Jurassic rocks down below the alluvium and Tertiaries, and between Lyon and Valence the ancient rocks of the massif abut against the river. North and south, however, a narrow and discontinuous fringe of Mesozoics remains west of the river. This fringe is important out of all proportion to its small area of outcrop. In it the Lias and Tithonian take on their Mediterranean facies. Just as from the north the Jurassic of the Paris Basin spreads through the Langres portal and fringes the massif through the Côte d'Or and Mâconnais, with an outpost in the Mont d'Or, NW. of Lyon, so in the south the Jurassic deposits swing round the southern border.

Fig. 6.—Map of the Jurassic outcrops in the south-east of France.
of the massif. At the south end of the Cevennes they turn a corner and fill a gulf in the southern side of the massif, forming dry limestone plateaux called the Causses (? from Latin calx). The chief limestones and dolomites building the Causses are Bajocian and Bathonian, but a similar facies continues in places to the Tithonian. The special vegetation nourishes sheep from whose milk the celebrated Roquefort cheese has been made since Roman times in underground caverns in the limestone. The Pliensbachian and Toarcian are exceptionally well developed as marls with a rich and perfectly-preserved Mediterranean ammonite fauna, and the Lower Lias forms a lower limestone plateau, the Avant-Causses.

The Tithonian outcrops begin at the spectacular rock on which the Château de Crussol is perched, on a precipice above the Rhone opposite Valence. They continue southwards through Bas-Vivarais, Gard and Languedoc, to the Mediterranean coast. In Bas-Vivarais are the classic localities of Privas and Berrias (after which is named the lowest stage of the Cretaceous), where the ammonite succession is critical for world correlation.

The Jurassic of the area formed the subject of detailed studies by Oppel (1865; 1866, posthumous). Little more than thirty years later was published the thesis by Prof. F. Roman (1897) on the Bas-Languedoc, which began a lifetime's study of the stratigraphy and palaeontology of the area. Far more on the Jurassic than can be condensed here will be found in both his books, the 'Géologie Lyonnaise' (1926) and the posthumous 'Bas-Vivarais' (1950). Between these three were issued a long series of monographs on individual stages, written often in collaboration with colleagues or pupils, and published in the Travaux du Laboratoire de Géologie de Lyon, which he financed out of his own resources. Among these is the standard work on the Montagne de Crussol (Riche & Roman, 1921), the source of the marvellous Tithonian and Kimeridgian material figured in the early monographs of Fontannes (1879) and Dumortier & Fontannes (1876). Still earlier Dumortier (1864-74) published a four-volume monograph on the Lias of the Rhone basin, and the Middle and Upper Lias ammonites of Aveyron have been profusely illustrated in a series of monographs by Monestier (1921-34). The Causses have been well described stratigraphically by Agadèle (1939).

Thanks to these and other workers, so much is now known of this region that a mere tabulation of the ammonite horizons present is all that need be attempted here for most of the stages. The detail can easily be filled in by consulting the works of Roman, which give copious references to the other literature. There is even an account in English (Roman, 1936) of the Lyons-Crussol area, prepared for a memorable excursion of the Geologists' Association, in which I was fortunate to take part. The Lower and Middle Jurassic of the northern part of the area have also been ably summarized and analysed by Mouterde (1953) in the volume so often drawn on in the previous section.

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Plate 4a.—The Montagne de Crussol, with the ruins of the castle perched on the Kimeridgian limestone. (See Fig. 8.)

Plate 4b.—The Château de Crussol and summit limestone, looking over the valley to the River Rhone.
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[BERRIASIAN (LOWER CRETAUCEOUS)]

Zone of *Berriasella boissieri* (Pictet). The Berriasian stage (Coquand, 1875, p. 686; Toucas, 1890, p. 564) at Berrias, Dept. of Ardèche, was founded upon 22 m. of limestones and marls (immediately underlying the Valanginian marls) which Toucas ascribed wholly to the Upper Tithonian but which Pictet (1867) who first monographed the ammonites and Coquand (1875) who introduced the stage name considered wholly Cretaceous. It has since been determined that two faunas were mixed by Pictet and Toucas: the upper is Berriasian, the lower Tithonian. From Berrias and neighbouring localities, the following succession of faunas has been established in the Berriasian (Mazenot, 1939, p. 25):

Upper Berriasian, subzone of *Kilianella aff. pexiptycha* (Uhlig) and *Thurmanniceras aff. pertransiens* (Sayn).

Middle Berriasian, subzone of *Dalmasiceras dalmasi* (Pict.) and *Neocomites occitanicus* (Pict.).

Lower Berriasian, subzone of *Berriasella paramacilenta* Mazenot and *B. grandis* Maz.

The chief distinctions from the Upper Tithonian are absence of Perisphinctidae and presence of numerous *Spiticeras* spp., *Negreliceras negreli* (Math.) and *Neocomites* spp. (For many figures see Djanelidze, 1922, 1922a.)

UPPER TITHONIAN (ARDESCIAN), c. 30-40 m.

This is the type region of the Ardessian stage, named after the Ardèche (Toucas, 1890, pp. 565-6). (=Zone of *Virgatosphinctes transitorius*). There is no lithological or stratigraphical and little faunal break between the Jurassic and Cretaceous. The two zonal indices of the Upper Tithonian proposed by Kilian (1887 and 1895) and often since used, namely *Berriasella calisto* (d'Orb.) and *B. privasensis* (Pict.), are according to Mazenot (1939) commoner in the Berriasian but straddle the boundary, and therefore are useless. Mazenot instead uses two other indices, *Berriasella chaperi* (Pict.) above (formerly the Calisto Zone) and *B. delphinensis* (Kilian) below (formerly the Privasensis Zone). The order of superposition, however, seems to be only inferred and to have no basis in direct observation. Accordingly the original zonal index proposed by Neumayr in 1871 is now used for the Ardesian (Upper Tithonian), namely *Virgatosphinctes transitorius* (Oppel); Mazenot (1939, p. 24) records it from the Upper Tithonian limestone of Berrias. This limestone is poorly fossiliferous. The rich fauna of the Upper Tithonian, with *Berriasella cf. delphinensis* and many other species, also *Micracanthoceras microcanthus* (Oppel), *Corongoceras rhodanicum* Maz., etc., comes from 5-10 m. of marls lying between the Upper Tithonian and Berriasian limestones at localities around Chomerac (Roman & Mazenot, 1937). When turned up by the plough on the fields about 1 m. of these marls

yields abundant small inner whorls of pyritized ammonites. The same preservation, at the same horizon, occurs in Tunisia, where the Upper Tithonian fauna of Jebel Nara contains at least 50 per cent. of Chomerac species of ammonites (see below, p. 272). For abundant figures of Tithonian and Berriasian *Spiticeras* see Djanédizé (1922) (Fig. 7).

Southward into Languedoc the Upper Tithonian is developed in coral-reef facies, in which ammonites are rare but still include *Virgatosphinctes transitorius* and *Micracanthoceras microcanthum* and some 20 other forms, together with a rich and well-preserved fauna of other molluscs and brachiopods, especially reef-building species of *Diceras* (Yin, 1931).

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**Fig. 7.—** Section of the Tithonian, Berriasian and Valanginian 500 metres NW. of Fontasse, near Brune, near Chomerac, Ardèche, after Roman & Mazenot, 1937. Vertical scale exaggerated. The whole sequence is conformable.

5, Valanginian marls; 4, Berriasian limestone with marly intercalations; 3, Upper Tithonian marls and marly limestone (22 m.) with pyritic ammonites (5-10 m.); 2, Upper Tithonian false breccias and nodular limestones (classic horizon of *La Boissière*); 1, Tithonian limestones, grey, more or less thickly bedded.

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**MIDDLE AND LOWER TITHONIAN (UPPER AND MIDDLE KIMERIDGIAN) (15 m. +)**

The lower part of the Tithonian is developed as limestone of various sorts, including massive, semi-marmorized, bedded, nodular, and breccioïd varieties. Thicknesses are hard to establish owing to uncertainty of palaeontological boundaries in described sequences and to different groupings adopted by successive authors. At le Pouzin, Toucas (1890, p. 566) described 15 m. of limestones with *Subplanites contiguus, Perissphinctes pseudocolubrinus* and an abundance of Perissphinctids and Phylloceratids, with rare Berriasellids, *Lytoceras, Haploceras elimatum, H. caractheis*, etc. Below this, however, are 50 m. of massive limestones containing the fauna of the Lithographicum Zone, and also that of the Beckeri Zone, which is pre-Tithonian as here understood (as restricted by Zittel, Neumayr, Kilian and Toucas). The boundary between them remains to be determined.

At Crussol it is possible that the very highest beds of the pink summit limestone at the castle belong to the Lithographicum Zone, but collections made there, assigned to the Lower Tithonian by Roman (1950, p. 71) still contain *Hybonoticeras beckeri* (Neum.) and *H. harpephorum* (Neum.) of the underlying Beckeri Zone (Middle Kimeridgian) (Fig. 8).
MIDDLE AND LOWER KIMERIDGIAN (Plate 4)

With the possible exception of the very highest few metres, as just mentioned, the great mass of marble-like, ruiniform limestones, forming the upper part of the Mountain of Crussol, and for a considerable distance below, belong to the Middle and Lower Kimeridgian. The Beckeri Zone forms the top part, while the base of the Pseudomutabilis Zone falls at or near the top of the Carrière Mallet, source of most of Fontannes' ammonites. The Carrière Mallet was worked mainly in the Tenuilobatus Zone, in which among a wonderful profusion of southern Phylloceratids, Taramellliceras, Haploceras, Streblites, Glochiceras, etc. (Fontannes, 1879, pls. i-vii) there occurs an occasional northern element such as Amoeboceras subtilicaelatum Font. sp. (pl. ii, 7), Rasenia trimera Oppel sp. (pl. ix, 6), Rasenia emancipata Font. sp. (pl. xi, 8), R. desmonota (Oppel), Prorasename stephanoides (Oppel), etc. (Dumortier & Fontannes, 1876, pl. xiv, 2, 3). Unfortunately the stratigraphical relations of these to the Ataxioceratids (including Idoceras) and other Perisphinctids has not been determined and probably never will be, since the quarry has been out of use for many years. The thickness in the quarry is about 33 m. and some sub-division has been attempted (Roman, 1950, p. 64). Although many forms of Ataxioceras occur in the quarry, A. lothari (Oppel) with A. discobolus (Font.), A. polyplocus (Rein.) and other species are said to occur on a lower horizon in an old quarry at the head of Ravin d'Enfer (Riche & Roman, 1921, p. 63); this is the lower part of Oppel's Tenuilobatus Zone, characterized by A. polyplocus and Sutneria platynota in Swabia (Polyplocus Subzone).

Crussol species from the Tenuilobatus Zone worth mentioning for their correlation value, and because inadequately placed by Fontannes, are Sowerbyceras loryi Mun. sp. (D. & F., 1876, pl. v, 2), Streblites tenuilobatus Oppel sp. (pl. vi, 1), Katroliceras crussoliense Font. sp. (pl. xiv, 3), Subdichotomoceras lacertosum Font. sp. (pl. xv, 1), Idoceras spp. (pls. xvi, xvii, 1), and Nebrodites (pl. xvii, 3).

OXFORDIAN (c. 50-70 m.)

At Crussol something less than 30 m. of limestones represent the Bimammatum Zone and yield the zone-fossil (already recorded by Oppel, 1865); below, about 50 m. of grey marls and marly limestones represent the Transversarium and Cordatum Zones. Better and more fossiliferous sections occur at La Voulte, where the Lower Oxfordian is developed in

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Oxford Clay facies with abundant small pyritized ammonites of the Mariae and Cordatum Zones (Marnes de Meyssset) (Sayn & Roman, 1928-30, see especially pp. 48, 214 ff.). At the top is a small thickness of marl characterized by Protophites christoli, which is probably on about the horizon of the catena beds, basal Plicatilis Zone, in England. There follows a poorly developed fauna of the Transversarium Zone, lacking the Perisphinctids of Trept, Isère. The Trept fauna (p. 95) comes in again farther south, at Naves (Roman, 1950, p. 60) and in Hérault, where it is found in abundance in a glauconitic limestone at the base of the Upper Oxfordian, overlying 10 m. of black marls with pyritized ammonites of the Mariae Zone, including Scarburgiceras praeccordatum and Creniceras renggeri (Tintant, 1942). Westward the Upper Oxfordian transgresses towards the old rocks of the Cevennes and finally the Oxfordian wedges out altogether (Tintant & others, 1946, 1947).

CALLOVIAN (c. 50-90 m.)

Upper Callovian. At La Voulte the Oxford Clay facies continues downwards to embrace the Upper Callovian, in which three horizons have been recognized (Sayn & Roman, 1928, p. 45, called Oxfordian):

- Marls with Quenstedtoceras lamberti, Hecticoceras rossiene (Teiss.), Sowerbyceras tortisulcatum (d’Orb.) (here at its maximum abundance) and other Phylloceratidae.
- Marls with Peltoceras athletoides (Lahusen), P. torosum (Oppel), with many Quenstedtoceras brasili Douv., Q. henrici Douv., etc. (Beds H1-3 at Villers).
- Marls with ferruginous limestones: Peltoceras athleta, Quenstedtoceras praelamberti Douv., Kosmoceras [spinosum Sow.].

Both at Crussol and at Naves the Upper Callovian is missing; and at Pic-Saint-Loup, Hérault, it is reduced to a thin bed of glauconitic marl full of ammonites (Tintant, 1942).

Middle Callovian. The Anceps Zone is represented at Pic-Saint-Loup by 50 m. of dolomites with Reineckeia anceps and R. douvillei. At Naves marls (Oxford Clay facies) extend through the whole Middle and Lower Callovian to a total thickness of just over 50 m., and the line of division has not been strictly determined. At the top is a 25 cm. condensed bed crowded with ammonites, including Erymnoceras coronatum, Kosmoceras sp. (‘jason’ is certainly a misidentification in this position; perhaps cf. Lissajous, 1912, pl. vi, 4), Reineckeia aniceps, many Hecticoceras spp., Phyloceras spp., etc. (Roman & de Brun, 1924, p. 19, bed 13; referred to the Athleta Zone, but obviously an assemblage of the Coronatum Zone.) The remaining 50 m. (ibid., pp. 16-18, beds 11, 12) contain elements of both Middle and Lower Callovian faunas. Better results have been obtained at La Voulte, where the Middle Callovian is well demarcated because condensed (Sayn & Roman, 1928-30, p. 22, beds 4d, e, p. 39).

Lower Callovian. At Pic-Saint-Loup, Hérault, under the 50 m.  

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of Middle Callovian follow 40 m. of Lower Callovian marls and dolomitic limestones with *Macrocephalites* (Tintant, 1942). In western Ardèche the Macrocephalus Zone resumes the facies of Dalle nacrée as in the east of the Paris Basin (Tintant & others, 1946). At La Voulte there is an alternation of marls and limestones with two distinct ammonite faunas. The upper horizon, with *Macrocephalites canizzaroi* (non Gemmellaro) identified by Sayn & Roman, 1928, p. 152, with *M. canizzaroi* Couffon, which is holotype of *Dolikephalites gracilis* Spath, 1928) and other small Macrocephalitids, also *Proplanulites teisseyri* Tornquist, *Phlycticeras*, *Kheraiceras*, *Bamburites*, *Oecoptychius* and many other genera (Sayn & Roman, 1928, pp. 36-7) correlates approximately with the Koenigi Zone. The lower assemblage (ibid., p. 33) does not appear to be much older and probably is not basal Callovian. The true Macrocephalus Zone is, however, represented in the Mâconnais by Upper Cornbrash with numerous *Macrocephalites* and large *Choffatia* of the subbakeriae group and *Bullatimorphites* cf. *bullatus* (Parent, 1942). From this came the type of *M. (Kamptokephalites) macconnensis* Spath (1928, Cutch, p. 190; in Lissajous, 1912, pl. vi, fig. 7) and *M. macrocephalus* (Lissajous, 1912, pl. vi, fig. 9).

**Bathonian** (c. 90 m.)

With the Bathonian the centre of interest shifts north to the Mâconnais, the subject of one of the most important monographs on Bathonian ammonites yet published (Lissajous, 1923, posthumous). The Upper Cornbrash, just mentioned, is immediately underlain by Lower Cornbrash with *Clydoniceras discus* and *Choffatia subbakeriae*, just as in England and northern France (Parent, 1942). Below come about 40 m. of marly limestones and marls with many brachiopods, including *Dictyothyris coarctata*, *Ornithella digona*, *Rhynchonella boueti*, *Eudesia cardium*, and at the base an ammonite bed 1.5-2.5 m. thick, crowded with *Prohecticoberas reticostatum* (de Gross.), *Oecotraustes serrigerus* Waag. et spp., *Oppelia aspidoides* (Oppel), *Clydoniceras discus* Sow. sp. (Lissajous, 1923, pl. xxiv, 2), *Delicticeras delictum* Arkell (pl. xxiv, figs. 5-7), *D. cf. Ptychothorrum* Neum. sp. (pl. xxiii, 6), *Polyplectites richei* Liss., *P. denseplicatus* Liss., *Bullatimorphites suevicus* (Roem.), various *Pseudoperisphinctes*, *Siemiradzkia*, *Choffatia* (pl. xiii, 1), etc., and *Epistrenoceras histricoides* (Rollier). This, the Retrocotostatum Zone of Lissajous, is part of the Aspidoides Zone and its position is at or near the base of the Upper Bathonian (cf. Cailllasses de Fontaine-Henry and Blainville in Normandy, p. 48). Under the ammonite bed and included in the Retrocotostatum Zone by Lissajous is 9-10 m. of hard limestone called Choin, with problematic markings but few fossils.

The lower part of the Bathonian comprises 35-40 m. of limestones and marls with a rich ammonite fauna of great interest. Lissajous (1923, p. 21) considered it to embrace the whole Lower and Middle Bathonian, from Zigzag Zone to Subcontractum Zone inclusive, and he called it the

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'Zone of Zigzagiceras arbustigerum'. This was unfortunate, because all the 'Zigzagiceras' figured by him are misidentified Procerites, Wagnericeras, etc., which can be much later, and no Parkinsonia, Morphoceras, or Ebrayiceras occurs. The Zigzag Zone is therefore not represented. On the other hand the Subcontractus Zone is represented by such forms as Lycetticeras bulbosum Arkell, 1953 (holotype Lissajous, 1923, pl. xxi, 1), Sphaeroptychius buckmani Liss., Rugiferites davaiense Liss. sp. and R. angulicostatum Liss. sp. (pl. xxi, figs. 2-4), Tulites aff. cadus Buck. (pl. xx), and probably by some of the curious Bullatimorphites spp. such as B. costatus Arkell, 1952 (holotype pl. xviii, 1), B. perisphinctoides Ark., 1953 (holotype pl. xvii, 1) and among the Perisphinctids the Wagnericeras spp. (pl. vii, 4, viii, 3, xv, 2) and some others.

The rest of the fauna appears to be earlier than Subcontractus Zone. Part may be of the age of the Progracilis Zone, but probably the strangeness of so much of it can be accounted for by its having lived at the time of the Lower Fuller’s Earth of England and northern France where ammonites were almost non-existent. This applies to most of the Procerites spp. which were mistaken by Lissajous for species of the Zigzag Zone (pl. x—Gracilisphinctes spp. ?; pl. xi—not clausiprocerus Buckman; pl. xiv) and to the remarkable forms Garantiana baihonica Liss. and Spiroceras sp. (pl. iii, pl. iv, 1, 3). If these really came from the Bathonian, as Lissajous was convinced they did, the peculiar beds in Normandy resting directly on the Grès de May could be Bathonian also (p. 50). He has been confirmed by the finding of Spiroceras in the Upper and Garantiana bathonica in the Lower Bathonian of Provence by Parent (see below, p. 150).

At Crussol the Bathonian is greatly reduced, consisting of up to 3·25 m. of limestone of the Zigzag Zone, with Zigzagiceras, Morphoceras and Ebrayiceras, also Phylloceras and Lytoceras, then a 10-15 cms. ferruginous bed with Prohecticoceras retrocostatum, overlain by shales with Posidonia, which are 20 m. thick but in their upper part are Callovian, with large Macrocephalites macrocephalus (Riche & Roman, 1921, pp. 47-9). The thickness remains reduced through Ardèche and Gard (Roman, 1950, pp. 45-50), and near Saint-Brès, Gard, it amounts to only 1·5 m. but still contains three ammonite horizons, the lowest the Zigzag Zone as at Crussol, the highest with a mixture of ammonites of the Bathonian and Lower Callovian (de Brun, 1929). At Privas the Zigzag Zone forms the top of the Bajocian iron ore and contains characteristic ammonites (Roman, 1935; p. 48, pl. v, figs. 1, 2, pl. viii, 2, 3), including Zigzagiceras romani Arkell (p. 27, figure).

West and south-west of the Cevennes the Bathonian thickens and takes on a great limestone and dolomite development in the Causses du Larzac and Aveyron. Ammonites are so scarce that little progress has been made in correlation. The total thickness reaches about 80 m. and there is much variety of lithology: besides dolomites there are thick lithographic limestones, oolites and marls, sometimes richly fossiliferous. The lower
part contains bituminous limestones with lignite, rootlet beds, and several horizons with assemblages of small gastropods and pelecypods referred to the freshwater and brackish genera Planorbin, Cyrena, etc. (e.g. Glangeaud, 1895, pp. 154-72; Nicklès, 1907, p. 582). These supposedly brackish beds extend for 250 miles along the south and west of the Plateau Central. A fauna from the Causses du Larzac recently studied (Maubuge, 1949; Cox & Maubuge, 1950) is for the most part a normal marine one and bears a striking resemblance to that of the Upper Great Oolite (Bladon Beds) of Oxfordshire. The genera Viviparus (Paludina), Ampullaria and Paludestrina previously recorded are held to have been misidentified. This does not, however, dispose of the records of Planorbin and Chara, and of lignites with cycads, in the Tournemire area (south of Millau, Aveyron) published by Nicklès (1907, p. 583). These beds form the local base of the Bathonian but may be Upper Bathonian in date and disconformable on the Bajocian. This tends to support the conclusion of Agadèle (1937) that the dolomites of the Causses include the Callovian and even Oxfordian and Kimeridgian. The subject calls for a research with fascinating possibilities, in view of the transgressive 'estuarine' late Bathonian beds reported from so many parts of the world (e.g. Southern Tunisia, Egypt, Cutch, Burma).

UPPER BAJOCIAN (up to 77 m.)

Zone of Parkinsonia parkinsoni. In the Mâconnais an ironshot oolite, c. 6 m., contains P. parkinsoni, Cadomites deslongchampsi, Morphoceras dimorphum, as well as Garantiana garantiana (Roche, 1939), but at Crussol the zone seems to be missing, and it is usually recessive or absent, or devoid of ammonites. It may be represented in the Privas ironstone, which embraces from Lower Bathonian down to Toarcian (Roman, 1935, p. 22).

Zone of Garantiana garantiana. Persistent and fossiliferous in many places. Reaches a great development in the Mont d'Or Lyonnais where it is developed as the Ciret, 70 m. of homogeneous fine-grained limestone with wonderfully-preserved silicified fossils (Roman & Pétouraud, 1927; Marzloff & others, 1936). The fauna consists predominantly of Garantiana spp., Pseudogarantiana dichotoma Bentz (Roman & Pétouraud, 1927, pl. vi, figs. 1-6, 12-17), and Spiroceras spp., with rather numerous Phylloceratidae and Lytoceratidae and Vermisphinctes (ibid., 1927, pl. v, figs. 1, 3, 4), Cleistosphinctes (pl. v, fig. 2), Lissoceras oolithicum, Oppelia subradiata, Cadomites, etc. A small specimen figured as Parkinsonia parkinsoni (pl. vi, fig. 22) is certainly not that species and is not evidence of any admixture of the Parkinsoni Zone. In the Mâconnais the zone is represented by about 12 m. of compact limestone with rare Garantiana.

Zone of Strenoceras subfurcatum. Recognized in the Mâconnais (Roche, 1939, p. 114) as limestone (1·65 m.) with silicified brachiopods and a mixture of ammonites of the Blagdeni, Subfurcatum and Garantiana Zones, some believed to be derived. At Mont d'Or it occurs as a bed
o-20 cms. thick, under the Ciret. As stated above, the common ammonite in the Ciret figured by Roman & Pétauaud, 1927, pl. vi, as *Strenoceras subfurcatum* is *Pseudogarantiana dichotoma* Bentz of the Garantiana Zone; this throws doubt on other records of *Strenoceras* in the area.

**MIDDLE BAJOCIAN (up to 70 m.)**

Zones of *Stephanoceras humphriesianum* and *Otoites sauzei*. In the Mâconnais (Roché, 1939; Mouterde, 1953, p. 304) there is at the top a yellowish or whitish limestone, 0-8 m., with *Teloceras blagdeni*; and derived specimens of *T. banksi* Sow., *T. blagdeniforme* Roché and *Normannites orbignyi* Buckman occur in the Subfurcatum Zone. Beneath come up to 50 m. of crinoidal limestone (Calcaire à Entroques supérieur) with *Stephanoceras humphriesianum* and *S. brodiaeii* (Sow.) in the upper part and *Otoites sauzei* in the lower part. Below again are limestones and marls (0-8 m.) with *O. sauzei*, *Emileia polyschides* (Waagen), etc. passing up locally into sandstones. At Mont d’Or, the so-called *blagdeni* beds are somewhat older, containing various large *Stephanoceras* (but no *Cadamites*), with *Normannites latansatus* (Buckman), *Chondroceras evolvenscens* (Waag.), *Dorsetensia subtecta* Buckman, etc. (Roché, 1943). This bed rests disconformably on the Concavum horizon of the Lower Bajocian. At Crussol the Sauzei and lower Humphriesianum horizons are present (Roman, 1950, p. 40), but the Blagdeni and Subfurcatum horizons seem to be absent.

Zones of *Sonninia sowerbyi*. Limestones and marls (1-4 m.) in the Mâconnais have yielded large Sonninids, *Euhoploceras* cf. *acanthodes* (Buck.), *E. aff. umbilicatum* (Buck.), and *E. aff. marginatum* (Buck.), which Roché (1939, p. 95) assigned to the Concavum Zone; but he was misinformed, for these species, although figured by Buckman as from that zone, came from *Sonninia* beds which he later designated *Discites [Subzone]* and put at the base of the Sowerbyi Zone (see p. 33). This date has been confirmed by subsequent discovery of *Hyperlioceras curvicostata* Buckman (Mouterde, 1953, p. 301). The assemblage is the same as that already recognized, with a much richer fauna, at Trémardières near Poitiers and identified as of Discites date by S. S. Buckman (Welsch, 1928a) (see above, p. 54). The middle and upper parts of the Sowerbyi Zone (Trigonalis and Laeviuscula Subzones) are both missing, however. In the Mont d’Or this gap widens and the whole Sowerbyi Zone is missing (Mouterde, 1953, p. 335). It comes in again at Crussol and Privas, with *Sonninia* cf. *reformata* Buckman (Roman, 1935, pl. iii, 6) (Discites Subzone).

**LOWER BAJOCIAN (up to c. 50 m.)**

In the Mâconnais four successive ammonite horizons have been recognized, corresponding to the Zones and Subzones of Concavum, Bradfordensis, Murchisonae, and Opalinum. *Graphoceras concavum* occurs rather above the middle of the Calcaire à Entroques inférieur.
The Opalinum Zone consists of marly limestone, sometimes ironshot, with a rich fauna, partly contemporary, partly derived from erosion of the Aalensis Zone (Roché, 1939; Mouterde, 1953, p. 304). The total thickness hardly exceeds 20 m. In the Mont d'Or Lyonnais the corresponding beds are 50 m. thick, chiefly made up by Calcaire à Entroques. Ammonites figured include *Ludwigia*, *Tmetoceras*, *Erycites*, *Planammato­ceras*, etc. (Riche, 1896; Roman, 1913; de Riaz, 1907; Riche & Roman, 1921, pl. ii; Roman & Boyer, 1923). At Crussol the beds are highly condensed and incomplete, only a few centimetres thick, but rich in Graphoceratidae. At Privas only the Opalinum Zone is represented in some places, while in others wisps of the Murchisonae and Concavum faunas appear (Roman, 1950, pp. 36–7). In parts of the Causses du Larzac the Murchisonae Zone is very thick and contains sandy limestones with *Cancellophycus* (Nicklès, 1907, p. 582). The Bajocian of the Causses is still almost untouched from the point of view of ammonite stratigraphy, and it offers the attractions of exceptional difficulty (see Boisse de Black, 1933; Agadèle, 1939; Maubeuge, 1949, p. 210).

**Lias**

All stages of the Lias are present, and though the thicknesses and lithology vary as usual, the Lias obeys the rule that it is much more uniform than the rest of the Jurassic. There is not enough departure from ammonite sequences established on the east of the Paris Basin to warrant devoting space to a recapitulation of the succession here. The stages are followed in detail, with minute attention to palaeontology, round the massif of Morvan into the Mâconnais and Mont d'Or Lyonnais by Mouterde (1953). Thence southward all the outcrops through the Bas-Vivarais are dealt with by Roman (1950) and sections in the Upper Pliensbachian and Toarcian in Gard by Stchepinsky (1937). The Causses region is especially favoured, with a thorough stratigraphical revision and correlation-tables by Boisse de Black (1933) and the magnificently illustrated monographs on the Pliensbachian and Toarcian by Monestier (1921, 1928, 1931, 1934), and good illustrations of an Upper Toarcian fauna of *Dumortieriae* by Roquefort & Daguin (1929). Finally for the whole area there are the monographs by Dumortier (1864–74) for the Rhone basin, and by Reynès (1868, 1879) for Aveyron and a much wider region. The monograph by Reynès (1879) has been revised by Donovan (1955, Mém. Soc. géol. France (NS) vol. xxxiv, no. 74).
CHAPTER 4

THE JURA MOUNTAINS

The folded ranges of the Jura form an almost perfectly symmetrical arc or crescent, about 245 miles long on the outer side and 212 miles long on the inner, with a maximum width in the centre of 40 miles. The southern horn of the crescent is joined to the outer front of the Alps near Grenoble; the north-eastern horn narrows to a point in the Tertiary lowland as the single anticline of Lägern, near Baden. From the two extremities inwards the folds multiply fanwise in text-book virgations, until in the middle of the arc there are about twenty anticlines and as many synclines. Most of the folds are formed of Jurassic rocks, but many long and narrow outliers of Cretaceous and even Tertiary sediments are pinched in the synclines; for simplicity these are not shown on the sketch-map (fig. 9).

On the convex rim of the arc, except on the north-west side, the outer fold range abuts against unfolded Jurassic; this constitutes the plateau Jura (Jura tabulaire, Tafeljura) as opposed to the folded Jura (Kettenjura, Jura plissé). The boundary is shown approximately by a dot-dash line on fig. 9. At no great depth under the plateau Jura lies crystalline basement. In the north the basement is an extension of the Vosges and Black Forest massifs; in the centre is another massif which comes to the surface only in a small inlier of crystallines overlain by Permo-Trias, the La Serre massif; in the south another small inlier of Pre-Cambrian basement crops out at the north-west edge of the Ile Crémieu, which is an isolated remnant of plateau Jura. This southern outcrop of basement rocks belongs to the Massif Central, from which it is severed by the rift valley of the Rhone-Saône. The rifting occurred at the same time as that of the Rhine valley between the Vosges and Black Forest and before the main Jura folding. The plateau Jura bordering the Black Forest on the south and east is riven by a system of faults parallel to the Rhine valley rift-faults, and this system is overridden by the outer thrusts and asymmetric folds of the Kettenjura.

The air traveller from England to Geneva who is lucky enough to pick a day on which there is a low cloud-sea, hiding the plateau Jura and the midland valley of Switzerland, sees the arcuate fold ranges of the Kettenjura with their forested tops rising above the cloud like a barrier-reef cutting the ocean. Beyond the cloud-filled midland valley stand the Alps, their bare white peaks raised high in the blue sky and glittering in the sun. This unforgettable sight impresses on the mind a vivid picture of the relation of Jura to Alps. The Jura folds are ruckles in front of the great pile of nappes. The size and arcuate shape of the whole crescent...
of ruckles was evidently determined by the frame of resistant horsts—
Black Forest, Vosges, Serre, Crémiou—within which the Mesozoic cover
was able to crease.

Attempts to draw scale-sections through the Jura anticlines show that
such tight folding cannot be continued at depth: there is no room for
ancient core rocks inside the looped Jurassic formations. Tunnels have
confirmed this: none has revealed any rocks older than Trias inside the
anticlines. Thus the Jura ranges have long been renowned as text-book
examples of disharmonic folding of cover rocks torn bodily from their
resistant basement above a plane of lubrication—here Triassic marls
and salt (fig. 10).

In essence this interpretation is unchallengeable: the disharmony
(décollement) is manifest. That the basement is flat and totally unfolded,
however, by no means follows. The implication that the thrust was
transmitted horizontally through the Mesozoic cover for thirty or forty

Fig. 9.—The Jura Mountains. Jurassic outcrops in black, but including numerous
narrow elongate outcrops of Cretaceous and Tertiary sediments in the synclines.
The division between the folded or chain Jura and the plateau Jura is shown by a
dot-dash line (simplified).
Fig. 10.—Two horizontal sections through parts of the Chain Jura, after Buxtorf. Above, section along the line of the Grenchenberg tunnel; below, section along the line of the Weissenstein tunnel.
miles, while the cover was held down by the weight of the Molasse in the midland valley, stretches credulity too far. As argued by Cadisch (1934), Aubert (1945), and Lees (1952), it is more probable that the basement under the fold Jura was weaker than in the horsts and that the main anticlines and thrust faults in the cover reflect strike-thrusts or thrust-anticlines in the basement. Support for this hypothesis has been provided by closer study of the Jurassic stratigraphy. The main facies-changes in some of the Upper Jurassic stages occur along lines roughly parallel to the chain (Aubert, 1947); the migrating coral reefs of the Upper Oxfordian and Kimeridgian occur in bands parallel to the present strike of the folds (Bourgeat, 1887); and according to Carozzi (1948) and Donze (1950) the freshwater beds of the Purbeckian occur in separate ellipses which to a considerable degree coincide with existing anticlinal culminations. It therefore appears that embryonic folding of the basement was already taking place in the Jura in Upper Jurassic times, long before there was any weight over the midland valley to hold down the cover. Moreover, there is a series of tear-faults which disjoint the otherwise even sheaves of folds and must surely be controlled by tears in the basement. Nevertheless these modifications do not seriously detract from the pre-eminence of the Jura as an illustration of disharmonic folding of a mighty sedimentary cover (the Jurassic alone is up to 1700 m. thick) shortened to accommodate itself to a yielding substratum within a semicircular frame of resistant horsts. Since the Miocene molasse and Pontian freshwater beds are intimately involved in the structures, while the earliest Quaternary deposits (Deckenschotter) lie across their eroded edges, the main phase of folding and thrusting must have taken place in the late Miocene to Pliocene (Favre & Jeannet, 1934, p. 56). No doubt much of the disharmonic detail was controlled by the distribution and behaviour of Triassic salt deposits (Bonte, 1943; Lees, 1952, p. 19).

The floor of the midland valley did not remain entirely free from folds. The ridge of Mont Salève, south of Geneva, and some other folds farther south, although separated by most of the narrowing midland valley, can only be classed with the Jura, tectonically and stratigraphically.

During the Jurassic, as usual, the trough now occupied by the Jura became progressively more differentiated. In Liassic times it was merely a continuation of the Rhone valley and Paris Basin, with which it remained at all times in direct communication through the broad Langres portal. But in the Middle Bajocian coral reefs began to grow, and during the Upper Oxfordian and Lower Kimeridgian these assumed great importance, building up in elongated bands parallel to the present strike of the folds, as remarked above, but also migrating south-eastwards as time progressed, as if advancing out from the Langres portal towards the Alpine geosyncline. The latest reefs are in the Tithonian in the most south-easterly outcrops, at Mont Salève and Echaillon. Dating of
individual reefs has led to prolonged controversies, owing to the difficulty of tracing them laterally into bedded deposits yielding ammonites. Closer study of the corals, however, may in time enable reefs to be more accurately dated from internal evidence; for four successive coral zones have been recognized within the Upper Oxfordian and Lower Kimeridgian of the southern Jura (Pelletier, 1952). The pelecypod *Diceras* is an important constituent of some of the reefs. Farther east sponges predominated and their remains are rock-builders in the lower part of the Transversarium Zone.

Of the extensive documentation of this classic region only the most outstanding contributions can be referred to here. For those not requiring a general account on the monumental scale of de Margerie's (1922-36) there are excellent summaries by Heim (1919) and by Favre & Jeannet (1934). Heim's tables give thicknesses, a feature all too rare in the literature, and some of the readings are surprising—such as 500 m. for the Transversarium Zone. Although nothing like such great thicknesses appear in the palaeontological monographs that have been chiefly used for the present account, Heim's figures are given here because they are for the most part taken from Swiss Geological Survey memoirs, which (with a few exceptions) are too numerous and detailed to be referred to here.

A particularly beautiful coloured map and study of an important part of the Kettenjura between Liestal and Solothurn is available (Delhaus & Gerth, 1912), and there are good studies, also with coloured maps, of the plateau Jura in the north-east (Brändlin, 1911; Braun, 1920). The history of research in the northern Jura since 1900 has been interestingly told by Schmassmann (1950).

The outstanding works on the stratigraphy and palaeontology of the Jurassic of the Jura are a memoir by Moesch (1867) and the magnificent series of monographs on Upper Jurassic ammonites and other mollusca by de Loriol (1876-1904). These set a standard for stratigraphical palaeontology the world over.

Unfortunately the progress of stratigraphy in the Jura has been particularly bedevilled by ambiguous and overlapping nomenclature. The terms Argovian, Rauracian, and Sequanian have been used in such different senses by de Loriol, Rollier, and Haug that they have ceased to convey any meaning and are abandoned in this book. The most inaccurate and regrettable usage was that of Rollier (whose baleful influence on Swiss Middle Jurassic stratigraphy also has been shown by Lieb, 1945, pp. 121-3), and it is unfortunate that Rollier's misleading scheme of stages was adopted in Heim's great work *Geologie der Schweiz* (1919). In order that these terms as used by the principal authors may be interpreted, a comparative table for the Upper Jurassic of the Jura has been drawn up, using as standard scale the stages and zones now adopted throughout this book (table 6, p. 93).
Plate 5a.—Mont Salève, near Geneva. Limestones ranging from Kimeridgian to Barremian.

Plate 5b.—Typical landscape in the Jura Mountains, near Waldenburg. The hills are folded Jura overthrust towards the north (right).
PLATE 6.—The castle of Neu Falkenstein in the Kettenjura, perched on vertical Upper Jurassic in a fol...
THE SOUTHERLY AND SOUTHWEST-EASTERLY OUTPOSTS OF THE JURA

The folds of the Jura Mountains take off from the front of the Alps as a virgation in the northern subalpine ranges of the Grande Chartreuse, between Grenoble and Chambéry. Near Chambéry the western folds of the virgation turn northward to run into the Jura proper, while the eastern or Alpine structures continue north-eastwards, parallel to the main Alpine front. In between are minor folds of hesitant strike, with Upper Jurassic cores, forming the Bauges group and the mountains by the Lake of Annecy. The last of these intermediate ranges is the faulted ridge of Mont Salève, south of Geneva (Plate 5).

This region is of special importance for its bearing on the stratigraphy of the uppermost Jurassic and basal Cretaceous and for the problem of the boundary between the two systems. Its mountains hold the key to these problems more surely than any other outcrops in Europe; for here we are on the border between the Mediterranean province with its marine Tithonian and Berriasian, with good ammonite faunas, and the northern lagoonal or lacustrine province of the Purbeckian, prevalent in the Jura proper and in north-west Europe. Here the two provinces overlap and their characteristic deposits interfinger.

Unfortunately, owing to discontinuity of the outcrops, it is impossible to trace the passage of Purbeck Beds laterally into their marine equivalents, but they overlap in area, and the order of succession has been established. Marine Tithonian continues north to Mont Salève, and Purbeckian, with freshwater gastropods as in the typical Purbeckian of the Jura proper, occurs on Mont Salève and southwards into the Grande Chartreuse group as far as Les Echelles and La Buisse (Moret, 1933, p. 82). Moreover, the Lower Tithonian at Saint-Concors, near Chambéry, contains an extensive ammonite fauna correlating with the Neuburg Beds of the Franconian Alb (Blanchet, 1923; Donze, 1948) and thus enables that otherwise unique fauna to be placed in relation to overlying beds, whereas in the Franconian Alb it is in the highest formation present and so can be related only to underlying beds.

Perhaps the highlight of this region, however, is the occurrence of ammonites in the Purbeck Beds. They have been recorded in two places from measured sections and in close association with, but overlying, beds containing freshwater gastropods such as *Valvata, Viviparus, Physa, Planorbis* and *Lymnaea*: at Cluse de Chaillé near Les Echelles (about midway between Chambéry and Grenoble) (Maillard, 1886, pp. 7, 9 and pl. i, fig. 1), and at Mont Salève, south of Geneva (Joukowsky & Favre, 1913, pp. 313, 477). All the fragments have been sent me on loan from Geneva and Lausanne Museums and I am able to confirm the independent identifications of H. Douvillé and W. Kilian, who determined them as *Perisphinctes* (now *Berriasella*) lorioli (Zittel), of the Upper Tithonian of Straumberg. Both collections, however, also contain unmistakable fragments of *Berriasella richteri* (Oppel), another Straumberg species, which

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on account of its dense, projected secondary ribbing Uhlig included in his Spiti Shales genus *Kossmatia*. Mazenot (1939) now regards both *lorioli* and *richteri* as *Berriasellae* belonging to a group lacking a ventral smooth band. Both species are abundant in and characteristic of the Upper Tithonian (Ardescian, Transitorius Zone), but both have been recorded, rarely, in the Berriasian. There is also a single record (Mazenot,
The general limits of deposition of the Jura Purbeckian were sketched on a map by Maillard (1883, pl. A), but his subsequent discovery at the Cluse de Chaille, north of Les Echelles (1886), and others by Moret, extended the known distribution of the Purbeckian freshwater facies considerably farther south, to the right-angle bend of the River Isère, NW. of Grenoble. Moret’s revised map of this southern extension of the Purbeckian swamps or lake is reproduced here (fig. 11). Like Maillard, he interpreted the boundary as the original limit of deposition, south of which the Purbeckian must pass laterally into the Upper Tithonian (Moret, 1933, p. 81).

The succession of the topmost Jurassic and basal Cretaceous in this critical region is as follows:—

[BERRIASIAN]

In the Bauges and Chartreuse groups the following composite section has been inferred by piecing together a number of separate exposures (Donze, 1951):—

Upper Berriasian: marly limestones; Chara absent, and Dasycladacean algae dying out (Clupeina jurassica Favre).

Middle Berriasian: ‘Calcaire grossier’, a detrital limestone largely composed of echinoderm fragments, comminuted shells and pseudo-ooliths, locally oolitic, always rich in Dasycladacean algae, often with Chara; there are also some black limestone pebbles containing Chara and supposed to be derived from erosion of Purbeck Beds (Moret & Pachoud, 1948). From a lenticular development on this horizon at Nivolet, east of Chambéry, have been obtained (Gidon, 1948) Protacanthodiscus euthymi (Pictet), Neocosmoceras aff. curelense (Kilian), Berriasella boissieri (Pict.), Spiticeras sp., Neocomites occitanicus (Pict.), Lytoceras honoratianum (d’Orb.), an assemblage of the main or middle Berriasian horizon (Boissieri Zone) of Mazenot (1939, p. 25). This bed is about 15 m. thick around Chambéry but thins southwards to about 30 cms. in the middle of the Chartreuse group, and is replaced locally by marly limestones similar to others in the Berriasian.

Lower Berriasian: marly limestones locally rich in foraminifera, and with Dasycladacean algae.]

UPPER TITHONIAN (ARDESCIAN) AND PURBECKIAN

In the Bauges and Chartreuse groups this consists normally of Calpionella and cephalopod limestone, locally pseudo-oolitic and sometimes developing a feeble reef-facies towards the top (Donze, 1951).
In the valley of the Isère NW. of Grenoble are celebrated localities—
Aizy, Noyarey, Le Chevallon (for summary and bibliography see Mazenot,
1939, pp. 18-21), which have yielded the rich ammonite fauna of the
uppermost Upper Tithonian, characterized by *Berriasella chaperi* (Pictet),
*B. aizyensis* Maz., *Dalmasiceras progenitor* (Oppel), *D. djanelidzei* Maz.,
*Neocomites suprajurensis* Maz., etc. This assemblage is believed (Mazenot,
1939) to be higher than the main Upper Tithonian assemblage of Chomerac,
or Delphinensis Subzone, which contains *Promiceras pronum* (Oppel)
and (important in the present context) the Berriasellids without a ventral
groove, *B. lorioli* (Zittel) and *B. richteri* (Oppel).

The Cluse de Chaille section, with the Purbeck Beds, is on the north­
west side of the Grande Chartreuse group. The detailed profile described
by Maillard (1886, pp. 6-7) shows just over 10 m. of marls and thin beds
of limestone, underlying supposed ‘Valanginian’ [Lower Berriasian]
limestones. Less than a metre from the top is a 0-7 m. band of
shelly limestone with *Berriasella cf. lorioli* (Zittel), *B. richteri* (Zittel)
and marine gastropods identified as *Tylostoma* and *Chemnitzia*. At
2-37 m. below this is a thin seam of greenish grey marl (0-15-0-2 m.)
enclosing fragments and nodules of limestone and filling pockets in
the bed below; in this bed occur *Physa* and other indeterminable
freshwater shells.

From here northwards in the ranges that link up with the Jura proper
the Purbeck Beds are fully developed but no sections are known to show
clear relations to dateable Tithonian or Berriasian. In the mountains
on the north-east side of Lake Bourget the beds have been studied by
Donze (1950) and confirm Carozzi’s conclusion in the Jura proper (see
p. 83) that anticlines were already rising in Purbeckian times. On the
flanks of the anticlines the Purbeckian is up to 50 m. thick, but the
proportion of freshwater to marine beds is low; while on top of the
anticlines the thickness is much less and the proportion of freshwater
beds much higher. There is in places on the anticlines a conglomerate
of pebbles derived from destruction of underlying limestones which are
undated but are customarily known in the Jura as ‘Portlandian’.

Finally, on the ridge of Mont Salève is the series of sections described
in detail by Joukowsky and Favre (1913, pp. 310-18). Here the Purbeckian
is 40 m. thick and overlain by about 100 m. of limestones and other beds
assigned to the Berriasian but without ammonites. The Purbeckian
consists of lithographic limestones, marly limestones and marls, with
several bands of conglomerate or breccia; and *Chara*, ostracods and
foraminifera occur throughout. The fragments of *Berriasella lorioli*
and *B. richteri* were found in a marl parting in a limestone band 0-9 m.
thick, at a level 3-2 m. below the top of the section, and marine Jurassic
gastropods (*Nerinea, Aphanoptyxys, Exelissa, Natica*) and *Corbula*
overlie them. Only 0-75 m. below the ammonite bed is again a pebbly marl with
freshwater shells: here *Valvata helicoides* and *Planorbis loryi*, with *Chara*
and *Cypris*. This particular section was at Aiguebelle. At other sections

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on the range Physa wealdiana, Viviparus inflatus and Lymnaea have been found (Joukowsky & Favre, 1913, pp. 477-9, pls. 32, 33).

The Abbé Donze, under whose guidance I visited the sections in the Cluse de Chaille in 1954, allows me to state that he has collected ostracods bed by bed and that they indicate that the Purbeckian there, as described by Maillard, is to be correlated closely with that in the Jura.

LOWER TITHONIAN

Below the Purbeckian at Mont Saleve are 65 m. of thick-bedded limestones, partly oolitic, partly massive and compact, partly in reef facies, full of Diceras and Nerinea, known as ‘Portlandian’, but no ammonites have been found.

What becomes of this thick formation in a southerly direction is a problem still unsolved. In part it may have been eroded away, as suggested by the pebble conglomerates in the Purbeck Beds; in part at least there may be a change of facies into ammonite-bearing limestones. At any rate, at Saint-Concors, north of Chambéry, the normal [Middle] Kimeridgian is succeeded by the celebrated Lower Tithonian with the swarms of Perispinctids of the Neuburg fauna (Franconian Alb), which can be seen to dip below the Upper Tithonian limestones (Mazenot, 1939, pp. 17-19). The Perispinctids of this formation (Blanchet, 1923; Donze, 1948, 1948a) are too numerous to list, but include Subplanites pseudocolubrinus (Kilian) and many Sublithacoceras, Pseudocirrigatites, Anavirgatites, Virgatosphinctes, etc., and the genus Paraberriasella Donze, which seems to be very close to Pectinatites. Donze counted 48 species of ammonites, of which 17 agree with species of the Ciliata Zone at Neuburg (see p. 110) and 5 with species of the Lithographicum Zone, and from this and the presence of Lithacoceras ulmense (Oppel) and L. geron (Zittel) he concluded that Saint-Concors is slightly older than Neuburg. Rather, it must contain older elements; apparently representatives of the Lithographicum and Ulmense Zones as well as the Ciliata Zone, here condensed into one thin lenticle.

On palaeontological grounds Mazenot (1939, p. 25) postulated a gap between the Saint-Concors Lower Tithonian and the Chomérac Upper Tithonian, and in it he would expect to find a fauna with numerous Perispinctids, and with Berriasellids intermediate between those of Neuburg and the true Berriasella of the Upper Tithonian. If, as is now clear, the Purbeckian is equivalent to the lower part of the Upper Tithonian, and the Neuburg fauna is approximately of the date of the Pectinatus Zone (see p. 111), i.e. Upper Kimeridgian, Mazenot’s gap may in fact cover the whole Portlandian and the upper part of the Upper Kimeridgian (the thick Pavlovia Zones). (See table 5, p. 91). It coincides, moreover, with the time of uplift of the Franconian Alb above sea-level and the close of deposition over the whole Swabian-Franconian Jurassic trough until the Upper Cretaceous transgression. It also accounts for the absence from SE. France of any Middle Tithonian faunas such as

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occur in South America and Mexico (see table 24, p. 581); and it is consistent with the widespread pre-Upper Tithonian movements known in many parts of the world (for instance, overstep of Upper Tithonian on to Palaeozoics in parts of Andalusia: p. 246).

Such an extensive uplift accounts for the failure of the uppermost Kimeridgian and Portlandian ammonites to penetrate into these southern basins. Contemporary uplifts elsewhere would also explain the independent and divergent evolution of the Volgian ammonites in north-eastern seas which must have been more or less shut off from the Portlandian basin of NW. Europe. Later uplifts completely isolated the north-western basin and introduced the freshwater regime of the Purbeck and Wealden Beds, just when in the south uplift had given place to subsidence and initiated the Upper Tithonian-Berrriasian cycle of deposition in the Tethys. If the ostracods and freshwater mollusca are to be relied upon as even approximate zonal guides, the hingeing movement took place in the Lower and Middle Purbeckian; for this facies and its peculiar fossil assemblage is alone common to the two areas, and it ends the gap in the south and begins the gap in the north (see table 5, p. 91).

**THE SUCCESSION IN THE JURA PROPER**

[**BERRIASIAN?**]

Under indubitable Valanginian and resting on the Purbeckian are 15-45 m. of limestones and marls. The lower part consists of coarsely oolitic grey marls and limestones, the upper part of ‘bastard marble’. These beds are considered on insecure evidence to represent a littoral facies of the Berrriasian, but the only ammonites that appear to have been found are both doubtful: one seems to be an *Acanthodiscus* misplaced from the Hauterivian, and the other was compared to a Valanginian ammonite (*Am. hystrix* Phillips) from the Speeton Clay (Baumberger, 1903-10, pl. xxi, fig. 1; and part vi, p. 39). The supporting fauna is meagre and undiagnostic, but some ingredients, and also the same ‘bastard marble’ facies, occur in undoubted Berriasian farther south, in the subalpine ranges.]

**PURBECKIAN (12-25 m.)**

The Purbeckian is most complete and fossiliferous in the territory west of Lake Neuchâtel and the Lake of Bienne, to beyond the River Doubs. The interesting molluscan fauna has been monographed by de Loriol & Jaccard (1865) and Maillard (1884, 1886), and their stratigraphical results have been checked and amplified by Carozzi (1948), from whose detailed monograph the following succession emerges:

| Couches saumâtres supérieures (brackish beds) | Upper Purbeck |
| Couches lacustres (freshwater beds) with ‘Intercalation marine’ in the middle | Middle Purbeck |
| Couches dolomitiques inférieures, in part replaced laterally by Marnes à gypse | Lower Purbeck |

Ostracods collected by Carozzi and by Heap are being studied by F. W. [http://jurassic.ru/](http://jurassic.ru/)
### Table 5—Correlation of the Uppermost Jurassic and Basal Cretaceous

<table>
<thead>
<tr>
<th>Stages</th>
<th>England</th>
<th>Tethyan Zones</th>
<th>Haute Savoie, Savoie, Isère</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BERRIASIAN</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Formations</strong></td>
<td><strong>Zones</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>? Wealden Beds</td>
<td></td>
<td>Berriasian, with in middle B. boissieri, Neocomites, Spiticeras, etc.</td>
</tr>
<tr>
<td><strong>ARDESCIAN or PURBECKIAN</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>? Upper Purbeck Beds</td>
<td>chaperi</td>
<td>Upper Tithonian of Aizy with B. chaperi fauna</td>
</tr>
<tr>
<td></td>
<td>Purbeck Beds</td>
<td>delphinensis</td>
<td>Upper Tithonian of Chomérac with B. delphinensis, B. lorioli, B. richteri; and Purbeckien</td>
</tr>
<tr>
<td><strong>PORTLANDIAN</strong></td>
<td>Portland Beds</td>
<td></td>
<td>Gap (possibly filled at least in part at Mont Saleve and in the Jura by so-called Portlandien without ammonites)</td>
</tr>
<tr>
<td><strong>UPPER KIMERIDGIAN</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kimeridge Clay (upper and middle parts)</td>
<td></td>
<td>Lower Tithonian of Saint-Concors with the Neuburg and earlier faunas</td>
</tr>
<tr>
<td><strong>MIDDLE KIMERIDGIAN</strong></td>
<td></td>
<td></td>
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</tbody>
</table>
Anderson, who confirms Carozzi's dating. Collections from about 4 m. above the base of the Purbeckian at localities near the NW. shore of Lake Neuchâtel consisted up to 95 per cent. of Candona bononiensis Jones and corresponded to assemblages from the upper part of the English Lower Purbeck (Anderson, 1951). Mr Anderson informs me (in lit., 1953) that the 'Intercalation marine' in the middle freshwater beds is of the date of the marine beds in the Middle Purbeck, and that so far there is no evidence for the upper part of the Upper Purbeck.

The mollusca comprise many of the same brackish and freshwater genera as in the English Purbeck; in particular there are seven and perhaps ten species of freshwater gastropods, including Valvata, Hydrobia, Planorbis, Physa, Lymnaea, Viviparus and Ellobium.

PORTLANDIAN ? AND UPPER AND MIDDLE KIMERIDGIAN (50-150 m.)

In Randen and the NE. Jura, Plattenkalke, 30-70 m. thick (where not removed by erosion), have long been recognized as belonging to Oppel's Steraspis Zone of Bavaria, on the strength of yielding Streblites (Neo-

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<table>
<thead>
<tr>
<th>Stages and Zones now adopted</th>
<th>Formations (Moesch, 1867, etc.)</th>
<th>Marcou, 1848 Gressly, 1867</th>
<th>Moesch, 1867, p. 207</th>
<th>De Lorol &amp; Girardot, 1896-1904</th>
<th>Haug, 1910</th>
<th>Heim, 1919 (mainly after Rollier)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LOWER KIMERIDGIAN</strong>— Aulacostephanus pseudomutabilis (Wanderer, 1906; = 'mutabilis' Oppel, 1863)</td>
<td>Wettingen Beds</td>
<td>Kimeridgien</td>
<td>Kimeridgien</td>
<td>Kimeridgien</td>
<td>Kimeridgien</td>
<td></td>
</tr>
<tr>
<td><strong>Streblites tenuilobatus</strong> (Oppel, 1863)</td>
<td>Baden Beds (Astartien) Letzi Beds</td>
<td>Sequanien (Marcou, 1848)</td>
<td>Kimeridgien</td>
<td>Sequanien</td>
<td>Sequanien</td>
<td></td>
</tr>
<tr>
<td><strong>UPPER OXFORDIAN</strong>— Epipeltoceras bimammatum (Oppel, 1863)</td>
<td>Wangen Beds (Corallien)</td>
<td>Rauracien (Gressly, 1867)</td>
<td>Corallien</td>
<td>Rauracien</td>
<td>Rauracien</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crenularis Beds Geissberg Beds</td>
<td>Argovien III</td>
<td>Argovien II</td>
<td>Argovien</td>
<td>Argovien</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Effingen Beds Birmensdorfer Beds Terrain à Chailles pars</td>
<td>Argovien</td>
<td>Oxfordien</td>
<td>Oxfordien</td>
<td>Oxfordien</td>
<td></td>
</tr>
<tr>
<td><strong>LOWER OXFORDIAN</strong>— Cardioceras cordatum (d'Orbigny, 1850)</td>
<td>Terrain à Chailles and Pholadomya Beds</td>
<td></td>
<td>Oxfordien</td>
<td>Oxfordien</td>
<td>Oxfordien</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quesnestdoceras mariae (H. Douville, 1881)</td>
<td>Renggeri Marls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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of the Mutabilis and Cymodoce Zones (de Loriol, pl. xiii—this and subsequent references are to the Baden monograph), including Prorasenia stephanoides (Oppel), Rasenia trimera (Oppel) and its allies, Rasenioides lepidulus and R. moeschi (Oppel), etc., as well as some of the Perisphinctids. These are far outnumbered, however, by southern elements such as Streblites, Glochiceras and Taramelliceras (de Loriol, pls. i-iv), Sutneria (pl. xv, 1-5), Idoceras (pl. xv, 6-8, pl. xvi, 1) and a great throng of Ataxioceratidae (pls. x, xi), including Progeronia spp. (pls. vii-ix, xii, 1-2; Butticaz, 1943, pl. iii, 1, pl. v, 2, pl. vi); also Katroliceras crussuliense Font. sp. (de Loriol, pl. v, 7). Peculiar local forms are ?Pararasenia schmidlini (Moesch) and Oxydiscites laffoni (Moesch). Aulacostephanus phoricus (Font.) and A. cf. pseudomutabilis suggest that the Baden Beds straddle upwards into the next-higher zone (de Loriol, pl. xvi, figs. 2-4).

Although the Baden Beds are only 6 m. thick at their type locality in the extreme east of the Jura, they expand to 130 m. at Reculet, where Butticaz (1943, p. 10) found five ammonite horizons up to 100 m. from the base (the top 30 m. being unfossiliferous). Unfortunately the two Perisphinctids from the lowest horizon are not figured, and as both are misplaced generically it is impossible to judge the age of this level; if the species are rightly identified (Dichotomosphinctes fontannesi Choffat sp. and Ringsteadia ? streichensis Oppel sp.) it is probably Upper Oxfordian.

At the southern extremity of the Jura, in Bugey and in the He Cremieu, the Ataxioceras fauna occurs again, in the latter at least with Involuticeras and other Rasenids, forming a link with Crussol (Roman, 1926, p. 198; Pelletier, 1953). This is the Polyplocus Subzone, which is conspicuous also in the Jura Vaudois (Aubert, 1943, p. 15). To it probably belong a number of inadequately figured new species from Porrentruy (Thurmann & Étallon, 1861-64; see also Salfeld, 1914, p. 229; in 1954 the types could not be found).

**UPPER OXFORDIAN (100-660 m.)**

*Zone of Epipeltoceras bimammatum.* Wangen Beds with coralline facies (Diceratien), Crenularis Beds with Hemicidaris crenularis, and Geissberg Beds (total 60-160 m.). The ammonites of the Wangen and Crenularis Beds, as listed by Moesch (1867, pp. 160, 174) deserve more attention than they have so far received. They include *E. bimammatum* (Quenst.), *Sowerbyceras tortisulcatum* (d’Orb.), *Amoeboceras alternans*, various Oppeliids and Perisphinctids, and what appear to be two species of *Ringsteadia*: streichensis (Oppel) and vicarius (Moesch, 1867, pl. ii), the latter comparable to the Pomeranian *Balticeras ramlowi* Dohm. In the Faucille range, west of the Lake of Geneva, these beds are probably represented in the thick marls which are there classed as Upper Argovian (Lee, 1905, p. 47). At the southern extremity of the Jura, in the Ile Crémieu, the zone is highly fossiliferous and well developed, with numerous *Epipeltoceras bimammatum*, *Ochetoceras marantianum* and many other ammonites, but it has been incorrectly correlated with the
The Geissberg Beds (see table, p. 93) seldom contain ammonites, but if as supposed they are equivalent to the Argovien III of de Loriol and Girardot (1903) in the Jura Lédonien, they contain ‘Sutneria ledonica’ de Lor. and three inconclusive Perisphinctids, one of which could well be of the age of the Cautisnigrae Subzone (1903, p. 84, pl. x, fig. 1). The ‘Rauracian’ as understood by de Loriol (see table, p. 93) also yields few ammonites except Perisphinctes chavattensis (de Loriol, 1894, 1895).

Zone of *Gregoryceras transversarium*. Effingen and Birmensdorf Beds (Argovien II and I of de Loriol) and part of the Terrain à Chailles locally (40-500 m.). These beds undergo great changes of facies, from massive or poorly bedded coral limestones and oolites in the north-west (Rauracian facies of some authors) to marls and marly limestones and sponge beds in the south and east (Argovian facies). The most celebrated and most ammonitiferous locality of all is Trept in the Ilé Crémié, in the extreme south. The rich fauna here is dominated by Perisphinctids, many identical with NW. European and English species, with some *Euaspidoceras* spp., combined with *Sowerbyceras*, *Lytoceras*, and many Oppeliidae of southern affinities, especially *Taramelliceras* and *Ochetoceras* (de Riaz, 1898, revised Arkell, 1946).

In the centre and north of the Jura the deposits are thicker and more varied and difficult to classify. Essentially they consist of the Effingen Beds (Argovien II) above and Birmensdorf Beds (Argovien I) below. Much of the Trept fauna occurs in the Birmensdorf Beds, which overlap both eastwards near the Black Forest (Randen) and southwards (La Faucille, Ilé Crémié) across the Lower Oxfordian and Upper Callovian and come to rest on the Middle Callovian. These ‘Argovian’ formations are the ‘Oxfordien supérieur et moyen’ of de Loriol’s monographs (1896-97, 1901, 1902-04). The ammonites figured include mainly forms proper to the Transversarium Zone (=Martelli Zone), but also some from the Terrain à Chailles and Pholadomya Beds, which belong to the upper part of the Cordatum Zone. The majority come from Argovien II, in which *Gregoryceras transversarium* occurs, with *Perisphinctes martelli* Oppel sp. (de Loriol, 1903, pl. viii), *P. parandieri* de Loriol (pl. vii) and most of the other forms figured in plates i-xv. *G. transversarium* or closely allied forms characterize the Birmensdorf Beds in many places (Moesch, 1867, p. 140; Jeannet, 1951, p. 199). The assemblage at Chezery and La Faucille, figured by Lee (1905) and Ronchadzé (1917), lacks the earlier species and is precisely equivalent to the fauna of Trept. The small size of most of the specimens figured is probably due to artificial selection, as with collections of Perisphinctids from the Elsworth Rock. (For facies-faunas in the north, see Leuthardt, 1928.) Some of the most striking specific correspondences with English
ammonites are shown by those from Liesberg (de Loriol, 1896; detailed
section by Koby, in de Loriol, 1898-9, pp. 205-6). From 28 m. of beds
of the ‘Oxfordien sup. et moy.’ come *Perisphinctes maximus* Young &
Bird sp. (1896, pl. vi, fig. 2), *P. pickeringius* Y. & B. sp. (pl. vii, fig. 1),
*P. kingstonensis* Arkell (pl. viii, fig. 1), and probably *Euaspidoceras catena*
Sow. sp. (pl. ix). These are some of the essential species of the Plicatilis
Zone of the Oxford district, and one might suppose them to be on a
somewhat lower horizon than the Trept and La Faucille fauna, and even
de Loriol’s other Argovien I and II faunas, but at Liesberg they are
within a maximum of 28 m. below the base of the ‘Rauracien’ (as under­
stood by de Loriol; see table, p. 93) and *Gregoryceras transversarium*
ocurs with them.

**LOWER OXFORDIAN**

*Zone of Cardioceras cordatum.* Terrain à Chailles and Pholadomya
Beds (lower part), and the thin Cordatum Beds of Herznach. On pls. i-v
of de Loriol’s Jura Lédonien monograph (1902), pls. i-vi of the Jura
Bernois monograph (1896) and pls. i-iii of the supplement (1901) are
figured many ammonites of the genera *Taramellliceras* (Proscaphites),
*Popanites*, *Protophites*, *Creniceras*, *Cardioceras*, *Properisphinctes*, *Miro­sphinctes*, *Tornquistes*, etc., which can only be assigned to the Cordatum
Zone, although many of them are said to be from Argovien I and the
Rhabdocidaris Beds, which are included by Girardot (in de Loriol,
1904, p. 295) in Argovien II. The explanation presumably is that the
Rhabdocidaris Beds are a facies which transgresses the zonal boundaries,
and that where Rhabdocidaris Beds rest directly on Pholadomya Beds
and are thus believed to have overlapped Argovien I (Girardot, p. 296),
they are in reality earlier than in those places where they occur in
Argovien II.

In the extreme north-east, at Herznach, the Cordatum Zone is well
differentiated from the Birmensdorf Beds above and rich in ammonites
although condensed to a bed 1 to 2 cm. thick (Jeannet, 1951, pp. 5, 7,
bed F). An iron-oolite of this age which occurs at the base of the Argovien
at Pontarlier and Crosettes contains a mixture of ammonites of the
Cordatum and Transversarium Zones and is probably a condensed
representative of parts of both (Dreyfuss & Tintant, 1946). In the south
(Ile Crémieu), the Cordatum Zone has not been found and appears to
be overlapped (a fauna found by Blondet at Trept and attributed to this
zone—Roman, 1926, p. 187—manifestly belongs to the Mariae Zone).

*Zone of Quenstedtoceras mariae.* To this zone belong the Lower
Oxfordian Marls or Renggeri Marls or clays, which form many steep
but landslipped slopes throughout the Jura. In some places they average
50-100 m. in thickness but they are in many places thinner (for instance
25 m. at Liesberg and in the Jura Lédonien generally), and towards the
Black Forest they wedge out to 28 cms. at Herznach. Palaeontologically
and lithologically they are a continuation of those on the east of the

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Paris basin. The ammonites have been monographed by de Loriol (1898-99, 1900), whose plates show the usual profusion of beautiful, small, pyritized Oppeliidae, Cardioceratidae, Aspidoceratidae and Perisphinctidae. *Sowerbyceras* and some other Phylloceratids also occur. The swarms of *Scarburgiceras alphacordatum* Spath (de Loriol, 1898-99, pl. ii, 1-3), *S. lahuseni* Maire (fig. 9) and their allies, with *Pavloviceras mariae* d’Orb. sp. (pl. iii), *Hecticoceras, Proscaphites* (pls. iii, iv) and *Creniceras* are accompanied by *Poculisphinctes petitclerci* de Loriol sp. (pl. v, 16), *Properisphinctes bernensis* (de Loriol), *Euaspidoceras habeum* (d’Orb.) and inner whorls of various Peltoceratids difficult to place, all just as in the same zone in England. Interesting aberrant Oppeliids are *Scaphitodites scaphitoides* (Coquand), *Sphaerodomites calcaratus* (Coquand) and *Berniceras inconspicuum* (de Loriol). A few specimens may have come from the Cordatum Zone: e.g. *Vertebriceras sequanicum* Maire (de Loriol, 1898-99, pl. ii, 10), which occurs in the Yorkshire Ball Beds.

**CALLOVIAN** (0·5-82 m.)

The Callovian is condensed and richly fossiliferous, excepting the Macrocephalus Zone, which is often unrepresented by fauna, either owing to absence or owing to development in the facies of crinoidal limestone (Dalle nacrée), which in places has yielded large Macrocephalitidae. Apart from this the prevalent facies is oolitic ironstone or ironshot marls. For the most part the ores belong to the Middle Callovian and the upper part of the Lower (Calloviense and Koenigi Zones). At Herznach mines, near the north extremity of the Jura, the whole Callovian is only 3·25 m. thick and at Chanaz, near the south extremity, even less. At both places the ironstone has yielded magnificent ammonite faunas, monographed respectively by Jeannet (1951) and Parona & Bonarelli (1897). At Chanaz the Upper Callovian (and Lower Oxfordian) is missing, the Transversarium Zone resting on the Anceps Zone, but at Herznach, although less than half a metre thick it is separable into Lamberti Zone above and Athleta Zone below. In the Hauenstein area near Olten both Upper and Middle Callovian are missing (Erni, 1942, p. 162), while in the Ile Crémieu the Middle alone is present (de Riaz, 1895, p. 368). The detailed ammonite succession at Herznach (Jeannet, 1951) makes it a type section; but the order of occurrence of some of the genera and species within the Middle Callovian (beds B2-7 and Cr, total 1·95 m.) is probably valid only locally. For instance, *Erymnoceras* has its maximum abundance above *Reineckea anceps* (Jeannet, 1951, p. 7) whereas at Salins in the west-central Jura, where the development is similar, the order is reversed (Piroutet, 1919). Reversibility of the *anceps* and *coronatum* epiboles was noted also on the outcrops of the eastern Paris Basin (above, p. 60).

A particularly important ammonite succession has been published for the Weissenstein area near Solothurn (Erni, 1934):

Upper Oxfordian, Birmensdorf Beds, above.

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Lower Oxfordian marls, 4-6·5 m.

Upper Callovian, Athleta Zone, 15-22 cms. (0-15-0-22 m.); oolitic ironstone crowded with ammonites belonging to 52 named species, including Peltoceras athleta, all the Kosmoceras species characteristic of the Athleta Zone at Oxford, Proscaphites spp., Hecticoceras (11 spp.), Horioceras, Distichoceras, Phylloceras, Paralicidio, Sowerbyceras sub-tortisulcatum, Phylloceras sp., Lissoceras erato, Grossoveria spp. and 4 new species: Distichoceras quenstedti, Rursiceras subfilatum, Collotia inermis, and Proscaphites taurimontanus (all of Erni, 1934, pp. 123-4, plate). Reineckeia anceps is also recorded, indicating that this thin bed includes part of the underlying zone, otherwise missing.

Lower Callovian, Callovienese Zone, Spatkalkbank, 0·29-1 m. Blue-grey, fine-grained, siliceous limestone, with the fauna of the Planicerclus Subzone of South Cave mixed with southern elements: Catasigaloceras planicerclus Buck., C. curvicercus Buck., Kosmoceras gulielmi (Sow.), common, numerous Perispinctids, Reineckeia dawillei Steinmann, Hecticoceras heticum (Rein.), H. pauper P. & B., H. pleurospanium P. & B., Lissoceras voultense (Oppel), and various stout-whorled Macrocephalitids [presumably Pleurocephalites].

Lower Callovian, Macrocephalus Zone, hard limestones 0-6-5 m, with Macrocephalitids; in some places absent, replaced by clays, 18-38 m., of uncertain date.

Other important works on the Callovian ammonites have been published for the Ile Crémieu (Roman & Blondet, 1926; Blondet, 1935a, 1935b), the Mont du Chat range near Chanaz (Lemoine, 1932), Chézery and La Faucille (Lee, 1905; Tsytovitch, 1911; Pfachler-Erath, 1938), and Baume-les-Dames, Doubs (Petitclerc, 1906; revised and enlarged by Fallot, Corroy & Gardet, 1933, p. 19).

In the dept. of Doubs (and probably elsewhere) the Lamberti Zone is developed as clay and tends to be inseparable lithologically from the overlying Mariae Zone (e.g. Fallot, Corroy & Gardet, 1933, p. 22).

UPPER AND MIDDLE BATHONIAN (up to 15 m.)

Varians Beds (1-15 m.): somewhat sandy limestones with abundant Rhynchonella alemanica (varians auct.), containing ammonites of the Discus, Aspidoides and Subcontractus Zones, though it is likely that all three zones are not everywhere present. Oppelia aspidoides is common at most places, but Clydoniceras and Morrisiceras are more partial in their occurrence and both zones are probably missing where the Varians Beds are thin. Besides Upper and Middle Bathonian species recorded—Clydoniceras discus (Sow.), Oppelia aspidoides (Oppel), Morrisiceras morrisi (Oppel) (Mühlberg, 1900, p. 349; Erni, 1941, 1942)—I have seen from Basel Museum Tulites schlippei Arkell, T. (Rugiferites) sp., and Bullatimorphites aff. suevicus (Roemer) from the Varians Beds of Hauenstein Tunnel (last two) and ‘Argovian Jura’ (first); also Tulites pumilus Arkell and T. (Rugiferites) rugifer (Buck.) from Liestal (F. Lieb Coll.).

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These ammonites prove that the lower part of the Varians Beds is of the age of the Subcontractus Zone, as are the Varians Beds on the east of the Paris Basin (see above, p. 61). (For a further list of Oppelidi from Chanaz see Blondet, 1935.)

The riddled limestone with stylolitic partings in the southern Jura called Choin (Rollier, 1911, pp. 327-8; Roman & Blondet, 1926, p. 376) must come in somewhere in the middle of the Varians Beds if it is truly contemporary with its namesake in the Mâconnais as correlated by Lissajous (see above, p. 75 and table, p. 101). Lithologically, the Choin has much in common with Dagham Stone in the Cotswold Great Oolite.

**Lower Bathonian (up to 20 m.)**

Below the Varians Beds are beds which vary greatly in facies from place to place, from clays and marly limestones with *Ostrea knorri* to sparry limestone (Spatkalk) and coarse white oolite (Grober-Oolith) (Schmassmann, 1945, p. 176). The more marly facies is called Ferrugineus Schichten after *Parkinsoniae* of the Zigzag Zone. Thicknesses approaching 20 m. are rare; less than 5 m. is more usual, especially for the Ferrugineus Schichten facies. At the base of the Spatkalk in the north is 2 m. of marl with *Eudesia cardium* in great quantity, associated with *Parkinsonia württembergica* Oppel sp. (Erni, 1942), so that the brachiopod appears here much earlier than in northern France. In some places at least, in the northern Jura near Olten (Erni, 1942, p. 161), the *Eudesia cardium* marl separates the Spatkalk above from the Grober-Oolith (2-8 m.) below, and a 'Ferrugineus-Oolith' (3-8 m.) lies below that. From the contained ammonites all three divisions below the Spatkalk are Lower Bathonian, and all three can pass laterally into Grober-Oolith (Lieb, 1946, table, p. 226; Schmassmann, 1945, p. 176). Where thickly developed the Grober-Oolith forms an upward passage from the Bajocian, having yielded ammonites of both the Parkinsoni Zone and the Lower Bathonian (Mühlberg, 1900, table, p. 330; Maubeuge, 1950). *Procerites aff. fullonicus* (Buckman), of the Zigzag Zone, has been figured from the Marnes du Fucil (Clerc, 1904, pl. 1, 2-3), and Clerc’s *Parkinsoniae* (pl. 1) are probably of this age also.

**Upper Bajocian (up to 105 m.)**

The Upper Bajocian coincides almost perfectly with the Hauptrogenstein (Grande Oolithe) plus marly limestones at top with *Terebratula movelierensis* (Movelier Schichten) and, at least locally, the lower part of the Grober-Oolith, as already made clear by Mühlberg (1900, table, p. 330). In the plateau Jura near Basel this sequence reaches over 100 m. in thickness (Schmassmann, 1945, p. 176). The lower part of the Hauptrogenstein passes eastwards into lumachelles of *Ostrea acuminata* (to 10 m.), which probably belong to the Subfurcatum Zone (Mühlberg, 1898, 1900). Ammonites are rare in all three beds but various records indicate the presence of all the three Upper Bajocian zones, and it seems to be established that *Teloceras*, recorded by several authors as *T.*

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blagdeni, occurs also. In the Staffelberg area a coral reef started to grow at the time of the Blagdeni Zone and continues upwards well into the Lower Hauptrogenstein, showing continuity of conditions.

**MIDDLE BAJOCIAN (up to 190 m.)**

Zone of *Stephanoceras humphriesianum*. This is divisible into Blagdeni Beds above (sandy limestones and marls, 3-20 m.) and Humphriesianum Beds below (largely ironshot marls and ironshot oolites, 1-7 m.). As remarked above, *Teloceras* sp. or spp. customarily identified as *blagdeni* pass up into the Subfurcatum Zone. The Humphriesianum Zone yields large *Stephanoceras* and *Skirrocera*, and also *Sphaerooceras bronniarti*, *Chondroceras gervillii*, *Poeciloceramus cycloides*, *Oppeliasubradiata* (Greppin, 1898, pp. 23-7, 34-5) and *Strigoceras strigifer* Buck. sp. (Maubeuge & Lieb, 1950). Some areas have considerable coral growth in this zone.

Zone of *Otoites sauzei*. Marls and sandy limestones, up to c. 30 m., passing in places into crinoidal limestones and coralline limestones: *Emileia polymera* (Waag.), *E. polyschides* (Waag.), *Otoites sauzei* (Greppin, 1898, pls. i-iii), *Normannites cf. braikenridgei* (Sow.), *Skirrocera macrum* Quenst. sp. (Pelletier, 1950).

Zone of *Sonninia sowerbyi*. In the southern Jura this zone reaches a thickness of 130 m., consisting chiefly of marly to sparry limestones, with some bands of chert nodules and a coral band (15 m.) in the *Laeviuscula* Subzone (Pelletier, 1950). In the lowest 11 m. Pelletier records a large *Euhoploceras* and, immediately above, a bed (c. 6 m.) with *Hyperlioceras*, *Graphioceras*, *Reynesella* and *Sonninia*. In the Basel region the thickness of the zone is only 12-35 m. at a section described in detail by Strübin (1900), which yielded *Sonninia*, *Poeciloceramus* and *Hyperlioceras*. In this region Maubeuge & Lieb (1950) find all three subzones identifiable by distinctive ammonites.

The details of this and other Bajocian zones in the Rhine valley near Lorrach are described by Wittmann (1949).

**LOWER BAJOCIAN (up to 125 m.)**

The Lower Bajocian consists of very variable beds of limestone, marl and ironshot oolite (2-18 m.), which pass down into the Opalinum Clays (Mühlberg, 1900). The normal thickness for the Opalinum Clays is about 50 m., but in a boring at Buix near Porrentruy they were 157 m. thick and, although no fossils were found in them, they overlie Toarcian shales with *Posidonia*, under which were pyritized *Pleuroceras spinatum* and *Spiriferina*, so that no mistake was possible (Schmidt & others, 1924). Probably, however, the Jurense Zone is represented in this great thickness, for there is a gradual passage in some places at outcrop. Often, also, the upper part of the Opalinum Zone is represented in the base of the overlying limestones and ferruginous beds.

In the north-eastern part of the Jura an exceptionally valuable ammonite succession, correlating with Germany and England, has been established.
<table>
<thead>
<tr>
<th>Stages</th>
<th>Zones</th>
<th>Mâconnais</th>
<th>Jura</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bathonian—</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Upper</strong></td>
<td>Clydoniceras discus</td>
<td>Lower Cornbrash, Brachiopod marls, and basal ammonite bed ('Retrocostatum Zone') 40 m.</td>
<td>(some missing?)</td>
</tr>
<tr>
<td></td>
<td>Oppelia aspidoides</td>
<td></td>
<td>Varians Beds 1-15 m.</td>
</tr>
<tr>
<td><strong>Middle</strong></td>
<td>Tulites subcontractus</td>
<td>? Choin, 10 m., and marls and limestones:</td>
<td>Spatkalk</td>
</tr>
<tr>
<td></td>
<td>Gracilisphinctes progracilis</td>
<td>'Arbustigerus Zone' 40 m.</td>
<td>Knorri Clays 5-20 m.</td>
</tr>
<tr>
<td><strong>Lower</strong></td>
<td>?</td>
<td>Missing</td>
<td>Ferrugineus Beds</td>
</tr>
<tr>
<td></td>
<td>Zigzagiceras zigzag</td>
<td></td>
<td>Grober-Oolith</td>
</tr>
<tr>
<td><strong>Bajocian—</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Upper</strong></td>
<td>Parkinsonia parkinsoni</td>
<td>Ironshot oolite, 6 m.</td>
<td>Hauptrogenstein, 100 m.</td>
</tr>
<tr>
<td></td>
<td>Garantiana garantiana</td>
<td>The Ciret, 70 m.</td>
<td>Ostrea acuminata beds, 10 m.</td>
</tr>
<tr>
<td></td>
<td>Strenoceras subfurcatum</td>
<td>Brachiopod beds, 1-65 m.</td>
<td></td>
</tr>
<tr>
<td><strong>Middle</strong></td>
<td>Stephanoceras humphriesianum</td>
<td>Blagdeni bed, 8 m. and Calcaire à entroques, 50 m.</td>
<td>Blagdeni and Humphriesianum beds, 20 m.</td>
</tr>
<tr>
<td></td>
<td>Otoites sauzei</td>
<td>Missing</td>
<td>Sauzei beds, 30 m.</td>
</tr>
<tr>
<td></td>
<td>Sonninia sowerbyi</td>
<td></td>
<td>Limestones up to 130 m.</td>
</tr>
</tbody>
</table>

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by Lieb (1951, 1954). In the following summary all the species are Buckman's except where otherwise attributed.

Zone of Graphoceras concavum, with G. concavum and numerous other Graphoceras spp., Brasilia, Reynesella, Eudmetoceras ampletens, E. infernense, E. euaptetum. A distinct horizon at base of the zone contains a mixture of Graphoceras, some of which occur in the Concavum Zone, others in the Bradfordensis Subzone in England.

**Table 8.—The Lower Bajocian in the Northern Jura**

<table>
<thead>
<tr>
<th>Zones (with dates proposed)</th>
<th>Subzones in the Jura (Lieb)</th>
<th>NW. Germany (Hoffmann)</th>
<th>England</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphoceras concavum (Buckman, 1890, Haug, 1891)</td>
<td>Graphoceras concavum (and 'praeconcava')</td>
<td>concavum</td>
<td>concavum</td>
</tr>
<tr>
<td></td>
<td>Brasilia bradfordensis (Buckman, 1893)</td>
<td>murchisonae</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stauferia staufensis (Hoffmann, 1910)</td>
<td></td>
<td>staufensis</td>
</tr>
<tr>
<td></td>
<td>Costileioceras discoideum (Hoffmann, 1913)</td>
<td>discoideum sehnense toltarium</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tmetoceras scissum (Neumayr, 1871, emended Buckman, 1898)</td>
<td>Tmetoceras scissum (with Costileioceras sinon)</td>
<td>sinon (Hoffmann, 1910)</td>
</tr>
<tr>
<td></td>
<td>Leioceras opalinum (Brauns, 1864)</td>
<td>Leioceras opalinum (with Costileioceras costosum)</td>
<td>costosum</td>
</tr>
</tbody>
</table>

Zone of Ludwigia murchisonae.

Subzone of Brasilia bradfordensis, with B. bradfordensis, B. platychora, B. subcornuta, Ludwigia falcata, L. similis, L. wilsoni, Graphoceras impolitum, Stauferia staufensis Oppel sp. (rare).

Subzone of Stauferia staufensis. About 4.5 m. below the foregoing ammonite bed at Duntelen is a horizon with rather common S. staufensis (Oppel), as in Germany.

Subzone of Costileioceras discoideum (Qu.), which combines Hoffmann’s subzones of C. discoideum, C. sehnense and C. toltarium in Germany and already contains Ludwigia murchisonae, as in the Swabian Jura (see p. 125). Since Costileioceras toltarium (Dumortier) occurs in England in the Scissum Zone, this condensed Swiss zone apparently embraces

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the lower part of the Murchisonae Zone, the 'Ancolioceras beds', and part of the Scissum Zone of England.

Zone of *Tmetoceras scissum*, with *T. scissum* (Ben.), *T. regleyi* (Thiol.), *Costileioceras sinon* (Bayle), *Costileioceras spp.*, etc. This assemblage unites the faunas of the Scissum Zone in England, Canada, and Argentina, with the Sinon Zone of Germany, which are thus shown to be contemporaneous (Lieb, 1950, p. 452). The same association also occurs in the Swabian Jura (see below, p. 125).

Zone of *Leioceras opalinum*, with *L. opalinum* and *Costileioceras costosum* (Qu.). These two forms also occur together in the Swabian Jura (p. 125), so that *costosum* at most marks a subzone of the upper Opalinum Zone.

At Saint-Quentin la Verpillière, at the southern extremity of the Jura, *Leioceras opalinum, Tmetoceras scissum* and *Ludwigia murchisonae* occur with *Pleydellia aalensis* in a condensed bed 15 cms. thick, directly overlain by the Humphriesianum Zone (Riaz, Riche & Roman, 1913, p. 89).

**TOARCIAN** (up to 20 m.)

Throughout most of the Jura the Toarcian is highly condensed, consisting of a few metres of clays, marls, or shales, sometimes with the usual thin mudstone or micaceous sandstone bands, fish beds, or *Posidonia* shales. The maximum thickness at outcrop seems to be about 20 m., reached in the Bernese Jura, but underground near Porrentruy a boring proved greater thickening (Schmidt, 1924). The most celebrated locality for fossils is Saint-Quentin, at the southern extremity of the Ile Crémiou, where the Toarcian is about 3.5 m. thick and developed largely as an oolitic iron ore, formerly worked at la Verpillière mines (de Riaz, Riche & Roman, 1913). From these mines were obtained most of the ammonites figured by Dumortier in his fourth volume (1874), but they were not accurately localised stratigraphically. They include a wealth of well-preserved species of both Lower and Upper Toarcian age, indicating that nearly all the subzones are present, highly condensed, several often mixed in the same thin beds. Some subzones represented in Dumortier's collection (at Lyons: see Roman, 1937) cannot now be located in sections still accessible and are therefore assumed to have been lenticular and strictly limited in area. As remarked above, a single bed 15 cms. thick, at the top yields *Pleydellia aalensis, Leioceras opalinum, Tmetoceras scissum* and *Ludwigia murchisonae*, and is overlain directly by the Humphriesianum Zone in some places and the Garantiana Zone (Ciret) in others. The Toarcian of the dept. of Doubs is described by Grosjean (1922) and by Fallot, Corroy & Gardet (1933, p. 7).

Near Salins, the following ammonite succession is recorded (Piroutet, 1920), but no thicknesses are mentioned:

- Subzone of *Pleydellia aalensis*, with *Dumortieria radiosa* in the lower part and *Leioceras opalinum* in the upper part
- Subzone of *Dumortieria radians*

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Subzone of *Catulloceras* sp.
Subzone of *Phlyseogrammoceras dispansum*
Subzone of *Hammatoceras insigne*, *Lytoceras germani* and *Paroniceras sternale*
Subzone of *Grammoceras fallaciosum*
Subzone of *Haugia variabilis* and *Phymatoceras erbaense*
Subzone of *Hildoceras levisoni* and *H. boreale*
Subzone of *Dactylioceras annulatum*, *D. mucronatum*, and *Catacoeloceras raquineanum*

**MIDDLE AND LOWER LIAS (up to c. 50 m.)**

The outcrops along the outer edge of the Jura south of Besançon and the Langres portal are a continuation of those on the east of the Paris Basin and of those along the east side of the Massif Central. Their stratigraphy and faunas have not been the subject of illustrated studies and they call for no special comment. All the stages and principal zones, from marls with *Amaltheus margaritatus* down to Lower Hettangian with *Psiloceras*, are present (Guérin, 1954), even to the southernmost extremity of the Île Crémieu (de Riaz, Riche & Roman, 1913, pp. 82-6). The outcrops of the northern Jura similarly are a continuation of those of Württemberg, except that thicknesses are reduced (maximum less than 50 m.); the successions have been tabulated by Heim (1919, table, p. 486); for sections and fossil lists see Brändlin (1911). Notoriety has been achieved by a Liassic sequence on the inner edge of the Jura west of Geneva, at Champfromier, north of Bellegarde, dept. of Ain, described by Bovier (1931). Bovier recorded here a sequence of ammonite epiboles in the Sinemurian and Pliensbachian widely different from those established by Lang’s collecting on the Dorset coast, and his results were publicized by Spath (1931) who used them to discredit Buckman’s ‘polychemeral’ system of correlation. It appears to have been only some years after publishing this paper, however, and after it had been widely quoted, that Dr Spath examined the material, and in consequence he asserted that, so far as the Liparoceratidae were concerned, ‘the apparent anomalies in the succession are easily explained by misidentification’ (Spath, 1938, ‘Cat. Amm. Liassic family Liparoceratidae’, Brit. Mus., p. 36). Unfortunately no reference was made to the other anomalies; but doubt is inevitably cast on them also, and is enhanced by Mouterde’s observation that the order of certain beds may have been disturbed by slipping (1953, Bull. Serv. Carte Géol. France, no. 236, p. 407). In the light of this the Champfromier succession urgently needs reinvestigation. Its importance far transcends local interest. (Roche, 1939, pp. 31-3, in his enthusiasm for Buckman’s polychemeral system proclaimed, somewhat cryptically, that the fact that it does not work at Champfromier confirms its value; if now the anomalies turn out to be illusory, presumably one should draw the opposite conclusion?)

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CHAPTER 5

WESTERN GERMANY

THE SWABIAN AND FRANCONIAN ALB

The folded Jura dies out near Baden, but the plateau Jura continues north-east as a narrow band skirting the Black Forest massif through Randen and Klettgau, then widens into the great cuesta of the Swabian Alb in Württemberg. The Lias and Keuper form the subedge plain, the Middle Jurassic forms a foothill step similar to that of the Middle Lias in front of the Cotswolds, and the Upper Jurassic builds the main escarpment of white limestones. The scarp is about 120 miles long and reaches heights of over 3000 ft. above sea-level. It strikes north-east, with the scarp edge facing towards the Rhine and the counterscarp or dip-slope running down to the Danube. The two drainage systems provide a striking contrast of scenery, comparable with the two sides of the Severn-Thames watershed in the Cotswolds; but here the heights are multiplied by three. Tremendous forested coombs with limestone walls approaching the vertical lead down through gorges, more like those of the Wye at Symonds Yat, into the Neckar and the Rhine; on the other side, on the high Alb surface, a mature network of shallow valleys slopes gradually towards the relatively high local base-levels of the upper Danube. The upper parts of these old valleys are dry and often end at the escarpment edge in wind-gaps. But although in so many essentials the Cotswolds are reproduced on a magnified scale, the landscape is very different. When one has wound one's way up the scarp face by many hairpin bends through forest, and arrives suddenly on the top, instead of a bare plateau with stone walls there is a well-wooded landscape with villages and orchards, and the ubiquitous apple trees line the roads up to the escarpment edge.

Dividing the Swabian from the Franconian Alb is the Miocene explosion crater of the Ries, about 13 miles in diameter. Blocks of Jurassic limestone blown out of the vent are strewn over the surface for miles around. The Ries stands on a transverse swell, where nearly all the Jurassic formations become thinner and the escarpment declines: an analogue of the Market Weighton axis but with much milder effect on the outcrops (Dorn, 1937). Beyond the Ries the escarpment regains rather more than half its stature in the Franconian Alb, then gradually declines and disappears in northern Bavaria. Towards the Bohemian Forest much of the Jurassic is cut out by Cretaceous overstep. The total length of the Franconian and Swabian Jurassic outcrops is about 225 miles.

The Ries crater is not the only place where the Jurassic rocks have been involved in volcanic activity during the Miocene. In the Swabian Alb there is a smaller crater at Steinheim, and around Urach a cluster of more

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than 100 volcanic necks are filled with tuff and breccia. In some of these blocks of limestone have fallen down hundreds of feet below their original level.

Another and more characteristic feature of both the Swabian and Franconian Alb is the prevalence of sponge-reefs through all parts of the Oxfordian and Kimeridgian; that is, through a limestone series which reaches a total of not less than 650 m. The presence of these reefs greatly complicates the stratigraphy, for from place to place any part of the succession is liable to pass laterally into unfossiliferous, unbedded mudstone or saccharoidal, subcrystalline limestone or dolomite, and to swell out into lenticular or ramifying knoll reefs. Ammonite or other fossil zones can seldom be traced through the knoll reefs and the normal bedded succession is completely interrupted by them, or liable to arch over them (Fischer, 1913; Dorn, 1932; Roll, 1934; the sponges monographed by Kolb, 1910). In some places (as near Balingen) sponge reefs begin in the Transversarium Zone and continue in force in the same general area through all subsequent zones. Elsewhere sponge growth came and went more fitfully, until in the Pseudomutabilis and Beckeri Zones it spread through the entire length and breadth of the Alb: possibly as the result of a retreat of the shore-line from the rising Black Forest massif and the

Fig. 12.—Jurassic outcrops of the Swabian and Franconian Jura.
general shallowing and shrinking of the Upper Jurassic seas in central Europe. Some of the sponge reefs have a spectacular expression in the landscape, standing out from the escarpment edge as white crags, too steep to give foothold to the forest. Sometimes a castle is perched on the summit.

The Black Forest and the Rhenish slate mountains probably were not the nearest land to the Swabian trough of deposition; another shore probably lay to the south-east, not far from the present line of the Danube. This was the Vindelician landmass (so called by Gümbel after the Roman province of Vindelicia, the capital of which was at Augsburg), also sometimes called the Alemannian landmass, which existed during the Lias and began to be submerged in the Toarcian and early Lower Bajocian but persisted at least as a string of islands to the Callovian or Oxfordian, when it broke up and sank below the sea (Frank, 1937a, p. 76). It was a south-westerly prolongation of the Bohemian Forest and originally linked the Bohemian and Black Forest massifs. Direct proof has been afforded by a boring south-west of Augsburg, which showed Lower Bajocian Opalinum Zone clays resting on continental Trias (93 m.) and that on gneiss (Roll, 1952). The Bohemian and Vindelician massifs were no doubt the chief suppliers of at least the sandy sediment of the Swabian and Franconian Middle Jurassic (Schmidtill, 1925, p. 79; Bozenhardt, 1936, p. 78), but it has not been possible to establish mineralogically the source of the sand grains (Aldinger, 1953).

To the south-east, a gulf from the Franconian Jurassic sea extended from Regensburg down the Danube valley towards Passau (von Ammon, 1875; Pompeckj, 1901; Wanderer, 1906). When the Vindelician land broke up a direct connexion was established this way with the Cracow area of Poland, by a sea skirting south of the Bohemian Forest. Close resemblance between the Stephanoceratids of Franconia and the eastern Alps indicates a seaway across the Vindelician barrier hereabouts as early as the Middle Bajocian (Schmidtill & Krumbeck, 1938, p. 322).

Towards the north, on the contrary, and in the west (Black Forest) uplift and retreat of the sea took place about the same time as subsidence in the south and east. In Lower and Middle Jurassic times the Alb trough connected through a strait between the Rhenish and Bohemian massifs with the North German sea, but with the advent of the Upper Jurassic this strait appears to have been closed by uplift of the Thuringian Forest (Pompeckj, 1908). The Black Forest also rose above sea in the early Upper Jurassic if not in the Bajocian (see p. 39).

In Franconia at the time of deposition of the celebrated lithographic ‘slates’ of Solnhofen and Eichstädt the sea is thought to have contracted to a small lagoon, surrounded by Upper Jurassic rocks already raised into low-lying land (Roll in Dorn & others, 1935, p. 669). In and around the shallow lagoon, in tropical heat, thrived a rich mixed land and sea fauna—pterodactyls, archaeopteryx, dragon-flies, jellyfish, and a great variety of other animals—miraculously preserved in the lithographic limestone. (For attractive illustrated descriptions see Walther, 1904, and Abel, 1922).
Of almost equal renown are the superbly preserved and prepared reptile skeletons of the Upper Lias at Holzmaden, at foot of the Swabian Alb (Hauff, 1921, 1953). Yet a third show-piece of palaeontology, even on a world view, are the famous Goldschnecken of the Franconian Callovian. Quantities of small ammonites are preserved as limonitic casts of the septate inner whorls bearing only the pearly layer of the shell; there results an iridescence like opal and a colour like gold, sometimes deepening to copper.

The Swabian Alb is the type example of a simple scarp landscape. It is also the birthplace of zonal stratigraphy and of the scientific study of ammonites from the systematic and stratigraphical points of view, for it was the scene of the labours of Leopold von Buch, F. A. Quenstedt, and Albert Oppel. Von Buch in 1837 divided the Jurassic into Lower

Jurassic, Lias or Black Jura, Middle or Brown Jura, and Upper or White Jura, and established three subdivisions of each. Quenstedt, who for more than fifty years worked and taught at Tübingen University, used the Greek letters alpha to zeta for six subdivisions of each of von Buch's three main divisions. But although these subdivisions were lithological, Quenstedt (1845-9, 1858, 1883-8) was the real founder of the scientific study of ammonites and an acute observer of their distribution. It was his pupil Oppel (1856-8, 1862-3), however, who founded the zonal system of classification and opened the possibility of correlation over theoretically unlimited distances. He shook himself free of Quenstedt's alphas, betas and gammas, but they have nevertheless remained in local use to this day because of their precision and convenience. As a basis for local work they are by far superior to the ill-starred stages used in the Franco-Swiss Jura (Argovian, Rauracian, Sequanian), which mean something different with every author and have led to a geological babel. Oppel's zonal system was first tried out by Waagen in his masterly maiden work (1864). Besides the classics mentioned, important early works of a lesser order,
Photo through the kindness of Dr. H. Helder, Tübingen.

PLATE 7.—The Swabian Alb from Böllat. (See Fig. 13.)

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Plate 8a.—The Swabian Alb under snow. (See Fig. 13.)

Plate 8b.—Conglomerate at base of transgressive Middle Kimeridgian (Gravesia Zones), Völksen am Deister, near Hanover.
with many ammonite figures, were published by Reinecke (1818), Stahl (1824) and Zieten (1830-35). General summaries of most value are those by Waagen (1864), Gümbel (1865, 1891), von Ammon (1891), Engel (1896-1908), Pompeckj (1901), Hennig (1923), Reuter (1927) and Dorn (1951). The best introduction to the Swabian Alb is Fischer's monograph (1913) on the Lochen area, near Balingen. Quenstedt's immense collection remains as his permanent memorial in the University of Tübingen. I am indebted to the present curator, Dr H. Hölder, for the loan or gift of a number of rare papers and for access to collections and excursions in the Swabian Alb in 1953.

Up to the top of the Callovian (Athleta Zone) correlation with northwestern Europe and Britain presents no special problems. Thereafter, however, comparison of the ammonite successions becomes extraordinarily difficult and full of interest. The topmost Callovian (Lamberti Zone) and the whole Lower Oxfordian (Mariae and Cordatum Zones) are condensed into a thin nodule bed, sometimes accompanied by thin clays; the top of this bed forms the boundary between the Dogger and Malm. The Transversarium Zone sensu stricto is likewise condensed, most of the fauna occurring in a thin and transgressive glauconitic band. Thus far the Oxfordian sequence is barely a hundredth of its thickness in the Jura. From this horizon upwards, however, there is enormous thickening (600 m. or more), with far more faunas than in NW. Europe, and correlations are beset with many problems. Owing to the richness of the faunas, the simplicity of structure except for the complication of sponge-reefs, and the intensive work that has been done during more than a century, this is the most important succession for the Upper Oxfordian and Kimeridgian in the world, and a commensurate amount of space must be devoted to it here. It is difficult to decide how many of the discrepancies can be attributed to geographical and climatic isolation (for instance total absence from England of Kimeridgian and Portlandian ammonites other than Perisphinctidae and a few Cardioceratidae), but it seems highly probable that a number of important breaks (disconformities) must exist in the English and NW. European sequence, at one time thought so complete. This is strongly suggested by the thinness of certain zones in England which are much thicker in Swabia; for instance in Swabia Ringsteadiae range through some 50 m. of strata, whereas in Dorset the Ringsteadia bed is 6 in. to 1 ft. thick, and its maximum is about 4 m. at Westbury. The Ringsteadia zone does not appear to exist in eastern and northern Britain, and with only a little less deposition in the south it might not have been represented at all in the British column. The higher Ringsteadia beds in Germany, and the overlying Galar and Platynota Zones, scores of metres thick, are populated almost entirely by genera that do not exist in the British region (Sutneria, Idoceras, Taramelliceras, etc.). There follow four marker genera, Rasenia, Aulacostephanus, Gravesia and Subplanites, which allow of correlation once more; but between the first two and the last two there are in Germany three subzones of the Beckeri
Zone which are probably all missing in England, as already suggested by Roll (1932). Finally, the German succession ends with a fauna (Lower Tithonian, Neuburg Beds) which has no parallel anywhere but in the French Alps, except for a faint and doubtful echo in Somaliland. In part, at least, this fauna may be of the age of the Pectinatus Zone and in that case still Upper Kimeridgian, but as a whole its ammonites are something altogether original. There is no sign of Upper Tithonian (Ardescian) or Lower Cretaceous (Berriasian, Valanginian); during these periods the Alb probably stood at or above sea-level.

**LOWER TITHONIAN—UPPER AND MIDDLE KIMERIDGIAN**

Zone of *Berriasella ciliata* and *Anavirgatites palmatus*. Neuburg Beds, 40 m. Present at Neuburg on the Danube, in Franconia, where quarries yield an extensive and unique fauna of Perisphinctids (Schneid, 1915). Schneid's identifications with Uhlig's Spiti genera have not been accepted, and despite many difficulties in individual cases it seems best to use new genera created for Schneid's figures by Spath (1925). Some of the outstanding species are *Sublithacoceras dicratus*, *S. penicillatus*, *S. caespitosus*, *S. callodiscus*, *Subplanites schlosseri*, *S. echidneus*, *S. serpens*, *Anavirgatites palma tus*, *A. franconicus*, *Pseudovirgatites silvescens*, *P. diffusus*, *Berriasella ('Parapallasiceras'—not accepted by Mazenot) ciliata*, *Simaspidoceras rafaeli*, *S. neoburgense*, *Simoceras schwertschlageri*, *Virgatosimoceras rothpletzi*.

In addition there are some forms, *P. racemosus* Schneid, *P. serotinus* Schneid (1915, pl. ix, figs. 1, 2; pl. x, figs. 1, 2) which seem indistinguishable generically from *Wheatleyites* of the Pectinatus Zone (Upper Kimeridgian) in England. The resemblance of other forms figured by Schneid, and in particular of the genus *Pseudovirgatites* Vetters, to *Pectinatites* and its allies has already been pointed out (Arkell, 1946, pp. 22-3). Donze (1948, p. 183) is right in assigning some of Schneid's forms to the Austrian genus *Pseudovirgatites* Vetters, although all the species for which Schneid used this name are different (*Anavirgatites*). (Vetters' fragment 'aff. sosia', however, is probably an *Anavirgatites*: cf. Schneid, pl. xi). According to Roll (1933, p. 557; 1934b, p. 151) it is to be inferred that the Neuburg Beds are represented in the Swabian Alb by the upper part of the Hangende Bankkalke, which are at least 150 m. thick and hardly susceptible of subdivision, but according to Geyer (1953, p. 132) the Neuburg Beds are restricted to the Franconian Alb.

Zone of *Subplanites vimineus*. Rennertshofen Beds, with Brenztal Oolite 60 m.; upper part of the Reisberg Beds of Schneid; passing laterally into *Diceras* and coral limestones. *Subplanites vimineus*, *S. reisi*, *S. vicinus* Schneid (1914). Schneid included in this zone a lower fauna with Schlosser's species of the Kelheim Diceras Limestone, but according to Roll this belongs much lower (see below), and the Rennertshofen Beds are in reality discordant on underlying beds (Roll in Dorn & others, 1935, p. 664). Spath in 1925 correlated this zone with the Subplanites Zone of the Middle Kimeridge Clay of Dorset; but it seems doubtful whether it

<table>
<thead>
<tr>
<th>Oppel's Zones</th>
<th>Quenstedt</th>
<th>Modern Zones</th>
<th>Strata (Roll, etc.)</th>
<th>Strata (Schneid)</th>
<th>Correlation (England)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neochetoceras steraspis</td>
<td>ZETA</td>
<td>Berriasella ciliata and Anavirgatites palmatus</td>
<td>Neuburger Schichten, 40 m.</td>
<td>Neuburger Schichten</td>
<td>? pectinatus ?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Subplanites vimineus</td>
<td>Rennertshofener Schichten, 60 m.</td>
<td>Reisberg</td>
<td>Subplanites spp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>?</td>
<td>Zementmergel, 10-80 m.</td>
<td>Schichten</td>
<td>? gigas</td>
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<td></td>
<td></td>
<td>Lithacoceras ulmense</td>
<td>Oberer Ulmensis Sch. and Nattheim coral reef, 30 m.</td>
<td>Solnhofener Schichten, 60 m.</td>
<td>Gravesiana</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Taramelliceras lithographicum and H. hybonotum</td>
<td>Solnhofener Plattenkalk, 8-60 m.</td>
<td>Solnhofener Plattenkalk</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Lithacoceras siliceum</td>
<td>Massenkalk und Dolomit</td>
<td>Kelheimer Diceraskalk</td>
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<tr>
<td></td>
<td>EPSILON</td>
<td>Virgataxioceras setatum</td>
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<td></td>
<td></td>
<td>Enosphinctes subeumelus</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Aulacostephanus pseudomutabilis ('mutabilis')</td>
<td>DELTA</td>
<td>Aulacostephanus pseudomutabilis</td>
<td>Quaderkalke Treuchtlinger Marmor, etc. &gt;200 m.</td>
<td>Stufe des Aul. eudoxus</td>
<td>pseudomutabilis</td>
</tr>
<tr>
<td>Streblites tenuilobatus</td>
<td>GAMMA</td>
<td>Idoceras balderum and Streblites tenuilobatus</td>
<td>Oberer grauer</td>
<td>Bankkalke</td>
<td>mutabilis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ataxioceras polyplocum and A. lothari</td>
<td>Mergelkalk, 45 m.</td>
<td></td>
<td>cymodoce</td>
</tr>
<tr>
<td></td>
<td>BETA</td>
<td>Sutneria platynota and S. galar</td>
<td></td>
<td></td>
<td>? baylei</td>
</tr>
</tbody>
</table>

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is a distinct zone separable from the Ciliate Zone (Roll, 1933, pp. 555-6). More work is required on this problem, as Roll remarked.

Zementmergel, 10-80 m. A constant formation that can be traced throughout the Swabian and Franconian Alb except where locally cut out by the unconformity below the Rennertshofen Beds (Roll, 1933, 1934). Few ammonites known: Ochetoceras zio (Oppel) (Joos, 1945, p. 15).

Zone of Lithacoceras ulmense. Upper Ulmensis Beds, 30 m., and Nattheim coral reef. Lithacoceras ulmense (Oppel) (type species of the genus) has been fully discussed and figured by Schneid (1914, p. 159, pl. iv, fig. 3). The occurrence of Gravesiae in this zone is to be inferred from the literature (but Roll’s Ulmensis-Schichten, 1932, p. 184, include the Plattenkalk of the Lithographicum Zone, and his records of Gravesia gigas in the Hangende Bankkalke, above the Zementmergel, appear to be negativized by his subsequent stratigraphical revisions in 1933, 1934b, and 1935).

Zone of Taramelliceras lithographicum. Solnhofen Plattenkalk, 8-60 m.; locally the upper part shows submarine slump structures (Krumbeck, 1928). Ammonites and aptchi from the celebrated lithographic limestone quarries of Solnhofen and Eichstätt were figured by Oppel (1863, pls. 68-74). They include T. lithographicum (Oppel), Neochetoceras steraspis (Oppel), Haploceras elimatum (Oppel), H. stazycii (Zeusch.) (Neumayr, 1870, pl. xxiii, figs. 5, 7), Enosphinctes bracheri (Berckhemen), Hybonoticeras hybonotum (Oppel; syn. autharis Oppel), Aspidoceras hoplisum (Oppel), Physodoceras pipini (Oppel), Subplanites ruppellianus (Quenst.) (Schneid, 1914, pl. iii, 3), Lithacoceras ulmense (Oppel) (ibid., pl. iv, 3), and a form that seems generically indistinguishable from true Himalayan Virgatosphinctes, V. eystettensis Schneid (pl. iii, 5). Unfortunately the records of Gravesiae do not make it absolutely certain that any have been found in this zone (see Roll, 1932, p. 185).

Zone of Hybonoticeras beckeri. This zonal index, proposed by Neumayr in 1873, seems appropriate for the various limestones and dolomites, from at least 50 to more than 100 m. thick, separating the Lithographicum Zone from the Pseudomutabilis Zone. The latter was included in the Beckeri Zone by Neumayr, but beckeri and its associates do not occur in the Pseudomutabilis Zone where that is palaeontologically recognizable. Lithologically it is often impossible to distinguish the two zones. The whole comprises a variety of facies—Massenkalk, Felsenkalk, dolomite and Diceras and sponge limestones, altogether exceeding 200 m. The Kelheim Diceras Limestone probably comes in the upper part of the Beckeri Zone, but its figured ammonites (Schlosser, 1882) are peculiar and have not been fitted into the sequence elsewhere (see Schneid, 1914, p. 133). Three subzones are recognized, as follows (Berckhemen, 1922; Roll, 1932, 1934b):

Subzone of Lithacoceras siliceum (Quenst.), with Taramelliceras wepferi (Berk.), T. vermiculare (Quenst.), Ochetoceras zio (Oppel), Enosphinctes rebholzi (Berk.) and ? Hybonoticeras beckeri (Neum.).
Subzone of *Virgataxioceras setatum* (Schneid), with *V. comatum* (Schn.), *Hybonoticeras beckeri* (Neum.), *Enosphinctes rebholzi* (Berck.), *Ochetoceras* spp., etc.


Only one of these genera is known in the English Kimeridge Clay, but from the position of the zone above the Pseudomutabilis Zone and below the Gravesia Zones, it must fall within the Middle Kimeridgian, of which it is presumably a basal part, completely missing in England, as suggested by Roll (1932). A stage-name, ‘Suebium’, has been suggested for it (Hennig, 1943; P. Dorn, 1951, pl. 8).

Subzone of *Virgataxioceras setatum* (Schneid), with *V. comatum* (Schn.), *Hybonoticeras beckeri* (Neum.), *Enosphinctes rebholzi* (Berck.), *Ochetoceras* spp., etc.

Lower Kimeridgian

Zone of *Aulacostephanus pseudomutabilis*. As remarked above, the zone is often lithologically inseparable from the Beckeri Zone, and even palaeontologically Roll admits 15-30 m. of passage beds to the Subeumelus Subzone. The Pseudomutabilis Zone is the Quaderkalk of Quenstedt. From it have been figured *Aulacostephanus pseudomutabilis* (de Lor.), *A. eudoxus* (d'Orb.), *A. phorcus* (Fontannes), *Orthaspidoceras orthocerum* (d'Orb.), *Nebrodites risgoeviensis* (Schneid) (all Schneid, 1914, pls. i, ii). The commonest ammonites are various large Perisphinctids, most of them belonging to the genus *Progeronia* (Schneid, 1914, pl. i, pl. ii, fig. 1; Quenstedt, 1888, pl. 123); also *Subdichotomoceras atavum* (Schneid sp., 1914, pl. ix, 1).
Zone of *Streblites tenuilobatus*. This zone, founded by Oppel (1862-3), is too rooted in the literature to abandon, although subsequent authors have pointed out that (as with so many others) the index species occurs commonly only in a part of the original zone, if it is not actually restricted to this part. Of the subzones proposed, the following are retained mainly because of priority:—

Subzone of *Idoceras balderum* (used by Salfeld, 1913) with *S. tenuilobatus* in the lower part (Beurlen, 1926); subzone of *Glochiceras dentatum*

**Table 10.—The Oxfordian and Callovian of the Swabian and Franconian Jura**

<table>
<thead>
<tr>
<th>Oppel's Zones</th>
<th>Strata Correlation (England)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epipeltoceras bimammatum</td>
<td>Beta</td>
</tr>
<tr>
<td>Idoceras planula</td>
<td>Werkkalk, etc.</td>
</tr>
<tr>
<td>Epipeltoceras bimammatum</td>
<td>pseudocordata</td>
</tr>
<tr>
<td>Amoeboceras alternans</td>
<td>Impressa Mergel</td>
</tr>
<tr>
<td>Gregoryceras transversarium</td>
<td>Gregoryceras transversarium</td>
</tr>
<tr>
<td>Mergelkalkbänke &amp; Glaconit-Bank</td>
<td>?</td>
</tr>
<tr>
<td>Euaspidoceras biammatum</td>
<td>Euaspidoceras biammatum</td>
</tr>
<tr>
<td>Knollenschicht &amp; Grenzzone</td>
<td>plicatilis</td>
</tr>
<tr>
<td>Peltoceras athleta</td>
<td>Athleta &amp; Lamberti</td>
</tr>
<tr>
<td>Castor &amp; Pollux</td>
<td>Ornamenton &amp; Goldschneckenton</td>
</tr>
<tr>
<td>Reineckeia anceps</td>
<td>Calloviense &amp; Enodatum</td>
</tr>
<tr>
<td>Macrocephalites macrocephalus</td>
<td>Gowerianum</td>
</tr>
<tr>
<td>Macrocephalites macrocephalus</td>
<td>Macrocephalens-Bank</td>
</tr>
</tbody>
</table>

of Wegele (1929) in Franconia. *Rasenioides striolaris* (Rein.) and other forms, *Katroliceras crussoliense* (Font.), *Progeronia ernesti* (de Lor.), and according to Wegele (1929, p. 192) *Ataxioceras lothari* (Oppel) and *A. inconditum* Font., range up into this subzone.

Subzone of *Ataxioceras polyplacum* and *A. lothari*. This is the Polyplacus Zone proper, so called by Hébert (1869), Salfeld (1913) and others, and the name need not be changed because the particular species selected as index (because the earliest named) has turned out to be rare. Wegele uses *A. suberinum* (von Ammon). This zone yields an enormously rich fauna of Ataxioceratidae (monographed by Wegele, 1929, and Schneid, 1944) and *Raseniae* (monographed by Schneid, 1939-40), also *Aspidoceras iphicerum* (Oppel), *Katroliceras crussoliense* (Font.), with *Streblites tenuilobatus* in the upper part (Wegele, 1929, p. 192), and a host of other forms.
The *Rasenia trifurcata* (Rein.) and *R. trimera* (Oppel) groups grade insensibly into *Involuticeras* Salfeld, of which Schneid (1939, pls. x-xiv) has figured a number under the wrong name *Ringsteadia*; there is misleading homeomorphy, but comparison with English Upper Oxfordian *Ringsteadia* shows that in Schneid’s forms the ribbing is much more regularly fasciculate and the inner whorls are totally different, purely rassenoid. Similarly, most of Schneid’s so-called *Pictonia*e (1940) are *Raseniae* of the Cymodoce Zone.

Subzone of *Sutneria platynota* (synonym *S. reineckiana* Quenst. sp., proposed as zonal index by Engel, 1883). The boundary between *beta* and *gamma* falls in the middle of this zone, and Beurlen (1926) subdivided it; Dieterich (1940) calls the lower part (*beta*) the zone of *Sutneria galar* with *Taramelliceras falculum*. This zone also yields a very rich fauna of *Ataxioceras, Progeronia, Taramelliceras*, etc., and from the prevalence of *Prorasia stephanoides* (Oppel) and *Pachypictonia* Schneid (both of which, however, range up into the lower part of the Polyplocum Zone) it may best be correlated with the Cymodoce and Baylei Zones of NW. Europe; those being in any case only reduced and incomplete representatives. The *Amoeboceras* of this zone are *A. lineatum* (Quenst.), *A. bauhini* (Oppel), *A. kappi* (Oppel), *A. kitchini* (Salf.), *A. fraasi* (Fischer) and *A. cricki* (Salf.). Several of these *Amoeboceras* occur in the Cymodoce Zone of Market Rasen.

UPPER OXFORDIAN

Zone of *Epipeltoceras bimammatum*. As with the Tenuilobatus Zone, the zonal index has since been found to be not good for the whole zone; it is in fact restricted to the lower part and to the top of what was formerly included on lithological grounds in the underlying Alternans Zone (the fossil-beds of Lochen cutting) (Dieterich, 1940).

Subzone of *Idoceras planula*. This index is used for the upper part of the zone, above the range of *E. bimammatum*, following Salfeld (1913), Wegele (1929), and Dieterich (1940). At the top is a band (‘zone’) of *Taramelliceras senzeli* (Oppel) (refigured Dieterich, 1940). According to Dieterich, *Ringsteadiae* do not range above the middle of this subzone, in which case there is presumably a gap above the Pseudocordata Zone in England and France; this again points to the Pseudocordata and Baylei Zones being mere wisps of zones (their total thickness may be only a few feet). ‘Rasenia’ daequéi and ‘R.’ *perispinhinctoides* Wegele (1929, pl. x figs. 1, 2) from this subzone, transferred to *Pictonia* by Schneid (1940), are neither. The latter species can be matched almost exactly by what is presumably a *Ringsteadia* in my collection from the Pseudocordata Zone of Westbury, Wiltshire. The former may be a tumid and coarse-ribbed offshoot of *Pseudarispinchinctes*, or even a side-shoot from the stock of *Ringsteadia perispinhinctoides* (Wegele), but it is not strictly congeneric with anything else yet published. There are numerous other interesting Perispinhinctids (figs. in Wegele, 1929), largely assignable to *Decipia* and

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Pomerania. Amoeboceras bauhini (Oppel), A. lineatum (Qu.), A. subtile-caelatum (Font.), A. schlosseri (Wegele) range from the Planula Subzone into the Platynota subzone.

Subzone of Epipeltoceras bimammatum s.s. This subzone is the principal source of Ringsteadiae, which are commonest around the junction between alpha and beta and in lower beta. None agrees exactly with English and NW. German species, but forms close to R. frequens Salf., R. brandesi Salf. and R. pseudo-yo Salf. occur, with R. limosa Quenstedt sp. (1888, pl. 124, fig. 3) (P. Dorn, 1925; Dieterich, 1940, p. 35). This is also the home of Orthosphinctes tiziani (Oppel), O. polygyratus (Rein.) and O. laufenensis (Siemiradzki) (Wegele, 1929, pl. i, figs. 4-6; Dieterich, 1940, pl. ii, fig. 8). In the fossil-beds at Lochengrundle cutting (see Fischer, 1913, pp. 34-7) the commonest of the many small ammonites is perhaps Amoeboceras ovale (Quenst.), which is replaced in the lower part of beta by A. lorioli (Oppenheimer) and A. bauhini (Oppel). (For figures of these and later Amoeboceras see Fischer, 1913a, whose determinations are corrected by Salfeld, 1915; and Wegele, 1929, pl. iv). In presumed equivalents of the Lochen Beds in Franconia Epipeltoceras berrense (Favre) is said to attain its maximum, but it also occurs in the underlying ‘Hypselum Zone’, with the closely allied E. circumcostatum (Dorn) and E. retrocostatum (Dorn).

It is not clear whether this Franconian zone of Euaspidoceras hypselum (Oppel) and Epipeltoceras uhligi (Oppenheimer) should be regarded as a lower part of the Bimammatum Zone or as equivalent to the Alternans Subzone (P. Dorn, 1925, 1930). Its ammonites are, however, much more allied to those of the Bimammatum Zone than to those of the Transversarium Zone: they include Amoeboceras ovale (Quenst.), A. subcordatum (d’Orb.), Prionodoceras sp. (Dorn, 1930, pl. xxxv, fig. 2—quite different from fig. 1), Euaspidoceras linki (C. Dorn), E. costatum (C. Dorn) (1923) and various Taramelliceras, but there are also still Ochetoceras canaliculatum (von Buch) and Amoeboceras aff. alternans (von Buch). Perisphinctes (Microbiplices) microbiplex (Quenst.), said to be common in the Hypselum Zone (P. Dorn, 1930, p. 161), occurs in England only in the zone of Ringsteadia pseudocordata and is therefore an indicator of a high horizon.

Zone of Gregoryceras transversarium (up to c. 100 m.). Between the Lochen Beds with E. bimammatum and its allies and the true Transversarium Beds in Swabia lie up to 90 m. of marly beds formerly called the Impressa Marls (or Clays), which Salfeld (1913, p. 179) called the Zone of Amoeboceras alternans (see Salfeld, 1915, p. 163, pl. xvi). The upper part, exposed in Lochengrundle cutting, has already been transferred to the Bimammatum Zone. In the rest ammonites are much scarcer, and it is still doubtful with what these beds should be compared. If they are to be correlated with the Franconian ‘Hypselum Zone’ just mentioned, they should be classed with the Bimammatum Zone. On the other hand, the evidence for this is inadequate, and it must be borne in mind that
Amoeboceras alternans occurs, though rarely, in the typical Transversarium fauna of Trept (p. 95), which also contains rather numerous fine-ribbed Perisphinctids (Discosphinctes spp.) of distinctly late aspect as compared with the Plicatilis Zone of NW. Europe.

The Transversarium Zone sensu stricto is only about 10 m. thick in the Lochen area and 2 m. around Geisingen and Blumberg, whence a large collection has been sent me by Dr P. L. Maubeuge. Though the Perisphinctids are nearly all fragmentary, the assemblage is largely identical with that of Trept, and includes the true P. wartae Bukowski; Ochetoceras canaliculatum (especially var. hispidum) and Trimarginites arolicus are abundant, and there are fragments of Euaspidoceras spp. The same assemblage is figured (P. Dorn, 1930) from the Transversarium Zone of Franconia (but the Perisphinctids require thorough revision, very few of Dorn's figures being correctly named). In many places the chief ammonite bed is glauconitic. This bed is the source of the type specimen of Perisphinctes chloroolithicus (G üm bel) (refigured Dorn, 1930, pl. iv, fig. 2), which is the inner part of a large variocostate. Part of the Transversarium Zone in Franconia is condensed with the Lower Oxfordian, to judge by ammonites recorded from the local Biarmatum Zone by Dorn (1926, 1930). Gregoryceras transversarium is always rare.

LOWER OXFORDIAN (usually 1 m. or less)

TheLower Oxfordian is so condensed that it has nothing of interest for the general succession. It usually consists of a few centimetres of nodules, sometimes with up to 4 m. of poorly fossiliferous clays. The nodules yield ammonites proper to the Cordatum, Mariae and Lamberti Zones and were described as the Zone of Euaspidoceras biarmatum (Zieten) by Oppel (1857, p. 618). As just remarked, in Franconia the condensation goes up into the early part of Transversarium times as well. In strata so highly condensed it is of no significance that, for instance, Quenstedtoceras (Pacloviceras) cf. mariae (Kuhn, 1939, pl. vi, figs. 5, 7) is recorded (sub Cardioceras aff. cordatum), as from the Castor & Pollux Zone of the Callovian, or that Spath (1949) finds that at Trockau Scarburgiceras and Quenstedtoceras s.s. ('Vertumniceras') overlap in a thin bed. (These anomalies resulting from extreme condensation are not to be confused with far graver assertions, such as that the Upper Oxfordian Perisphinctes falculae Ronchadze occurs in the Athleta Zone and the Upper Kimeridgian genus Pseudevrigatites 'without doubt' occurs in the Lower Callovian (Kuhn, 1939, pp. 510, 518), which must result from misidentifications.)

UPPER CALLOVIAN (up to 3·1 m.)

The most important section of the Upper Callovian is at Trockau in Upper Franconia, described by Model & Model (1938). It is the Ornatum Zone (recte Kosmoceras spinosum Sow.) of Reuter (1908, 1910, 1927), usually represented only by a layer of nodules or pebbles, and the Lamberti

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and Athleta Beds of Model. Spath (1949) showed that only Model's beds 2-6 are Upper Callovian, with a total thickness of 3.1 m., and he attempted to distinguish Athleta and Lamberti Zones on the basis of Model's collection now in the British Museum. In some places in the Swabian Alb the Lamberti Zone is represented in the nodule bed, for typical Quenstedtoceras cf. lamberti, in preservation too perfect to be derived, are found in the nodules, whereas in other places similar nodules yield typical Cardioceras of the Cordatum Zone (Quenstedt, 1887, pl. 90, figs. 8, 10).

Middle and Lower Callovian (up to 45 m.)

The maximum thickness of 45 m. is reached in the Lochen district (Fischer, 1913, p. 27) but it is usually much less. In Franconia about 10 m. of Ornatenton underlain by a thin Macrocephalenbank is normal. For richness of faunas and beauty of preservation, this Middle and Lower Callovian may be unrivalled, but owing mainly to ambiguities of nomenclature and poverty of clear exposures it is difficult to obtain an accurate picture of the ammonite sequence. From the work of Reuter (1908, 1910, 1927) the succession at least in Franconia seemed simple, but the more intensive work of Dorn (1916, 1922), Model (1914, 1916, 1935), Model & Kuhn (1935) and Kuhn (1935, 1939) revealed an unsuspected wealth of ammonites and complexity of distribution, and caused Model (in Model & Kuhn, 1935, p. 468) to repudiate the scheme of facies-changes worked out by Reuter (1908).

It is impossible here to summarize or even comment usefully on Model's and Model & Kuhn's detailed and valuable records and discussions of the ammonites, even though large numbers have since been figured by Kuhn (1939). The basic difficulties in using these figures are, first, that most come from the famous Goldschnecken clays, in which only septate inner whorls are preserved, and, secondly, that few are figured in ventral view or with whorl-sections.

Detailed correlation with England bristles with difficulties. For instance, Kosmoceras jason is recorded from as low as the Parapatoceras bed to as high as the obductum bed, and the specimen figured by Kuhn (1939, pl. i, fig. 8) is more like the nucleus of a gulielmi or stutchburri. Reineckeia anceps is recorded from immediately above the Parapatoceras bed, associated with Macrocephalites and Sigaloceras, a position substantially lower than would be expected if it is the same species as that in the main anceps level higher up. The 'calloviensis' of the Calloviensis-Enodatum Zone is according to Model & Kuhn (1935, p. 476) 'coarsely ribbed thick forms which seem to go back to Kepplerites keppleri', and therefore can hardly belong to Hyatt's genus Sigaloceras, while commonest in the upper Utzing beds is Catasigaloceras Buckman, which denotes a higher horizon (Planicerclus Subzone); and the two nuclei figured as S. calloviense by Kuhn (1939, pl. i, figs. 5, 7) appear to belong to Keppler-ites (gowerianus group). Some records of S. calloviense probably refer to S. franconicum See (type K. cf. calloviensis Reuter, 1908, p. 99, fig.).

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The Macrocephalitids are even more difficult, for they require still larger material to make subgeneric (still more specific) differences discernible. The 'Calloviensis' Zone is stated by Kuhn (1939, p. 480) to yield *M. (Pleurocephalites) folliformis* Buck. and *P. lophopleurus* Buck., but on plate iii, fig. 4, what appears to be a *P. folliformis* is figured as *M. (Kamptokephalites) herveyi* (Sow.), which if correct would imply a lower horizon, while a *M. (P.) aff. lophopleurus* Buckman is figured as *Kepl erites dorni* Kuhn (pl. i, fig. 12). *Macrocephalites verus* Buckman, the type of which is in a 'limonitic stone' from 'the base of the Callovian' at Ehningen seems to agree in characters and horizon best with Kuhn's 'M. aff. subcompressus'.

**Table 11.—Summary of the Callovian of the Swabian and Franconian Alb, with Provisional Correlation now Suggested**

<table>
<thead>
<tr>
<th></th>
<th>Swabia and Franconia (Model, 1935; Model &amp; Kuhn, 1935; Kuhn, 1939)</th>
<th>Correlation (England)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upper Callovian</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lamberti beds and nodules</td>
<td></td>
<td>up to 3 m.</td>
</tr>
<tr>
<td>Athleta beds</td>
<td></td>
<td>lamberti athleta</td>
</tr>
<tr>
<td><strong>Middle Callovian</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Castor &amp; Pollux Zone, with <em>obductum</em> layer in lower part and <em>refractus</em> layer at base</td>
<td>2 m.</td>
<td></td>
</tr>
<tr>
<td>Calloviensis &amp; Enodatum Zone, including the Utzing Beds, with the main Goldschnecken fauna (Jason Zone and upper part of Macrocephalus Zone of Reuter, 1908, 1910). <em>Parapatoceras</em> layer at base, with <em>Proplanulites</em> spp.</td>
<td>coronatum</td>
<td></td>
</tr>
<tr>
<td><strong>Lower Callovian</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gowerianus bed</td>
<td></td>
<td>0.2 m.</td>
</tr>
<tr>
<td>Macrocephalus bed; sometimes an iron-shot marl, or a band of phosphatic nodules</td>
<td>0.3 m.</td>
<td></td>
</tr>
</tbody>
</table>

Waag.' (pl. iii, fig. 2), rather than with the Calloviensis Zone specimens he figures as *M. verus* (pl. iv, figs. 3, 4, pl. ix, figs. 12, 13).

Such comments could be continued at length; the specimens here printed merely illustrate that a thorough revision of these magnificent Callovian faunas is sorely needed.

The ammonites of the basal Macrocephalus Bed in the Swabian Alb (for instance the Lochen district, Fischer, 1913, p. 26, and Lautlingen, where I was shown a good temporary exposure in 1953 by Dr Hölder) are worthy of special attention. The large *Macrocephalites* of this bed most resemble those in the English Upper Cornbrash and include the form which the International Commission on Zoological Nomenclature has been asked to fix as the type of *M. macrocephalus* Schloth. sp. (= *M. verus* Buckman, 1922, pl. CCCXXXIV, based on an Oppel-Zittel specimen from Ehningen), associated with *Bul latimorphites* (B. quenstedti Roemer sp. 1911, type Quenstedt, 1849, pl. xv, fig. 3), an association also found in Sicily (see p. 207). The smaller *B. weigelti* Kuhn sp. (1939, pl. vii, 3) is said...
to occur higher, in the *goewanus* bed in Franconia, with the Callovian genus *Kheraiceras*: *K*. *trigeri* Héb. & Desl. sp. and *K*. *dorni* Kuhn sp. (Kuhn, 1939, pl. vii, 1, 2). It appears (Stahlecker, 1926, p. 209) that the basal Macrocephalus Bed is the source of *Kepplerites keppleri* (Oppel), also first described from Ehningen (type figured Buckman, 1922, pl. CCLXXXIX). This is consistent with the occurrence of closely allied *Kepplerites cerealis* Buckman sp. in the English Upper Cornbrash (Buckman, 1922, pl. CCLXXXVI).

The great variety of Perisphinctids described by Pietzcker (1911) and figured by Kuhn (1939) belong overwhelmingly to the genus *Grossouvia*, with a few *Poculisphinctes* (pl. viii, 13), etc. These are nearly all later Callovian forms.

**Bathonian** (up to 30 m.)

Like the Lower Oxfordian and Callovian, the Bathonian is highly condensed, but it is extraordinarily persistent throughout the Alb, from Randen to the end of the outcrop in the Palatinate, where at the Weinberg near Schwandorf it is directly overlain by the Upper Cretaceous. Dorn (1939) has made a complete survey of the Franconian Alb, showing it in some 65 profiles, usually from half a metre to one metre thick, and with a maximum of 1.5 m., and it persists in the Regensburg gulf, with the same characters of clay and limestone (Pompeckj, 1901; Wanderer, 1906) and yielded many fossils on the Rhine-Danube railway (Schalch, 1897-9).

In the Swabian Alb it expands to a maximum of 30 m. in the Lochen-Laufen-Lautlingen area. From here southwards (becoming thinner) it consists almost entirely of clay between two similar ironshot limestone bands, the Macrocephalus Bed above and the Parkinsonia Bed below. In the northern Swabian Alb the clay is replaced largely or entirely by limestone, the Varians or Aspidoides Beds full of *Rhynchonella alemanica* Rollier (Waagen, 1864, pp. 88-91; Fischer, 1913; Stahlecker, 1926). Similar Varians Beds, often with numerous *Oppelia aspidoides* (Oppel), usually form the upper part of the stage throughout the outcrop, but the facies in places embraces the whole Bathonian.

**Upper Bathonian**

The identity of the abundant Oppeliids with *O*. *aspidoides* (Oppel) is uncertain (see Arkell, 1951a, p. 7), and in the absence of *Clydoniceras* or any other definitely Upper Bathonian ammonites it is doubtful whether any Upper Bathonian is represented. Considering the extreme condensation of the whole stage this is not surprising.

**Middle Bathonian**

That the Subcontractus Zone is widely distributed is indicated by numerous records of *Tulites subcontractus* (Morris & Lycett) from Waagen (1864, p. 89) onwards, and of *Morrusiceras morrisi* (Oppel), which was
correctly figured from Swabia by Burckhardt. Occasional records of *Cadoceras* in Braun Jura epsilon also refer to species of *Tulites*: for instance, Quenstedt’s [*Cadoceras* *sublaeve* (1887, pl. 79, fig. 2)] is a *Tulites* cf. *calvus* Buckman, as I noted in 1953 in the Quenstedt collection at Tübingen. These and various forms of *Ballatimorphites* are common in the Regensburg gulf, where they were discussed by Pompeckj (1901, p. 150; 1910, p. 73) and Wanderer (1906, p. 523). The most richly fossiliferous deposit of this date is at Schwandorf in the northern Palatinate, 35 km. north of Regensburg, where the entire Bathonian is only 24-45 cms. thick and consists of ironshot marl and marlstone packed with fossils. The commonest ammonites are *Oppelia* (*Oxycerites*) *aspidoides* auct. (Oppel ?), but in addition the following have been identified (Arkell, 1951):

*Oecotraustes* (*Paroecotraustes*) *splendens* Arkell
*Oecotraustes* (*Paroecotraustes*) *formosus* Arkell
*Tulites* cf. *tula* Buckman
*Tulites praeclarus* (Buckman)
*Tulites* (*Rugiferites*) *polypleurus* (Buckman)
*Schwandorfia marginata* Arkell
*Krumbeckia reuteri* Arkell
*Morrisiceras morrisi* (Oppel)
*Morrisiceras krumbecki* Arkell
*Morrisiceras fornicatum* (Buckman)
*Berbericeras schwandorfense* Arkell
Also *Perisphinctids* belonging to *Siemiradzkia*, *Gracilisphinctes* and *Wagnericeras*.

At least 9 of these species occur in the English Fuller’s Earth Rock. A similar assemblage occurs at Maxhütte near Burglengenfeld (Krumbeck, 1922; Arkell, 1951a, p. 5) and Müncheshofen (Wanderer, 1906, pp. 521-4).

**LOWER BATHONIAN**

The Zigzag Zone is represented by the ubiquitous Württembergica Beds, from which are sometimes locally separable ‘ferrugineus beds’, characterized by other *Parkinsoniae* recorded under the cryptic and invalid name *Ammonites ferrugineus* Oppel non Simpson. In these beds occur many Lower Bathonian ammonites figured by Quenstedt, such as *Parkinsonia wittembergica* Oppel sp. (based on *A. parkinsoni compressus* Quenstedt, 1849, pl. xi, fig. 4, another preoccupied name), *P. foveatum* (Quenst.) *P. dorni* Arkell (1951, p. 9, based on Dorn, 1927, pl. 4, figs. 5, 6), *P. planulata* Quenst. sp. (Dorn, 1927, pl. 6, fig. 1) and other *Parkinsoniae*, with still more characteristic forms figured by Quenstedt (1886-7, pl. 74, figs. 4-7), *Morphoceras multiforme* Arkell (ib. pl. 73, fig. 20), *M. patescens* Buckman sp. (pl. 73, figs. 18, 19), *M. perinflatum* Wetzel (pl. 73, figs. 23, 24, 27), *M. egrediens* Wetzel (pl. 74, fig. 1) and ? *Ebrayiceras sulcatum* Zieten sp. (pl. 87, fig. 23).

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UPPER BAJOCIAN (up to 28 m.)

Where most fully developed in the central Swabian Alb, in the Kirchheim-Urach district, the thickness is swollen much above the normal by the incoming of 20 m. of clay in the Subfurcatum Zone and by 6.7 m. of clay at top of the Parkinsoni Zone (the upper part of this perhaps transitional to the Zigzag Zone) (Stahlecker, 1926, pp. 201-5). In Franconia the usual thickness is seldom more than two or three metres. The synonymy of the numerous species of Parkinsonia, Garantiana and Strenoceras is so involved that no attempt to list the successive faunas will be made. (For notes on the types of the basic species see Arkell, 1951, p. 9, notes 3-5). The stratigraphy is fully treated, with numerous figures of the Parkinsoniae, by Schmidtill & Krumbeck (1931); see also Wetzel (1924, pp. 179-201). The succession where most fully developed, in the Swabian Alb, is as follows (Stahlecker, 1926, pp. 201-5).

Parkinsoni Zone
Upper parkinsoni beds, clays . . . . . . 6.7 m.
Parkinsoni Oolite . . . . . . 0.6-0.7 m.

Garantiana Zone
'Parkinsoni' nodules, with Garantiana

Subfurcatum Zone
Upper Subfurcatum beds or 'Hamitentone', clays . . 20 m.
Subfurcatenoolith, sometimes clay (with Strenoceras spp., Garantiana baculata, Spiroceras bifurcati, Teloceras spp.) 0.5-2 m.

In Franconia, condensation produces a mixture of part of the Garantiana and Parkinsoni Zones, which Schmidtill & Krumbeck separate as middle parkinsoni beds. This appears to be the main level of the true P. parkinsoni, which may overlap with Garantiana spp., just as various Garantianae overlap with Strenoceras spp. At Grubingen Teloceras of several species (but not T. blagdeni) have been obtained from the Subfurcatum Zone (Maubeuge, 1952).

MIDDLE BAJOCIAN (up to c. 40 m.)

Zone of Stephanoceras humphriesianum. Coronaten-Schichten. The subzone of Teloceras blagdeni at top is well differentiated (Blagdeni Schichten). In the Humphriesianum Subzone three levels are recognized in favourable places, characterized by different combinations of species of Stephanoceras, Skirroceras, Stemmatoceras and Normannites. The numerous well-preserved Stephanoceratids have been revised and figured by Weisert (1932) and Schmidtill & Krumbeck (1938). Stephanoceras cf. humphriesianum (Sow.) occurs in the middle level, in which Cadomites cf. daubenyi and C. cf. stegeus (Buck) are also recorded. Normannites and its subgenera go all through, starting with N. braikenridgei (Sow.) in the lower level. In basal clays with Megateuthis giganteus various Stephanoceratids occur with Chondroceras cf. grandiforme Buckman, and elsewhere Dorsetensia liostraca Buck., D. regadiens Haug (Stahlecker, 1926, p. 196, 1934, p. 95; Frank, 1942, pp. 21-29) and D. complanata Buck. (Maubeuge, 1950, p. 43). Some other mollusca are figured by Kuhn (1938).
<table>
<thead>
<tr>
<th>Oppel's Zones</th>
<th>Quenstedt</th>
<th>Modern Zones and Subzones</th>
<th>Strata</th>
<th>Correlation (England)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oppelia aspidoides</td>
<td></td>
<td>Tulites subcontractus</td>
<td>Aspidoides Schichten</td>
<td>subcontractus</td>
</tr>
<tr>
<td>Zigzagiceras zigzag</td>
<td>Epsilon</td>
<td>Zigzagiceras zigzag</td>
<td>Württembergicus Schichten Ferrugineus Schichten</td>
<td>zigzag</td>
</tr>
<tr>
<td>Parkinsonia parkinsoni</td>
<td></td>
<td>Parkinsonia parkinsoni</td>
<td>Ob. Parkinsonienschichten</td>
<td>parkinsoni</td>
</tr>
<tr>
<td>Garantiana garantiana</td>
<td></td>
<td>Garantiana garantiana</td>
<td>Unt. Parkinsonienschichten</td>
<td>garantiana</td>
</tr>
<tr>
<td>Strenoceras subfurcatum</td>
<td>Delta</td>
<td>Strenoceras subfurcatum</td>
<td>Subfurcatschichten</td>
<td>subfurcatum</td>
</tr>
<tr>
<td>Stephanoceras humphriesianum</td>
<td></td>
<td>Teloceras blagdeni</td>
<td>Coronatenschichten and Giganteustone</td>
<td>blagden</td>
</tr>
<tr>
<td>Otoites sauzei</td>
<td>Gamma</td>
<td>Otoites sauzei</td>
<td>Blaukalk</td>
<td>sauzei</td>
</tr>
<tr>
<td>Sonninia sowerbyi</td>
<td></td>
<td>Sonninia sowerbyi</td>
<td>Wedelsandsteine u.-tone Sowerbyibank</td>
<td>sowerby</td>
</tr>
<tr>
<td>Ludwigia murchisonae</td>
<td>Beta</td>
<td>Graphoceras concavum</td>
<td>Doggersandstein</td>
<td>murchisonae</td>
</tr>
<tr>
<td>Costileioceras discoidum</td>
<td></td>
<td>Staufenia staufensis</td>
<td></td>
<td></td>
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<tr>
<td>Costileioceras sehnense</td>
<td></td>
<td>Costileioceras sehnense</td>
<td></td>
<td></td>
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<tr>
<td>Costileioceras tolutum</td>
<td></td>
<td>Costileioceras tolutarium</td>
<td></td>
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<tr>
<td>Costileioceras sinon</td>
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<td>Costileioceras sinon</td>
<td></td>
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<tr>
<td>Costileioceras costosum</td>
<td></td>
<td>Costileioceras costosum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trigonia navis and Pachylytoceras torulosum</td>
<td>Alpha</td>
<td>Leioceras opalinum</td>
<td>Opalinus Ton</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Zone of *Otoites sauzei*. Blaukalk: hard sandy limestone 3-7 m. In the upper part *Otoites sauzei*, *Emileia* spp. (Quenstedt, 1886, pl. 64, figs. 4-13), etc. (Stahlecker, 1926, p. 191; Frank, 1942, p. 19). It is probable that the 'Stephanoceras humphriesianum' sometimes recorded from this bed are earlier forms (cf. *Docidoceras perfectum* Buckman?); Frank (1942, p. 19) calls them 'humphriesianus-like forms'. From the same bed, however, are also recorded *Sonninia sowerbyi* (Miller) and *S. arenata* (Quenst.) (Frank, 1942, p. 19), and the type specimen of *S. mesacantha* (Waagen sp., 1867, pl. 28, fig. 1) comes from here.

Zone of *Sonninia sowerbyi*. Gingen, in the Swabian Alb, was described by Waagen (1867, p. 532) as the most favourable locality known to him for the fauna of this zone. His specimens came mostly from the oolitic and coral-bearing Sowerbyi Bed (0-75-1 m.) at the base of the zone, above which follow 10-20 m. or more of clay with two or three levels of Wedelssandstein with *Cancelllophycus*, developed on different horizons in different places. Some of the many *Sonniniae* (listed by Stahlecker, 1926, p. 187, 190 and Frank, 1942, Textbeilage 2) occur indifferently throughout the zone. *S. sowerbyi* (Miller) and *S. fissilobata* (Waag.) occur at top and bottom, but the richest fauna is at the bottom, in the Sowerbyi Bed. *Dorsetensia tecta* Buck, is recorded from the top level, *Hyperlioceras discites* (Waag.) from the bottom, with *Sonninia gingsensis* (Waag.), *S. polyacantha* (Waag.), *S. jugifer* (Waag.), *S. furticarinata* (Waag.), *S. adicra* (Waag.) and *Emileia* (? *Docidoceras*) sp. (Waagen, 1867, pl. 24, fig. 3). In Franconia as usual, the zone is much thinner (Dorn, 1939), but it has yielded numerous well-preserved ammonites (figured Dorn, 1935); and here again what is near enough to the true *S. sowerbyi* (Miller-Sow.) is figured from the Sowerbyi Zone (pl. i, fig. 6). For the upper part of the Sowerbyi Zone in Franconia *Witchellia pinguis* (Roemer) is a subzonal index (Dorn, 1935, pp. 16, 116); this presumably corresponds to the Laeviuscula Subzone of Haug (1910). (Dorn's 'W. laeviuscula' from the Romani Subzone—1935, p. 106 and figures—is nothing like Sowerby's species; pls. xiv, 2, and xv, 3, appear to be *Dorsetensia aff. liostraca* Buckman.)

Lower Bajocian (80 m.)

Braun Jura Alpha and Beta. This is the sandiest subdivision in the Swabian Jurassic. Beta, 52-56 m. thick, consists largely of sandstones, sandy limestones and sandy clays (Doggersandstein); alpha, 25 m. more or less, consists of clay grading up into sandy loam and down into the Toarcian shales. The intricate lithological subdivisions and changes of facies have been studied in SW. Swabia by Lorcher (1934), in NE. Swabia by Bozenhardt (1936), and in the central region by Stahlecker (1926, 1934). The ammonite succession is best developed in the south-west; farther north-east ammonites are scarcer and poorly preserved, and in Franconia most of the zones are so poorly represented that Dorn (1935) omitted most of them from his monograph although affirming that in general the zonal succession is the same. The Graphoceratids are of special interest

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Zones of *Graphoceras concavum* and *Ludwigia murchisonae*. From Klettgau to Gosheim (Lörcher, 1934, p. 130) and in other places (Frank, 1942, p. 5) the Concavum Zone is united with the Sowerbyi Bed as a single inseparable stone band (max. 3 m.), just as in the Sherborne district of Dorset, where the union of these two zones caused Buckman so much confusion (see p. 33).

In SW. Swabia, Lörcher (1934) found an interesting subzonal succession with several puzzling anomalies. Instead of *Ludwigia murchisonae* being confined to a high horizon with *Staufenia staufensis* as at Sehnde near Hannover (see p. 143), he found that it appears much lower, in the Sehndense Subzone, and occurs in both the next following subzones of *discoideum* and *staufensis*. He attributed this to northward migration of *Ludwigia murchisonae* from the Tethys. Whatever the explanation, the facts are a vindication of Oppel’s original concept of a Murchisonae Zone, embracing the other horizons as subzones. Between Kirchheim and Metzingen these horizons are all represented by nothing but a pebble bed. Between Metzingen and Heckingen the gap widens downwards and embraces everything between the Concavum Zone and the Opalinum Zone. The subzones where the sequence is fully developed are shown in table 12 (p. 123).

Zones of *Tmetoceras scissum* and *Leioceras opalinum*. *Tmetoceras scissum* occurs at Balingen with *Costileioceras sinon* (Bayle), the index used by Hoffman in 1913 and identified by Stahlecker (1926, p. 162) and Lörcher (1934) in the Swabian Alb. *Costileioceras tolutarium* (Dumorrier), which indicates a subzone above *sinon* in the Swabian Alb (same references) was figured by Buckman in 1899 from the Scissum Zone in England. The Scissum Zone therefore probably covers both Sinon and Tolutarium Subzones.

The Wasserfallbank at the base of the Doggersandstein and of Braun Jura beta contains both *Leioceras opalinum* and *Costileioceras costosum* (Lörcher, 1934, p. 126), and the *costosum* horizon is therefore a subzone of the Opalinum Zone, as shown by Lieb (1950, p. 452) in the Swiss Jura. The rest of the zone, constituting Braun Jura alpha, comprises the Opalinum clay with nodules, for which a fair average thickness is 25 m. In Franconia (P. Dorn, 1923, 1936a) there is a gradual passage down into the Upper Toarcian clays and upwards into the Doggersandstein. Common fossils of the Opalinum Zone are *Pachylytoceras torulosum* (Schloth.) and *Trigonia navis* Lam., used by Oppel as zonal indices but abandoned in favour of *Leioceras opalinum*, introduced as index by Brauns in 1864.

**UPPER TOARCIAN (2-6 m.)**

Zone of *Lytoceras jurensense*: Lias Zeta. The Jurense marls are sometimes abruptly followed disconformably by the Opalinum Zone, but more often they pass up lithologically by gradations of more or less sandy
marls (P. Dorn, 1923). Although the formation is so thin, all the subzones except that of *Phymatoceras lilli* have been recognized in Franconia through the detailed work of Krumbeck (1943), who separates a marly basin facies and a marginal sandy facies, the latter confined to the Regensburg gulf. Krumbeck's work makes Franconia a highly important area for the ammonite succession of the Toarcian; accordingly the principal results are tabulated below from his numerous profiles, using the zonal indices standardized by Spath on grounds of priority and wider appropriateness:—

Subzone of *Pleydellia aalensis*, with *P. aalensis* (Zieten), *Pleurolytoceras hircinum* (Schloth.) abundant (whence *hircinum* beds), *Grammoceras mactra* (Dum.), *G. fluitans* (Dum.), *G. costulatum* (Ziet.), *G. subcomptum* (Branco), *G. leurum* (Buck.), *Hudlestonia aff. compressum* (Ben.), *Dumortieria kochi* (Ben.), *D. costula* (Rein.), *D. munieri* (Haug), *D. moorei* (Lyc.), *Pseudolioceras falcodiscus* (Qu.), *Phylloceras calypso* (d'Orb.), *P. cf. heterophyllum* (Sow.).

Subzone of *Dumortieria moorei* (radiosa beds), with *D. moorei* (Lycett), *D. pseudoradiosa* (Branco), *D. rhodanica* (Haug), *D. bleicheri* (Ben.), *D. cf. nicklesi* (Ben.), *D. cf. radians* (Rein.), *D. aff. brancoi* (Ben.), *Grammoceras cf. senescens* (Buck.), *Hudlestonia serrodens* (Qu.), *Pleydellia aalensis* (Ziet.).

Subzone of *Dumortieria levesquei*, with *D. cf. levesquei* (d'Orb.) and *D. striatulocostata* (Qu.).


Subzone of *Grammoceras struckmanni* (fallaciosum beds), with *G. cf. bingmanni* (Denck.), *G. cf. saemanni* (Denck.), *G. cf. mulleri* (Denck.), *G. aff. doerntense* (Denck.) (all in the sandy marginal facies) and *G. fallaciosum* Bayle. This horizon is usually missing from the basin facies.

Subzone of *Grammoceras striatulum* (thouarsense beds), with *G. striatulum* (Sow.) and *Pseudolioceras* cf. *württembergica* (Denck.).


* * * * * *

Near Boll at least the four highest subzones of the Upper Toarcian are condensed into a single half-metre of limestone or 'ammonite breccia' (Engel, 1894).

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LOWER TOARCIAN (c. 4-12.5 m.)

Posidonien-schiefer: Lias Epsilon. The world-famous Posidonia shales of Boll and Holzmaden at foot of the Swabian Alb have been worked for centuries in numerous quarries and their complete faunas have been recorded inch by inch (Hauff, 1921; 1953). The marvellous vertebrate fauna and the interest of the conditions of formation and palaeogeography have overshadowed all else (Beurlen, 1925; P. Dorn, 1936; Brockamp & others, 1944), and a modern analysis of the ammonite succession remains to be undertaken. From the careful records of Bernard Hauff senior (1921), however, it is evident that the beds correspond precisely with the lower Toarcian, as was realized by Quenstedt, Oppel and Waagen (see especially Waagen, 1864, p. 46; for a comparable profile for Franconia see Reuter, 1927, pp. 55-7). Ammonites from the oil-shales of Boll were figured by Knorr (1755, vol. i) and include the type of Lytoceras knorri-anum (de Haan, 1825) (type Knorr's pl. xxxvii, fig. 2), and four plates of photos showing species from both Falcifer and Bifrons Zones are given by Hauff in his excellent book (1953, pls. 73-76), augmenting Quenstedt's drawings (1885, pls. 43-6).

PLIENSBACHIAN (max. 30 m. in the south, 60 m. in the north)

Lias Gamma (Numismalismergel) and Delta (Amaltheenthone). The type locality for this stage, founded by Oppel (1858, p. 815) to replace d'Orbigny's 'Liasien', is the village of Pliensbach, near Boll, at foot of the Swabian Alb. It formed the subject of Oppel's first work (1853), carried out as thesis for a prize at Tübingen University, the subject having been set by Professor Quenstedt. The zones still used all over Europe are those originally proposed for this area by Oppel; so excellent was his maiden study that no changes have been required, though refinement is no doubt possible, as shown by the extremely detailed work of Krumbeck (1936) in Franconia.

The Upper Pliensbachian (Spinatum and Margaritatus Zones) is rich in Amaltheids but poor in all other kinds of ammonites, although a few forms of Coeloceras and of Eoderoceratidae and Polymorphitidae occur as rarities (Beurlen, 1924), whereas the Lower Pliensbachian has an extremely varied and prolific ammonite fauna. Beurlen (1924) attributes this difference to temporary near-closure of the Alb trough from southern seas; but the cause appears to have been more general, for the Upper Pliensbachian is noticeably poor in ammonites other than Amaltheids in the British Isles as compared with regions such as Italy, Sicily, and southern France. It happens that one of the best described exposures of the Lower Pliensbachian is on the tiny outlier of Langenbrücken, on the edge of the Rhine valley south of Heidelberg, remote from the Alb (Futterer, 1891), and later a rich fauna was obtained there also from the lower part of the Margaritatus Zone by means of a special excavation (Bessler, 1935). In the Franconian Alb the Lower Pliensbachian is often reduced to a single band of nodular marly limestone from 5 cm. to 1 m. thick (Schieber,
1936, p. 25), but in the north (Bayreuth) the Upper Pliensbachian expands to 60 m. (Reuter, 1927, p. 51). The changes of facies in Franconian Lias Gamma have been worked out in great detail by Krumbeck (1936).

The wealth of ammonites in the Swabian Lower Pliensbachian is well illustrated by Quenstedt’s (1884-5) plates 25-39, although many of his names require revision; by contrast, those of the Upper Pliensbachian occupy only plates 40-42.

Zones of 

Pleuroceras spinatum and Amaltheus margaritatus. The Amaltheids of the Amaltheenthone have been exhaustively studied by Frentzen (1934; 1937) on the basis of 10,000 well-preserved specimens collected bed by bed in special excavations at points along the entire length of the Swabian outcrop. He confirmed that Pleuroceras of the Spinatum Zone was derived by gradual transitions from various Amaltheus of the Margaritatus Zone, and he recognized four subzones:

Subzone of Pleuroceras spinatum (Brug.)
Subzone of Pleuroceras bechteri Frentzen
Subzone of Amaltheus margaritatus (Montf.)
Subzone of Amaltheus nodifer Buckman

Also from the Margaritatus Zone come Metacymbites centriglobus (Oppel) (type, Oppel, 1853, p. iii, fig. 7), Crucilobiceras zitteli (Oppel), Harpoceras kurrianum (Oppel) and Coeloceras pettos (Qu.), type species of the genus Coeloceras.

Zone of Prodactyloceras davoei. By contrast with the Ibex and Jamesoni Zones, this zone has relatively few ammonites, the principal being P. davoei, Androgynoceras capricornus (Schloth.) and Lytoceras jimbriatum (Sow.) and their allies. According to Schieber (1936, p. 26) early Amaltheids occur, although this was explicitly denied by Oppel (1856, p. 127).

Zone of Tragophylloceras ibex. Characterized by a wealth of Liparoceratidae, Polymorphitidae, etc.; especially T. ibex (Qu.), T. wechsleri (Oppel), Liparoceras striatum (Rein.), Beamiceras centaurus (d’Orb.), Acanthopleuroceras maugenesti (d’Orb.), A. binatum (Oppel), A. arietiforme (Oppel), A. subarietiforme (Futt.), Tropidoceras stahli (Oppel), T. futtereri Spath (based on Futterer, 1891, pl. xii, fig. 1), Crucilobiceras frischmanni (Oppel) and other forms which range up from the Jamesoni Zone.

Zone of Uptonia jamesoni. Some of the most characteristic ammonites of this zone are Uptonia jamesoni (Sow.) and its allies, such as lata and costata (Qu.), Polymorphites polymorphus (Qu.) and its allies, Platypleuroceras brevispina (Sow.), Tropidoceras falcoides (Qu.), T. stahl (Oppel), T. futtereri (Spath), Platynoticeras alterum (Oppel), Metoxynoticeras oppeli (Schloen.), M. cf. bwignieri (d’Orb.), Phylloceras zetes (d’Orb.), Apoderoceras spoliatum (Qu.), Hyperderoceras rugum (Qu.), Crucilobiceras filum (Qu.), C. submaticum (Oppel), C. nodogigas (Qu.), Phricodoceras taylor (Sow.), etc. At the base is a layer with many Eoderoceratidae, called by Oppel the Armatum Bed, but later in date than the true Eoderoceras armatum assemblage of the top of the Sinemurian, and considered

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by Hoffmann a separate subzone of *Crucilobiceras nodogigas* (Qu.) and *Phricodoceras taylori* (Sow.), which on grounds of priority should bear *P. taylori* as index.

**Sinemurian** (max. 30-40 m., thinning northwards)

Lias Beta and upper Lias Alpha. Although not the type area for the Sinemurian and Hettangian stages, this is the type area for the zones into which they were divided by Oppel (1856, p. 14). These zones have proved universally appropriate and useful ever since, with only two changes of index-species. One zone was given a non-ammonite index, *Pentacrinus tuberculatus*, although Oppel listed from it *Am. birchi, bonnardi* and *turneri*, but *Euasteroceras turneri* (Sow.) was substituted by Wright as early as 1860 and is now used instead. The next zone below this was called by Oppel the zone of *Arnioceras geometricum* (Oppel) *non* Phillips, but this name is an invalid homonym and was early replaced by Judd by an allied species, *Arnioceras semicostatum* (Y. & B.). With these two trifling improvements, Oppel’s scheme remains intact as the basis of the world standard.

The richness of the Swabian Sinemurian in well-preserved ammonites is probably unsurpassed anywhere in the world, and certainly the ammonites have never been so completely and profusely illustrated as in the first volume of Quenstedt’s great work (1884-5), in which pls. 17-24 show ammonites of the Upper Sinemurian and pls. 5-16 those of the Lower Sinemurian, chiefly from the almost fabulous Arietenkalk or Ariettid pavement. The most detailed stratigraphical collecting in the Upper Sinemurian (Lias Beta) has been done on the Langenbrücken outlier south of Heidelberg (Hoffmann, 1936-8) and in the Franconian Jura (Krumbeck, 1932), while the Lower Sinemurian and its ammonites have been treated in great detail in all the outcrops by Fiege (1926, 1929) and Frank (1931). As in higher stages, in northern Bavaria Krumbeck (1932) recognizes a basin facies of the Upper Sinemurian (0-8-15 m.) and a sandier marginal facies, only up to 0-8 m. thick.

**Zone of Echioceras raricostatum.** Between this zone and the Pliensbachian Hoffmann holds that there is in SW. Germany a non-sequence representing a subzone of *Eoderoceras miles* (Simpson) in NW. Germany and Yorkshire. The highest Sinemurian in SW. Germany consists of clays with limestone bands and yields *Echioceras raricostatum* (Zieten), *E. raricostatoides* (Vadasz), *Crucilobiceras densinodum* (Qu.), *Hemimicroceras subplanicosta* (Oppel).

**Zone of Oxynoticeras oxynotum.** Clays with *O. oxynotum* (Qu.), *Bifericeras bifer* (Qu.), *Angulaticeras lacunatum* (Buck.). At the base a non-sequence representing the subzone of *Oxynoticeras simpsoni* (Bean-Simpson) and *Gagaticeras gagateum* (Y. & B.) of NW. Germany and Yorkshire, which are missing in SW. Germany according to Hoffmann.

**Zone of Asteroceras obtusum.** At the top a limestone (Betakalk) with

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A. obtusum (Sow.), A. stellare (Sow.), A. betacalcis (Qu.) and Promicroceras planicosta (Sow.); below, clays with A. obtusum and P. planicosta. The Planicosta clays reach a thickness of 25 m. in the Swabian Alb, but in the marginal facies of northern Bavaria the zone is missing (Krumbeck, 1932).

Zone of Euasteroceras turneri. Pentacrinus tuberculatus bed, 1 m. Microderoceras birchi (Sow.), Asteroceras cf. brooki (Sow.), etc. Ammonites of this zone are also present at the base of the Obtusum Zone clays in the basin facies in north Bavaria.

Zone of Arnioceras semicostatum. The zone of Arnioceras geometricum Oppel non Phillips (see Hoffmann, 1938, pl. ii, fig. 2), with Euagassiceras sauseanum (d’Orb.), Agassiceras scipionianum (d’Orb.) and Paracoroniceras gmindense Oppel sp. (Fiege, 1929, pl. v, figs. 11, 12). Oppel (1856, p. 14) regarded this as a subzone of the Bucklandi Zone and omitted it from the complete table at the end of his book (1858), and in places it appears to be more or less combined with the Bucklandi Zone in the Arietenkalk.

Zone of Arietites bucklandi. Arietenkalk, Arietenbank, Arietenpflaster, or Schneckenfels, a band of limestone 6 in. to half a metre thick, packed with large ammonites, overlying clays with Gryphaea arcuata; average in the Swabian Alb 3 m. Where the limestone is laid bare over a considerable area, as in the bed of a stream at Ofterdingen near Tübingen, it resembles some of the wave-washed limestones of the Bucklandi Zone of Lyme Regis. A good idea of the fauna is given by Zieten (1830, pls. xxvi–vii), Quenstedt (1884, pls. 5–16) and Fiege (1929, pls. iii–vii). A few characteristic species are here listed from the revision by Donovan (1952) based on the contemporary ammonites in the Bristol district: Arietites solarium (Qu.), Vermiceras spiratissimum (Qu.), V. scylla Reynès sp. (Quenstedt, pl. 13, fig. 6), Coroniceras deffneri Oppel sp. (Qu. pl. 6, fig. 4), Euagassiceras striaries (Qu.), E. spinaries (Qu.). In the Aalen area there is a conglomerate at the base of the Arietenschichten, and derived specimens of Schlotheimia from the Angulata Zone have been found over a wide area incorporated with the large Arietitids (Schieber, 1936, pp. 8, 15–16). This has given rise to prolonged controversy about the zonal value of the ammonites (Vollrath, 1924, 1928; Pratje, 1924a). Besides these, however, the lower Arietenschichten contain some indigenous dwarf Schlotheimids (Hölder, 1936).

Hettangian (max. c. 25 m., usually much less)

Zones of Schlotheimia angulata and Psiloceras planorbis. The Hettangian of the entire Alb has been treated in great detail by Frank (1931) and it is impossible to summarize in one paragraph his 242 pages and folding diagrams. In Swabia the Angulata Zone is developed as limestones which form wide low plateaux rising above the Trias landscape. As has so often been established in the Jurassic, the lithological boundaries transgress the ammonite zones. An example is the Kupferfelsbank which in central Württemberg is a crystalline limestone in the basal Bucklandi Zone, but...
farther south and east is said to yield *Schlotheimia angulata* as its characteristic fossil; below is an oolite which in the central region is in the Angulata Zone and towards the south and east includes *Psiloceras (Caloceras) johnstoni* of the upper Planorbis Zone (Frank, 1931, p. 7). At the base is almost everywhere the Psilonotenbank, a hard limestone about a foot thick, packed with species of *Psiloceras* and occasionally *Psilophyllites* (Kuhn, 1935a, who also figures a number of small pelecypods). The Psiloceratidae and Schlotheimmiidae figured in Quenstedt’s first four plates (1883) were revised by Pompeckj (1893-6); the gigantic size of some of the Schlotheimids is noteworthy (Quenstedt, 1883, pl. 2, 4).

The Psilonotenbank is overlain in central Württemberg by up to 10 m. of clay, which wedges out both south and east, so that the Psilonotenbank is in contact with the overlying Oolithenbank. On Frank’s interpretation (1931, p. 198) this indicates a transgression of the Hettangian sea from the north or north-west towards the south and east (the opposite was inferred by Pratje, 1924, p. 43), the Psilonotenbank being its basal bed, laid down everywhere on the front of the advance and covered up by clays behind. Up to a point this interpretation may be true, but no attempt has been made to show whether the ammonite fauna of the Psilonotenbank is older in the central region than in the south and east. The next-following ‘Leithorizont’, the Oolithenbank, on the contrary, contains *Psiloceras johnstoni* in the peripheral areas and therefore is older there than in the central region, where it belongs to the Angulata Zone. In the two diagrams (Frank, 1931, pp. 217, 219) showing the alleged ‘wanderings’ of *P. johnstoni* and *S. angulata* it is likely that these specific names should in reality be equated merely with the genera *Psiloceras* and *Schlotheimia*, but even making allowance for that, the diagrams should be reconstructed with the four subzonal ammonites of the Hettangian in the left-hand column which is headed ‘Horizons’ and the lithological developments placed in the other columns, according to the contained ammonites.

The relations of the Planorbis Zone to the underlying Trias are complicated. In most places a Rhaetic bone bed and sandstones occur; in other places these wedge out and leave the Planorbis Zone in contact with the Keuper Knollenmergel. (For discussion and bibliography see Roll, 1933a; Hoffmann, 1935). In the Aalen area there are conglomerates with limestone pebbles, ranging in size from a hen’s egg to a plate, at the base of the Planorbis Zone and again at the base of and within and on top of the Angulatum Zone (Schieber, 1936, p. 8).

**LOWER SAXONY**

As already mentioned (p. 107), during the Lower and Middle Jurassic a seaway connected the Alb trough northward through the ‘Hessian strait’ with the basin of NW. Germany, or Lower Saxony, but in the Upper Jurassic the two troughs became severed and evolved independently. It follows from this that the Lower and Middle Jurassic deposits of Lower

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Saxony can be correlated zone by zone with those of the Alb trough, but that the Upper Jurassic succession shows marked peculiarities and requires fuller analysis and description; the ammonite connexions are decidedly with the north-west, with which even the Lias shows marked affinity—especially with Yorkshire. The Lias is extremely thick in the interior of the basin, under Friesland, where borings have proved over 1000 m.

The Middle Jurassic of Lower Saxony, even at outcrop along the southern margin of the basin, is also very thick in places, and is developed in clay facies with layers of nodules, producing an extensive succession of ammonite faunas of first importance for the world standard.

Over the greater part of the basin the Jurassic is buried beneath Cretaceous and later deposits of the North German plain, but much has been revealed by borings (fig. 15). The Lias is thickest under the mouth of the Weser and almost as far south as Bremen and as far east as the River Elbe (Hoffmann, 1949). West of the River Ems, in the region of the German-Dutch frontier, the Jurassic thins out against a submerged block,
which was probably an island, and certain Upper Jurassic formations overlap on to Trias (Bentz, 1926; Schott, 1951; Wolburg, 1954). Intra-Jurassic movements that preceded these overlaps also caused uplift and shallowing between the Weser and Elbe, where the Lias is thick, for parts of the Upper Jurassic there rest disconformably on eroded or incomplete Middle Jurassic (as under Lüneburg Heath). East of the lower Elbe was another non-subsiding area against which the Jurassic formations wedge out and are overlapped by Cretaceous: this is known as Pompeckj’s Swell; it stands on the site of an inferred island of Cambrian times to which Pompeckj first drew attention (Seitz, 1949).

The southern boundary of the basin of Lower Saxony is formed by the ancient masses of the Rhenish slate mountains, which are an extension of the Ardennes ridge, and the Harz, an extension of the Bohemian massif. Along the northern margin of these masses and at the entrance to the intervening ‘Hessian strait’ the Jurassic system crops out in an interrupted band over 150 miles long, between the River Ems and the River Aller, around Osnabrück, Hanover, and Brunswick (fig. 16). In these outcrops the rocks vary greatly in thickness and facies and are nearly all in shallow-water marginal development, contrasting with the open basin facies to the north.

This is the classic area of the Saxonian folding (Stille, 1910, 1913, 1922, 1925, 1932, 1949, 1953, etc.). The Mesozoic rocks occupy troughs of subsidence between resistant swells and massifs and have been compressed between them as within a frame, whence Stille’s concept of ‘frame folding’. Tectonic complication increases near the junction between the basins and their frames. In general there has been overriding movement towards the south or south-west, often with overturning and sometimes, as in the Osning range, low-angle overthrusting magnified in its effects by décollement (Stille, 1953). The tectonics are locally complicated by, or even largely caused by, salt domes. Maximum compression in the Tertiary was preceded and often conditioned by folding and faulting at several periods in the Jurassic and Cretaceous. The principal phases were (Dahlgrün, 1923):

- pre-Upper Valanginian (Hils phase)
- pre-Middle Purbeckian (Osterwald phase) (main phase)
- pre-Middle Kimeridgian (Deister phase)

Each is marked by unconformities and conglomerates. In addition to folding there was faulting during the Mesozoic. The Rhenish massif extended in Jurassic times over what is now the Munster basin, and its northern margin seems to have broken down progressively during Upper Jurassic and Lower Cretaceous times in a series of step faults, each step descending farther into the trough to the north (Stille, 1936; Wolburg, 1952). This recalls the behaviour of the southern margin of the Vindelician ridge bordering the Alpine geosyncline (see p. 155).

The anticlines and periclines in which the Jurassic rocks crop out
form elongated ranges of wooded hills, of which the principal are the Teutoburger Wald (including the Osning and Eggegebirge), the Wiehengebirge and Wesergebirge (divided by the gorge of the Weser at Porta Westfalica), and near Hanover the Sünelt and Deister, the Ith, and farther east the Salzgitter Hohenzug and many outlying masses around Brunswick. One of the most southerly outliers forms the complex Kahlberg, near Echte, close to the Harz (J. Perrin Smith, 1893).

In the numerous small oilfields of the area, limestones in the Bathonian (‘Cornbrash’ facies), Upper Oxfordian (Coralline Oolite) and Middle Purbeckian (Serpulite) and, in the east, Lower Bajocian sandstones are important reservoir rocks.

The Jurassic palaeogeography of the area has been studied especially by Hoffmann (1949), Schott (1932, 1938, 1949, 1951), Raecke (1932), Seitz (1949) and Wolburg (1954). Classic comprehensive works on the stratigraphy and palaeontology are those by Roemer (1836), Koch & Dunker (1837), Dunker (1846), von Seebach (1864), Brauns (1865-6, 1869, 1871, 1874), Struckmann (1878, 1880, 1882) and Salfeld (1914). Syntheses of the stratigraphy of the Lower and Middle Jurassic, of great value and indeed indispensable, have been published by Kumm (1940, 1952). Detailed works on special areas are too numerous to mention, but most of them are referred to in the following tabulated synopsis of the stratigraphy. Some of the most important areas for Jurassic stratigraphy are described in Survey memoirs by Grupe & Ebert (1927), Ebert & Grupe (1928), Naumann (1927), Naumann & Burre (1927) and others.

**PURBECKIAN**

Borings for oil in the northern basin facies, especially in and about the valley of the Ems, have revealed a Wealden up to 500 m. thick, developed as almost continuous clays or shales with only thin shell beds. Study of the ostracod has proved a succession of zones, through which the forms change gradually from predominantly Jurassic to predominantly Cretaceous types. On the basis of these fossils six subdivisions have been established (Wicher, 1940; Riedel & Wicher, 1942; Wolburg, 1949, 1950). The fauna of Wealden 1 is most closely allied to that of the Middle Purbeck, and Wealden 2 and 3 have an Upper Purbeck fauna. Between Wealden 3 and 4 is believed to be approximately the level where, in the marginal facies, the main sandstone development (Deister Sandstone) comes in; this was already correlated with the Hastings Beds, or Lower Wealden of England, by Struckmann (1880, pp. 15, 28: ‘Deister- oder Hastingssandstein’). Wealden 4 contains a characteristic ostracod which has been found near the top of the Weald Clay of Sussex (Wolburg, 1949a), but Professor P. Allen does not accept the implications of this. Wealden 6, which is brackish and immediately succeeded by the Lower Valanginian Platyloenticeras beds in Germany, therefore probably represents the marine Subcraspedites beds (Spilsby Sandstone) which are missing otherwise in Germany, as already suggested in 1924 by Spath.
Minute fragments of ammonite found in a boring at Wahn (Riedel, 1941) were identified with the Spiti Shales genus *Blanfordiceras*, but appear to be *Garantiana* of Upper Bajocian age. They must have been derived.*

On the evidence from Switzerland and the French Alps that the Middle and probably Upper Purbeckian are Upper Tithonian (see pp. 85-92),

**Table 13.—The Late Upper Jurassic and Early Lower Cretaceous**

Vertical lines indicate barriers to correlation still not broken down by research. Wavy horizontal lines indicate principal Jurassic phases of earth-movements in NW. Germany

<table>
<thead>
<tr>
<th>NW. Germany</th>
<th>England</th>
<th>Marine Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Polyptychites Beds</strong></td>
<td>Speeton Clay and Hundleby Clay</td>
<td>Middle Valanginian</td>
</tr>
<tr>
<td><strong>Platylenticeras (=’Garnieria’) Beds</strong></td>
<td>Spilsby Sandstone, <em>Subcraspedites</em> Beds</td>
<td>Berriasian (=Infra-Valanginian)</td>
</tr>
<tr>
<td>Wealden 6 (brackish)</td>
<td>Wealden 5 (freshwater)</td>
<td>Wealden 4 (freshwater)</td>
</tr>
<tr>
<td>Deister Sandstone</td>
<td>Hastings Sands (part)</td>
<td></td>
</tr>
<tr>
<td>Wealden 3</td>
<td>Wealden 2</td>
<td>Wealden 1</td>
</tr>
<tr>
<td>Süsswasserkalke of Hils Serpulite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Münder Marls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Einbeckhausen Plattenkalk</td>
<td>Upper Purbeck Beds</td>
<td>Upper Tithonian</td>
</tr>
<tr>
<td>Giagas Beds</td>
<td>Middle Purbeck Beds</td>
<td></td>
</tr>
<tr>
<td>Upper Kimeridge Clay</td>
<td>LOWER Purbeck Beds (Portland Beds (pars))</td>
<td>Middle Tithonian</td>
</tr>
<tr>
<td>Middle Kimeridge Clay of Kimeridge</td>
<td></td>
<td>Lower Tithonian</td>
</tr>
<tr>
<td>Upper Kimeridge Clay (Pseudomutabilis and Mutabilis Zones)</td>
<td></td>
<td>Lower Kimeridgian</td>
</tr>
<tr>
<td>Lower Kimeridge Clay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humeralis Beds</td>
<td>Ringsteadia pseudocordata Zone</td>
<td>Upper Oxfordian</td>
</tr>
</tbody>
</table>

The division between Jurassic and Cretaceous falls at the top of the English Purbeck Beds and therefore in the middle of the German Wealden (between 3 and 4, and below the Deister Sandstone). This leaves the English lower Wealden and German upper Wealden (4-6) to represent the Berriasian (Infra-Valanginian). An attempt has been made in table 13 to show these correlations and at the same time to make clear

* At my suggestion the cores have been re-examined and Dr Wolburg and Dr Seitz kindly inform me that no Wealden is present, the microfauna indicating Upper Valanginian and Hauterivian (December 1954).

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their limitations by introducing vertical bars where palaeontological links are still lacking.

It is interesting that the most important of the three phases of Saxonian folding, that preceding deposition of the Serpulite (pre-Middle Purbeckian), comes out as contemporaneous with the pre-Upper Tithonian movements which caused transgressions of the Upper Tithonian in many parts of the world.

The Purbeckian freshwater limestones of the Hils basin have proved to contain Middle Purbeckian ostracods and to be one of several local facies of the Serpulite formation (Schmidt & Wolburg, 1949). Furthermore, the Münder Marls, previously correlated with the Lower Purbeckian only, have yielded in the lower part marine Portlandian ostracods and accordingly are supposed to bridge the Upper Portlandian and Lower Purbeckian. The Purbeckian of NW. Germany is therefore as follows:—

<table>
<thead>
<tr>
<th>Upper Purbeckian</th>
<th>Wealden 2 and 3 of Wolburg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle Purbeckian</td>
<td>Süsswasserkalke of Hils basin (about 70 m.)</td>
</tr>
<tr>
<td></td>
<td>Serpulite (in many facies, with conglomerates)</td>
</tr>
<tr>
<td>Lower Purbeckian</td>
<td>Münder Mergel, upper and middle parts (altogether 150 m. at Münder, and up to 400 m. in other places, where the marls contain salt)</td>
</tr>
</tbody>
</table>

The most remarkable formation of this series is the Serpulite. It consists in some places of a mass of Serpula coacervata, in others of a lumachelle of oysters and other small pelecypods, in others of oolitic shelly limestone passing into marls or 'plattenkalk' or even sandstone. In many places it becomes conglomeratic, consisting of Upper Jurassic limestone pebbles, to which in places are added pebbles of Keuper and Muschelkalk and even occasionally of dark Palaeozoic rocks (Raecke, 1932, pp. 621-8). The Serpulite is transgressive on to Kimeridgian, Oxfordian and Triassic rocks. In borings in the German-Dutch frontier region it transgresses over the 'Cimbrian' land and the Serpula banks and other facies are aligned with the old coast (Schott, 1951). Figures and descriptions of the Purbeckian fossils will be found chiefly in Koch & Dunker (1837), Dunker (1846), Struckmann (1878, 1879, 1892) and Koert (1898); some of the gastropods have been revised by Arkell (1941) and the ostracods by Martin (1940).

PORTLANDIAN AND UPPER KIMERIDGIAN?

As stated above, the Münder Marls are 150 m. thick at Münder, near the Deister, but elsewhere expand to some 400 m. Most of this is Lower Purbeckian, but according to the ostracods the lower part is Portlandian. Where the thickness is greatest, deposits of salt and gypsum occur (reminiscent of the Lower Purbeck of Dorset). The lower part is locally red in colour and passes down imperceptibly into Einbeckhausen Plattenkalk (maximum about 100 m., in the Hils basin). This formation consists everywhere of dark grey, compact, ringing flagstones, interbedded with marls and grey marlstones. There are also occasional beds of oolite,
conglomerate and dolomitic limestone or dolomitic sandstone. Outside the Hils basin the thickness is much less, and in the Teutoburger Wald and near the Dutch frontier the formation is absent.

The fauna of the Einbeckhausen Plattenkalk consists of a few species of small pelecypods and gastropods of no dating value, and some fish and plant remains. They indicate a marine or brackish environment, but the freshwater *Valvata helicoides* is also recorded (Koert, 1898, p. 13).

![Figure 16](http://jurassic.ru/)

**Fig. 16.—Map of the principal Jurassic outcrops in Lower Saxony.**

(Einbeckhausen is a small place south-west of Hanover, in the Deister-Süntel area; not to be confused with Einbeck in the Leine valley near Northeim.)

**Middle Kimeridgian (up to 100 m.)**

Gigasschichten, or ‘Portlandkalk’ (average 60-80 m. in the Hils basin, rising locally to 90-100 m., but elsewhere much thinner). A series of limestones and marls, with conglomerates of rolled Jurassic limestones at the base and locally at higher levels. At Völksen on the Deister it consists of a single bed of coarse conglomerate up to 3 m. thick (plate 86), resting disconformably on basal Kimeridgian limestone and on Upper Oxfordian
coralline oolite (Schöndorf, 1914a). The formation marks an important transgression following the Deister phase of movements, which produced extensive alterations in the geography and the direction of transport of material (Raecke, 1932, p. 638). In the region of the Dutch frontier the formation is still more strongly conglomeratic, with conglomerates at top and bottom and sometimes in the middle, and containing pebbles of Bunter Sandstone, and borings have proved that it rests disconformably on Lower Callovian and on various parts of the Lias (Schott, 1951, pp. 218-20).

As the name implies, the Gigas Beds yield various species of the tumid, involute, giant ammonites of the genus *Gravesia*. Until the brilliant work of Salfeld (1914) they were mistaken for Portlandian *Titanites*. A number were figured by Struckmann (1887), and two of Struckmann’s figures were misidentified with Valanginian *Polyptychites* by Pavlow*.

Salfeld (1914, p. 154) recognized two horizons, as follows:—

Above, Zone of *Gravesia irius* (d’Orb.), with *G. gigas* (Zieten), which by priority should be called the zone of *G. gigas*

Below, Zone of *Gravesia gravesiana* (d’Orb.)

The genus requires monographic revision, for Salfeld doubted most of Struckmann’s identifications, and *G. gigas* (Zieten), from South Germany, has been considered by several authors to be an *Aspidoceras* of the group of *A. uhlandi* (Oppel). The only other ammonite figured from the formation, *Perisphinctes giganteus* Sow. of Brauns (1874, pl. i, figs. 4-6), cannot be interpreted from the crude drawings; and Salfeld (1914, p. 157) doubted its provenance.

**LOWER KIMEROIDIAN** (usually 30-80 m., locally to 250 m.)

Marls and clays with occasional hard bands, customarily divided into ‘Lower, Middle and Upper Kimeridge’. These are highly fossiliferous and have been subdivided into a number of beds distinguished by species of gastropods, pelecypods, brachiopods and echinoderms (Credner, 1863, 1864; Struckmann, 1878; Brauns, 1874; Schöndorf, 1909; etc.). *Exogyra virgula* is common in the upper part but also occurs in the middle and in the Gigas Beds. Ammonites have been found only in the middle part; they are *Aspidoceras longispinum* (Sow.) auct., *A. iphicerum* (Oppel), *A. caletanum* (Oppel), *A. acanthicum* (Oppel), *Aulacostephanus yo* (d’Orb.), *Aulacostephanus pseudomutabilis* (de Loriol) and *A. cf. eudoxus* (d’Orb.) (Löwe, 1913, p. 197). Salfeld (1914, pp. 145-151) proposed for this faunule a distinct zone of *A. yo*, but it has not proved to be recognizable elsewhere and there seems insufficient reason for separating it from the Pseudomutabilis Zone. For detailed profiles in the Brunswick area see Schott (1932). A greater variety of Lower Kimeridgian ammonites is known from Hohnstein near Dresden (Bruder, 1885).

* 1892, Argiles de Speeton, pp. 124, 127 of reprint: lectotype of *P. gravesiformis* pl. xiii, figs. 7, 8; lectotype of *P. lampluguhi*, pl. xiv, fig. 1, now designated.

http://jurassic.ru/
The Upper Oxfordian is developed as Coralline Oolite (20-100 m.) above, and Heersum Beds (5-15 m.) below. The top part of the Coralline Oolite is more marly and dolomitic and abounds in 'Terebratula' humeralis, and should be separated. The Humeralis Beds have yielded Rung­steadiae (Salfeld, 1914, p. 142), which correlates them with the Pseudo­cordata Zone. The upper true Coralline Oolite has not produced ammonites and may be equivalent to the Sandsfoot Clay. The middle Coralline Oolite contains Perisphinctes cautisnigrae Arkell (1937, p. 57, pl. xiii) and therefore correlates with the Dorset Trigonia clavellata Beds. The lower Coralline Oolite and the Heersum Beds contain the Perisphinctid fauna of the Plicatilis Zone.

The Heersum Beds bear a strong resemblance, lithologically and palaeontologically, to the Highworth Limestones of central England. The ammonites have been revised and figured by Arkell (1935-48, pp. 57-9, 390-3, etc.) and in an excellent memoir by Siegfried (1952). The Perisphinctids of both Upper and Lower Heersum Beds are typical of the Plicatilis Zone. They include such common English species as P. cotovui Sim. and P. maximus (Y. & B.).

In the Lower Heersum Beds, however, Cardioceratids are much more numerous than Perisphinctids, and Salfeld consequently made for them a separate zone of Cardioceras tenuicostatum. For the most part the Cardioceratids of the Lower Heersum Beds are similar to those in the Arngrove Stone and Berkshire Oolite Series about Oxford, namely the Plicatilis Zone, and are therefore early-Upper Oxfordian. Siegfried believes that C. cordatum (Sow.) also occurs, but the specimens he figures, with their prominent, tuberculate secondary ribbing and absence of any tendency to form a large, smooth, body­ chamber, are in my opinion C. (Subvertebriceras) zenaidae and C. (S.) densiplicatum (Boden?) (as interpreted by Spath and Arkell); and his C. costellatum is at least in part the later C. costulosum (Buck.).

Nevertheless there seem to be a few earlier elements in this fauna even in the Hildesheim-Heersum district, showing that the topmost part of the Cordatum Zone is present in condensed or derived form. Such elements are rare but seem to be represented by Cardioceras roemerii Siegfried, which appears to be a Scarburgiceras, and by two specimens of Goliathiceras more like species of the Cordatum Zone than those of the Plicatilis Zone.

In the Weser-Wiehengebirge there is a more definite and separate representation of the Cordatum Zone at the base of the Heersum Beds. The beds here contain bands of black limestone, from some of which come perfectly-preserved common English ammonites of the Plicatilis Zone, such as Perisphinctes pickeringius (Y. & B.). Not far away, however, * It is inexplicable how Siegfried (p. 302) failed to separate these two quite distinct species. Moreover, he overlooked P. kranaus and P. apolipon, both figured from the Heersum Beds (Arkell, 1935-48, pl. xxxviii, fig. 2, pl. xxxv, figs. 4, 5); and his P. martelli is nothing like either Salfeld’s or Oppel’s (which are two distinct species).
at Porta Westfalica, a similar black band at the base of the Heersum Beds yields species of *Euaspidoceras* and giant Peltoceratids, belonging to the Cordatum Zone of Scarborough (von See, 1910, pp. 656-60; Arkell, 1935-48, p. 201). Giant Peltoceratids also occur at Hohnstein near Dresden (Bruder, 1885). The succession may be correlated thus:

<table>
<thead>
<tr>
<th>Zone</th>
<th>Beds/Assemblage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudocordata Zone</td>
<td>Humeralis Beds</td>
</tr>
<tr>
<td>(undated)</td>
<td>Upper Korallenoolith</td>
</tr>
<tr>
<td>Cautisnigrae Zone</td>
<td>Middle Korallenoolith</td>
</tr>
<tr>
<td>Plicatilis Zone</td>
<td>(Lower Korallenoolith</td>
</tr>
<tr>
<td>Cordatum Zone (top sub-)</td>
<td>Heersum Beds of the Hildesheim district</td>
</tr>
<tr>
<td></td>
<td>Black limestone at base of Heersum Beds, Porta Westfalica</td>
</tr>
</tbody>
</table>

**CALLOVIAN (15-100 m.)**

The Upper and Middle Callovian are everywhere in Oxford Clay facies: the Ornatenton (up to 100 m.). From it are recorded the usual ammonites indicative of Lamberti, Athleta, Coronatum and Jason Zones; and *Erymnoceras schloenbachii* Roman comes from the area (type Schloenbach's 1865, pl. xxxi, fig. 1). Sequences of ammonites in these zones are given by Löwe (1913) and Kumm (1940, pp. 16, 17).

The Lower Callovian is more varied lithologically. The best sequence is at and near Porta Westfalica (von See, 1910). Under the Ornatenton is about 1 m. of ironstone, of which the upper layer contains abundant *Catasigaloceras planicercus* Buckman and therefore correlates with South Cave, Yorkshire (p. 26). The lower layer, which is an ironshot oolite, contains numerous *Macrocephalites, Pleurocephalites, Kemptokephalites, Kepplerites and Proplanulites*, and thus correlates with the southern English Kellaways Beds (lower Callovienne and Koenigi Zones). Underneath is the Porta Sandstone (c. 12 m.), in which *Macrocephalites* and *Choffatia* occur (Macrocephalus Zone).

For many local particulars of the Callovian see Kumm (1952, pp. 467-87). At Lechstedt, near Hildesheim, old lists of ammonites supposed to be from the Macrocephalenschichten (e.g. Brauns, 1869, p. 72) include some from the Upper Bathonian clays.

**UPPER BATHONIAN (about 35-40 m.)**

The best Upper Bathonian fauna in Germany, and perhaps in Europe, occurs in 22 m. of clays underlying the Macrocephalus Zone at Lechstedt brickyard, Hildesheim (Behrendsen, 1886; J. Roemer, 1911; Kumm, 1952, p. 466). It consists predominantly of Oppeliids and Perisphinctids. The Oppeliids include *Oxycerites* and *Prohecticoceras* (in part revised, and lectotypes designated, in Arkell, 1951-2, pp. 72-3), also *Oecotraustes*; and the Perisphinctids belong mainly to *Siemiradzkia* and *Pseudoperisphinctes* (lectotype of type species, Roemer's pl. viii, fig. 2), with *Choffatia acuticosta* (Roemer). In addition there are *Bullatimorphites quenstedti* (Roemer), *B. suevicum* (Roemer) and *B. hannoveranus* (Roemer) (= *bullatus* d'Orbigny?) (see Arkell, 1954, p. 108). That these beds are Upper Bathonian was confirmed by deepening of the pit in 1946-8, when
Clydoniceras discus (Sow.) and Bullatimorphites bullatus (d'Orb.) were found at the bottom (Kumm, 1952, p. 466).

The so-called Cornbrash is a limestone or sandy limestone facies, in places including oolites, and reaching over 50 m. in thickness, which can seldom be dated accurately but represents the whole (or in places parts) of the Bathonian. In some exposures Clydoniceras discus and Oppelia cf. aspidoides are recorded from it (Kumm, 1952, p. 465) indicating Upper Bathonian; in others Parkinsonia württembergica and many other fossils of the Lower Bathonian. It also contains the only (slender) evidence of Middle Bathonian in NW. Germany, namely records of 'Cadoceras sublaeve' (Schott, 1932, p. 8), which in the Bathonian in other parts of Europe have proved to be Tulites spp.

LOWER BATHONIAN (30 m.)

The Württembergicus Beds, clays and shales with nodules, up to 30 m. thick, are celebrated for fossils at Bielefeld clay-pits and formerly in a railway-cutting at Eimen, near Hanover; also called Walkererde (Fuller's Earth) and Ostrea knorri Beds (von Seebach, 1864, p. 39; Schloenbach, 1865; Steinmann, 1880; Wetzel, 1909, 1911, 1924, 1950; Kumm, 1952). The principal ammonites are Parkinsonia (Oraniceras) württembergica (Oppel) (for which the preoccupied and invalid name compressus Quenst. has been revived lately) and its compressed, involute allies, for which new names have been introduced by Wetzel, 1950. Other important forms are Parkinsonia (Gonolikites) postera (Seebach), P. (G.) convergens Buckman (Schloenbach, 1865, pl. xxviii, fig. 3), P. (G.) fretensis Wetzel, P. (P.) eimensis Wermbter sp., 1891 (type Schloenbach, 1865, pl. xxix, fig. 1), Procerites schloenbachi de Grossouvre (type Schloenbach, 1865, pl. xxx, fig. 1), Morphoceras sp. (Schloenbach, pl. xxix, fig. 5), Ebrayiceras sulcatum Zieten sp. (Schloenbach, pl. xxviii, fig. 5), Lissoceras psilodiscus (Schloenbach), L. inflatum Wetzel, and a number of species of Oppelia and Oxycerites (Schloenbach, 1865, pl. xxx; Wetzel, 1950, pl. ix, with many new names). The conclusion of Wetzel (1924, pp. 159, 163) that these beds represent the Zigzag Zone has been confirmed by the finding of Parkinsonia württembergica and its allies in the Zigzag Zone in Lorraine, Sicily, and North Africa.

UPPER BAJOClAN (up to 100 m.)

In famous exposures at Bielefeld the Upper Bajocian is entirely developed as clays and shales with layers of nodules. Owing to the numerous ammonites and unusual thickness this is perhaps the most important sequence of its age in the world (Wetzel, 1909, 1911, 1924, 1953; Althoff, 1928; Bentz, 1924, 1928; Kumm, 1952). The following is a summary of the sequence:

Zone of Parkinsonia parkinsoni. Upper Parkinsonia Bed (Wetzel, 1911, p. 144) (Middle Parkinsonia Beds of Kumm, 1952, p. 430), with P. parkinsoni Sow. sp. (syn. P. pseudoparkinsoni Wetzel), P. arieties Wetzel
P. neuffensis (Oppel), P. planulata (Quenst.), Strigoceras truellei (d'Orb.), Oppelia subradiata (Sow.), etc.

Parkinsoni-garantiana passage beds. Lower Parkinsonia Beds = Upper Garantiana Beds, with Parkinsonia rarecostata (Buckman, 1881: syns. P. orbignyana Wetzel, P. subarietis Wetzel, P. arietis Wetzel, Garantiana (Odontolkites, syn. Subgarantiana) subgaranti Wetzel, G. (O.) depressa Wetzel, etc., etc.

Zone of Garantiana garantiana. Bigotites Beds, with G. garantiana (d'Orb.), G. (O.) tetragona Wetzel and many Bigotites, Prorsisphinctes, etc.

Garantiana-subfurcatum passage beds. Pseudogarantiana Beds, with G. garantiana (d'Orb.) and Strenoceras subfurcatum (Schloth.), G (Pseudogarantiana) dichotoma Bentz, Spiroceras bifurcati (Quenst.), etc.

Zone of Strenoceras subfurcatum. Middle and Lower Strenoceras Beds, with S. subfurcatum (Schloth.) and other spp., Garantiana baculata (Quenst.), G. (Orthogarantiana) Schroederi Bentz, Spiroceras bifurcati (Quenst.), Sphaeroceras brongniarti (Sow.), Parkinsonia rota Bentz, P. inferior Bentz, etc. At the base a bed (1-1.5 m.) with small Leptosphinctes? ('Praebigotites' Wetzel, 1936).

As usual in an expanded and exceptionally complete sequence, there are transitions between the zones, with numerous overlapping species (cf. the Callovian of Cutch, p. 390). In NW. Germany the Bielefeld development is not found everywhere. At Harzburg (Benz, 1924) most of the sequence is condensed and takes on the facies of brown ironshot oolite, of the usual insignificant thickness. Signs of erosion and derived, Serpula-encrusted specimens of Teloceras in the Subfurcatum Beds suggest that something (Ermoceras beds?) may be missing at the base of the Subfurcatum Zone even in NW. Germany.

MIDDLE BAJOCIAN (up to 70 or 80 m.)

The representatives of the Middle Bajocian (as understood in this book) are usually grouped together as the Coronaten-Schichten and the Sowerbyi-Schichten. The former are commonly condensed and highly fossiliferous, though at Gerzen they expand to 60 m., mainly clays. The latter consist of pyritic clays with layers of nodules, usually less than 20 m. thick. As in the Upper Bajocian there is much overlap of genera and perhaps species between the zones and local subzones, and until the systematics and nomenclature of the numerous Stephanoceratidae and Sonniniidae have been revised, the important succession cannot be fully appreciated. The sequence worked out chiefly by Mascke (1907), Hiltermann (1939) and Kumm (1952) seems to range itself in the classical zones as follows (see also Westermann, 1954).

Zone of Stephanoceras humphriesianum. At the top is a subzone of Teloceras blagdeni (Sow.), with T. sparsinodum (Quenst.), T. multinodum (Quenst.), T. banksi (Sow.), Stephanoceras cf. pyritosum (Quenst.), Dorsetensia complanata (Buck.), D. subecta (Buck.), D. furticarinata (Quenst.); but from this (Kumm, 1952, p. 388) are also recorded anomalous
names such as *Strigoceras truelei* (d'Orb.), *Strenoceras latidorsatum* Bentz, etc.

In the middle are said to be two subzones characterized by *Stephanoceras humphriesianum* (Sow.) (above) and *S. umbilicum* (Quenst.) (below). Both contain numerous species of *Stephanoceras* and *Dorsetensia*, also *Normannites* and its subgenera, *Chondroceras*, etc., and the lower subzone also yields *Stemmatoceras* and *Skirroceras*.

At the base is a subzone characterized by *Stemmatoceras subcoronatum* (Oppel), *S. 'coronatum'* (Schlotheim non Brug.), but also with various *Normannites* and its subgenera, and *Sphaeroceras bronniarti, Chondroceras gereillii*, etc.

Zone of *Otoites sauzei*. This is likewise divided into two subzones (Kumm, 1952, p. 383) unlikely to have wider significance: the upper is characterized by *O. sauzei* (d'Orb.), the lower by *Emileia grandis* (Quenst.), but both contain a long list of *Otoites, Stephanoceras, Stemmatoceras*, etc., though *Emileia, Frogdenites* and *Labyrinthoceras* are confined to the lower subzone and *Chondroceras* to the upper.

Zone of *Sonninia sowerbyi*. The *Sonninia* fauna is extraordinarily rich and has been monographed by Hiltermann (1939). It also yields *Hyperlioceras discites* (Waagen) and *Fontannesia* spp., but few other ammonites.

**LOWER BAJORCIAN** (up to c. 130 m.)

Clays and shales with layers of mudstone or clay-ironstone nodules continue the sequence down to the Lias. Thicknesses vary greatly, from c. 30 m. to c. 130 m. In the Osning district the Opalinum Zone is missing or represented only in a basal conglomerate; at Bethel near Bielefeld the thickness is c. 30 m. and the Sinon Subzone (basal Scissum Zone) rests directly, with basal conglomerate, on the Dispansum Subzone of the Toarcian. Towards the east the Scissum and Murchisonae Zones develop sandstones containing oil.

The clays and nodules of Sehnde, near Hanover, contain probably the fullest and most important sequence of Lower Bajocian *Leioceras, Ludwigia* and *Graphoceras* faunas in the world. The total thickness here is about 50 m. Understanding of the sequence is unhappily bedevilled by the state of the nomenclature of these ammonites. Hoffmann (1913) and Althoff (1940), in their righteous reaction against the chaotic splitting of Buckman swung too far to the other extreme, and reverted to a trinomial nomenclature as backward as Quenstedt's, including everything in a single genus *Ludwigia*, to which they illegally subordinated even the long-prior genus *Leioceras* Hyatt. The succession established by Hoffmann (1913), and, for the basal beds by Stolley (1909), seems to fall into the standard zonal sequence as follows:—

Zone of *Graphoceras concavum*, with *G. concavum* (Sow.), *G. anguliferum* (Buck.) (type from the Discites Subzone), some Sonninids and Hammatoceratids, including *Eudmetoceras* cf. *amplectens* Buck. (Althoff, 1940, pl. vi, fig. 11).
Zone of *Ludwigia murchisonae*. *L. murchisonae* (Sow.) occurs only at the top, in the Staufensis Subzone, but the succession in the Swiss Jura and south Germany (pp. 102, 125) shows that this is only a local Teilzone and that the following horizons distinguished by Hoffmann are subzones:

- Subzone of *Staufenia staufensis* (Oppel), with *L. murchisonae*, *Brasilia bradfordensis*, etc.
- Subzone of *Costileioceras discoideum* (Hoffmann)
- Subzone of *Costileioceras sehndense* (Hoffmann)
- Subzone of *Costileioceras tolutarium* (Dumortier)

Zone of *Tmetoceras scissum*. *Tmetoceras* does not occur, but comparison with the Swiss Jura (p. 102) shows that to this zone belongs Hoffmann's subzone of *Costileioceras sinon* (Bayle).

At Bielefeld, where the whole Lower Bajocian is reduced to about 30 m., the subzones are not separable, owing probably to condensation and some penecontemporaneous erosion (Althoff, 1936, 1940; revised Kumm, 1952, pp. 372-8).

Zone of *Leioceras opalinum*. In the east this zone is more than 50 m. thick. The ammonite succession has been discussed at length by Stolley (1909), Hoffmann (1913), Kumm (1952) and others, but doubt about the identity of *L. opalinum* introduces uncertainty, and Kumm (1952, p. 346) uses as zonal index for the basal subzone a species, *Leioceras lineatum* Buck., which according to Buckman comes from the Scissum Zone and so is unsuitable as an index for the lower Opalinum Zone. *L. comptum* (Rein.) and *L. subcomptum* (Branco) also appear to have quite different dates of occurrence from those attributed to them in England by Buckman, and *L. costosum* (Quenst.), index of the upper Opalinum Zone according to Hoffmann, is a species of the Scissum Zone in England according to Buckman. These and other anomalies show that reliable subdivision of the Opalinum Zone is not yet possible and could only be established on the basis of thorough revision of the European *Leioceratinae* as a whole.

**Lias**

As already stated, the Lias and in part at least the Middle Jurassic sea of Lower Saxony was a direct continuation of that in the Swabian and Franconian Alb, and although the deposits in places (fig. 15) become very much thicker, the succession is essentially the same. Considerations of space preclude a recapitulation of the sequence by zones or even stages; more especially since up-to-date syntheses have been published by Kumm (1941*) and Hoffmann (1948*, 1949*).

For the Toarcian succession there are classic works by Denckmann (1887), Wunstorf (1905), Ernst (1923-5) and Althoff (1936), with abundant figures of the ammonites. The Doernten and Bielefeld sections are especially important for the Upper Toarcian. The zonal *Lytoceras*...
"jurense" is common and subzones have been established on the basis of numerous forms of *Grammoceras*, *Hudlestonia*, etc. The horizon of *Hudlestonia affinis* (Seebach) is said to be at the extreme top, between the Aalensis and Opalinum subzones (Denckmann, 1897). In places some of the subzones are missing (Kumm, 1940).

For the Upper Pliensbachian, Kumm (1940) has shown that the Amaltheid sequence worked out in SW. Germany can be recognized in the northern foreland of the Harz; and since the general works of Schloenbach (1863) and Brauns (1871) important refinements have been made in the Lower Pliensbachian by Hoffmann (1950). (These have already been referred to, p. 128.)

For the Sinemurian and Hettangian there is a more extensive literature, among which should be consulted especially: Emerson (1870), Monke (1889), Hoyer (1902), Schmidt (1914), Jüngst (1928), Fiege (1929) and Lange (1922, 1924, 1925, 1941, 1951).
CHAPTER 6

THE ALPS AND NORTHERN CARPATHIANS

PROVENCE, THE MARITIME ALPS AND SUBALPINE RANGES

Between Toulon and Cannes the coast cuts across the crystalline horst of Maures and Esterel, a protrusion of the ancient basement of the Alpine foreland comparable to the Massif Central, Vosges, and Black Forest, but partly mantled in Permian and Triassic sediments. On the north side the horst is bordered by a band of Jurassic outcrops which are also cut by the coast between Marseilles and Toulon and again between Cannes and Nice. The Jurassic sequence is epicontinental, neritic, with coralline Tithonian. The structure has been intensely complicated by folding, thrusting and décollement at a Triassic saline marl series, as in the Jura (Goguel, 1943; Bailey, 1953). Northwards the Jurassic passes into deeper-water facies, but is soon hidden by Cretaceous and Tertiary cover under the basin of the Durance. The deformations to which the sedimentary mantle has been subjected in this area have been portrayed in a vivid and original manner by Goguel (1943).

Farther north-east along the Riviera the sea-coast intersects the outer folds of the Alps between Nice and San Remo. They sweep inland as a great belt of arcs and turbulent interlacing ruckles, forming the Alpes Maritimes, Basses Alpes, Alpes du Dauphiné and Chaînes Subalpines. At their widest they reach nearly to the Rhône valley opposite Crussol, then they narrow north-eastwards near Grenoble. The Jurassic stratigraphy of the part near Grenoble and Chambéry has already been described with the Jura Mountains, which there originate as a virgation of the Subalpine ranges (Fig. p. 69).

From east to west in a broad band the Jurassic sediments are fine-grained and free from littoral influences. In the east at least, the Lias is exceptionally thick, while in the west and centre the Tithonian is poorly fossiliferous and comprises great thicknesses of false breccia of obviously contemporaneous origin and containing no extraneous fragments. These peculiarities have usually been attributed to origin in deep water. Paquier called this band the ‘fosse vocontienne’ (after the Vocontes, an ancient tribe), a term adopted by Haug (1891; 1910, pp. 1086, 1089) who defined it as ‘a deep depression where only fine-grained sediments were deposited’, and where the Tithonian is ‘unquestionably bathyal’, as in many parts of the Mediterranean region. Bathyal is a vague term, for it is defined by the ‘Committee on a Treatise of Marine Ecology and Paleoecology’ (1951, National Research Council, Washington) as applying to depths ‘from 100-200 m. down to somewhere between 2000 and 4000 m. Our present knowledge is inadequate to justify further.

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precision’, and it is applied by the Committee to the oceanic slopes. It is difficult to be sure how Haug understood the term, but Termier & Termier define it (1952, p. 100) as between 200 or 400 m. and 1000 m. It is commonly used nowadays for the Tithonian and Neocomian limestones all over the Mediterranean area, especially where they contain the characteristic pelagic microfauna since studied—*Nannoconus, Calpionella*, Protococcid algae, etc. (e.g. Colom, 1952). This fauna is said to characterize the ‘bathyal’, ‘abyssal’ or ‘deep-sea zones of the Mediterranean geosyncline’ (Colom, 1952), but in many places there are abundant signs that the sea was shallow; the sequence shows condensation, disconformities and shallow-water ammonite faunas like those in NW. Europe (see e.g. Sicily, p. 203, and Spain, p. 244). The Mediterranean was, in fact, in no sense a geosyncline (see p. 625) and still less was the ‘fosse vocontienne’, which appears to have been an ordinary trough of deposition, not differing essentially from others in many parts of Europe, but marginal to the composite Alpine geosyncline. (See also Goguel, 1944, 1954).

The origin of the false breccias is problematic, but a likely explanation is that they are due to shaking up and resettling of fine-grained bottom muds by earthquakes. (See interesting discussion by Fuchter, 1952, pp. 10-12.)

The great thickening of the Lias (to 2000 m.?) towards the east indicates a subsiding trough parallel to but outside the main Alpine geosyncline: a fore-deep of the Alpine arc in the early stages of its development.

The triangle between Grenoble, San Remo and the mouth of the Rhone is an important area for the uppermost Jurassic and Lower Cretaceous. It was the scene of Kilian’s prolonged researches (Sisteron and the Montagne de Lure lie at the centre of the triangle) and it includes Haug’s thesis area (the country between Gap and Digne) and the type-localities of the Lower Cretaceous stages Apt, Barrême, and Orgon (Urgonien). The amount of stratigraphical information available is enormous and all that can be attempted here is a synthesis of the ammonite faunas present in the area as a whole, with brief remarks on their significance. From south to north the most important regional works are: for Provence, Lanquine (1929-35); Alpes Maritimes, Kilian & Guébhard (1905); Basses Alpes, Haug (1891); Sisteron and Montagne de Lure, Kilian (1888-9, 1895); Mont Ventoux, Leenhardt (1883); Baronnies and Diois, Paquier (1900-01); Gigondas group, Fuchter (1952); northern Dauphine, Gignoux & Moret (1944). There is also a good summary in Gignoux, 1950 (pp. 387-92).

[BERRIASIAN

In the central region, marls, marly limestones and limestones are rich in ammonites of the Boissieri Zone (see especially Kilian, 1910; Mazenot, 1939). Towards the south ammonites become scarcer and it is difficult to separate the Berriasian from the Tithonian, but in the Alpes

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Maritimes there is typical bastard marble with *Natica leviathon*, as in the northern Dauphiné and Jura.]

**PURBECKIAN?**

Near the Riviera coast (Alpes Maritimes), the bastard marble with *Natica leviathon* is underlain by thick Tithonian limestones, at the top of which are beds of green and black marl and nodule beds containing multicoloured pebbles, small gastropods, and *Chara*, all closely resembling the Purbeckian of the Jura (Gignoux & Moret, 1937). Doubt has been cast on the chronological value of these beds, however (in the absence of more supporting evidence) by the discovery of marls with *Chara* and pebbles in the Middle Berriasian of the Chambéry area (see p. 87).

**TITHONIAN**

The Tithonian consists of dolomites and white limestones, hundreds of metres thick in the south. They build the white Riviera sea-cliffs between Nice and Mentone, and inland form karstic plateaux cut with canyons as much as 400 m. deep, or in the folded country rise in mural escarpments and crests almost bare of vegetation. In this southern facies fossils are rare and ammonites seldom obtainable. Kilian & Guébhard (1905, p. 817) give a long list of mollusca, echinoids, corals, etc., but only one ammonite, 'Perisphinctes (indet.)'; but subsequently Upper Tithonian ammonites have been recorded from the hinterland of Cannes and Nice: *Berriasella lorioli* '(Zit.), B. cf. calisto (d’Orb.), B. carpathica (Zit.)* (Lanquine, 1935, pp. 104-5). Unfortunately the levels of these rare finds relative to the 'Purbeck Beds' of the same area remain to be determined.

In the central and northern areas thicknesses are much less and the cephalopod facies comes in. The Upper Tithonian with a rich ammonite fauna as at Aizy near Grenoble is exposed at Claps de Luc in the valley of the Drôme near Die, and near Sisteron, and the list includes *Berriasella lorioli* and *B. richteri*, the two species which led Kilian to the conviction that this horizon 'is certainly equivalent to the Purbeckian of the Jura' (Kilian, 1895, pp. 676-9). Beneath comes Kilian’s Lower Tithonian, thick false-breccias and crystalline limestones with Perisphinctids (*contiguus, geron, pseudocolubrinus*, etc.) and *Pygope janitor* ('janitor' in reference to its occurrence at the 'Porte de France' at Grenoble).

**MIDDLE AND LOWER KIMERIDGIAN**

Haug (1891, p. 103) and Kilian followed Neumayr and classed the Beckeri Zone as Kimeridgian, not Tithonian, but did not distinguish it from the Pseudomutabilis Zone. As in other regions of the Mediterranean, however, distinction in the field is difficult, owing to the similar hard limestone facies, and Lanquine (1935, p. 110) lists *Hybotoniceras beckeri* among the few Tithonian ammonites, while Kilian & Guébhard (1905, p. 805) gave a mixed list from the 'Upper Kimeridgian and base of the Portlandian', and included an *Aulacostephanus* in their
Lower Kimeridgian list. Lanquine (1935, pp. 80, 86) lists and figures a representative fauna of the Lower Kimeridgian including the usual *Sowerbyceras loryi*, *Idoceras balderum*, *Katroliceras crussoliense*, *K. acrum*, typical *Ataxioceras* spp. (Lanquine, pl. xix, fig. 1, pl. xvii, fig. 1), *Lithacoceras* (pl. xvii, 3), numerous *Aspidoceras* and *Nebrodites* spp. (pl. xvii, 2; and Kilian & Guébhard, pl. L), *Haploceras subelimatum* Font., *Glochiceras fialar* (Oppel), *Streblites* spp., *Taramelliceras* spp.

**UPPER OXFORDIAN**

The Bimammatum Zone is in similar limestone facies but although already recognized by Haug (1891, p. 102) and indubitably represented, by *E. bimammatum*, *Gregoryceras cf. fouquei* (Kil.) and other records, it was not separated by subsequent authors: Kilian & Guébhard include it in their Lower Kimeridgian list and Lanquine in his list from the Transversarium Zone.

The Tranversarium Zone of Provence and the Alpes Maritimes is particularly rich in ammonites and from the long lists given by Kilian & Guébhard (1905, pp. 778-80) and Lanquine (1935, pp. 38-54) it evidently reproduces the fauna of Trept (see p. 95). (Some are figured by Lanquine: pls. xiii-xvi; pl. xiii, 2, is nothing like *P. plicatilis* and may be *P. falculae* Ronchadzé.)

**LOWER OXFORDIAN**

Haug (1891, p. 101) assigned to the ‘Zone of *Aspidoceras perarmatum*’ marls and limestones stated to contain little but *Sowerbyceras tortisulcatum*, but occasionally also *Cardioceras cordatum*, *Quenstedtoceras mariae*, various Peltoceratids, etc. Kilian & Guébhard’s list (1905, p. 778) comprises a mixture of Lower Oxfordian forms with others proper to the Transversarium Zone and the Athleta Zone (including both zonal indices), but from Lanquine’s annotated list (1929, p. 369) it is evident that the Lower Oxfordian is well represented.

**CALLOVIAN**

The same sources indicate a rich and apparently complete representation of the Callovian, though everything remains to be done to sort out the succession, and from the inclusion of *Quenstedtoceras lamberti* in Lanquine’s list for the Oxfordian it appears that, as in the Jura and elsewhere, there is a continuous passage up from marls of the Athleta and Lamberti Zones to similar marls of the Mariae Zone.

**BATHONIAN**

The Bathonian is very fully developed, up to 200 m. thick, and rich in ammonites, and this may be one of the most important areas in the world for establishing the zonal succession. To the extra-Alpine fauna is added a wealth of Phylloceratids (at least 9 species). In the country between Gap, Digne and Castellane are up to 150 m. of black *Posidonia*...
shales, poor in ammonites (Haug, 1891, p. 82), resting on richly fossiliferous marly limestones which are at latest Lower Bathonian in the north but rise progressively southwards until they include a horizon with *Wagnericeras wagneri* and *Bullatimorphites* which, if correctly identified, indicate the Aspidioides Zone (early Upper Bathonian); in other words, the *Posidonia* shales thicken northwards, away from the Esterel massif and towards the Alpine geosyncline, and engulf progressively earlier zones (Guillaume, 1938). Similar lateral changes of facies occur in the Dept. of Var (Parent, 1938).

An Upper Bathonian fauna with *Clydoniceras discus*, *Choffatia subbakeriae*, *Siemiradzkia aurigera*, *Spiroceras* sp., *Epistrenoceras subcontrarium* (Behr.) (see R. Douville, 1915, ‘Etudes sur les Cosmoceratidae’, pl. vii, figs. 10-25) and some 50 species of other mollusca, brachiopods, etc., is developed in marl layers among sands and sandy limestones in Provence (Dept. of Var), where the Bathonian is about 150 m. thick (Parent, 1935, 1940; see also Parent, 1933, 1940a).

The existence of other Upper and Middle Bathonian faunas in Provence is indicated by Lanquine (1929, pp. 315-22) who records *Prohecticoceras retrocostatum* (de Gross.), *P. haugi* (Popovici), *Schwandorfia lanquinei* Arkell (Lanquine, p. 316, pl. xi, fig. 5); and ‘*Pachyceras*’ sp. recorded by Haug (1891, p. 80) probably refers to a *Morrisiceras* or *Lycetticeras* as in other parts of Europe.

The Lower Bathonian is strongly represented with a long list of characteristic ammonites of the Zigzag Zone perhaps unequalled anywhere in the world; for it combines the extra-Alpine fauna with masses of Phylloceratids and also *Lytoceras adeloides* Kud. and *Nannolytoceras tripartitum* (Rasp.), as in Algeria and Sicily, but seems to be easier for the collector. Besides the usual *Zigzagiceras*, *Procerites*, *Morphoceras*, *Ebrayiceras*, *Parkinsonia*, *Oecotraustes*, *Oxycerites*, *Cadomites*, etc., there are some particularly interesting items, such as a form recorded by both Haug (1891, p. 79) and Parent (1938) as *Strigoceras cf. truellei* (d’Orb.), also *Bullatimorphites* (?ymir Oppel?) a genus usually not found before the Middle or Upper Bathonian, and *Garantiana bathonica* Lissajous. (Haug, 1891, p. 79; Lanquine, 1929, p. 315; Parent, 1938).

**Bajocian**

About Digne the Bajocian is at least 200 m. thick and consists mainly of compact or marly limestones with marly or shaly partings, poor in fossils excepting cephalopods, *Posidonia*, *Inoceramus* and *Cancelllophycus*, which abound at certain levels. There is an imperceptible passage upwards into the Bathonian and downwards into the Toarcian, the Opalinum Zone being developed as black clays indistinguishable from the Lias. In the Alpes Maritimes the Bajocian is represented mainly by dolomites, cherty limestones and oolites, with a varied fauna of pelecypods, gastropods, brachiopods, echinoids and corals, but no ammonites. In Provence the facies is also neritic but more variable and the mixed fauna of

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cephalopods and other organisms normal for extra-Alpine Europe is represented in strength, with many ammonites.

The Upper Bajocian is up to 40 or 50 m. thick and contains representatives of the Subfurcatum, Garantiana and Parkinsoni Zones, though these zones have not been distinguished. (See annotated lists by Haug, 1891, pp. 73-7; and Lanquine, 1929, pp. 304-10, the latter including all Middle Bajocian above the Sowerbyi Zone). The abundance of ferruginous Strenoceras, Garantiana, Spiroceras, etc. in grey marls and marlstones, often crowded with Posidonia (Haug, 1891, in the Digne area especially), is repeated in Algeria (see p. 278). There are at least six species of Phylloceras, also Lytoceras and Lissoceras.

The Middle Bajocian promises to be of special importance for future stratigraphical analysis. Haug unjustifiably sought to suppress Oppel’s Sowerbyi and Humphriesianum Zones and while recording S. humphriesianum and its allies in the Sauzei Zone, introduced a new zone of Dorsetensia romani for the beds between the Sauzei and Subfurcatum Zones, consisting in his area of marls with small ferruginous ammonites, similar to the Upper Bajocian. He claimed that the ammonites in these beds were common partly to the Sauzei and less to the Subfurcatum Zones and to a small extent peculiar. From his lists (1891, pp. 70-2) it appears that his Romani Zone is synonymous with at least the greater part (possibly excluding the base) of Oppel’s Humphriesianum Zone. He stated that the upper part is characterized by a special abundance of Teloceras blagdeni and a Normannites identified by him with braikenridgei Sow. of the Sauzei Zone.

From Haug’s lists from the Sauzei Zone (1891, pp. 67-9) it appears that he was unable in the field to separate that zone from the upper part of the Sowerbyi Zone and the lower part of the Humphriesianum Zone; but careful stratigraphical collecting and modern critical determination of the ammonites alone can solve these problems.

The Sowerbyi Zone, not recognized by Haug, is particularly well developed in Provence, in the Toulon area (H. Douvillé, 1885; Lanquine, 1929, pp. 292-9). Though thin, the zone yields a long suite of Sonninia, Witchellia, Zurcheria, Emileia, Bradfordia, etc. Lanquine’s list, however, contains many ammonites, such as Otoites sauzei, which belong to the Sauzei Zone according to evidence from England, Germany, and other parts of France; revision by an ammonite specialist is needed. However, an undoubted Otoites is figured (pl. ix, 6) from the Witchellia beds.

The Lower Bajocian is equally complete. Haug (1891) already distinguished the Opalinum, Murchisonae and Concavum Zones, and Tmetoceras scissum also occurs (Lanquine, 1929, p. 194).

TOARCIAN AND PLEISIOBACHIAN

These stages likewise have fully representative faunas of all the principal zones (Haug, 1891, pp. 33-57; Lanquine, 1929, pp. 89-210). Especially striking is the wealth of Dumortieria, Catulloceras, Grammoceras, Pleydellia
and *Hammatoceras* of the Upper Toarcian, also rich faunas of *Haugia, Phymatoceras* ('Lillia'), etc. (Lanquine, 1929, pl. vi), and the Upper Pliensbachian Hildoceratid fauna with many Italian and Central European *Arieticeras, Protagrammoceras, Fuciniceras*, etc. (Lanquine, pls. iii-v), as well as *Amaltheus* and *Pleuroceras*. Detailed stratigraphical collecting here, such as has been carried out in Portugal (see p. 241), would probably yield results at least as important. Lower Pliensbachian faunas are much less in evidence, but records indicate the probable presence of all the zones.

**SINEMURIAN AND HETTANGIAN**

These stages are together more than 140 m. thick in the Digne district and appear to contain all the major zones (Haug, 1891, pp. 29-32; Garnier, 1872, pp. 627-33). They consist mainly of limestones, with false breccias in the upper part and beds with *Psiloceras* at the base, resting on Rhaetian. In Provence ammonites are scarce; all those recorded seem to be Sinemurian; below the Lias is Rhaetian with *Pteria contorta*.

**WESTERN AND CENTRAL HIGH ALPS, HIGH LIMESTONE ALPS AND PREALPS**

In this section are included the tectonic elements known as the Helvetids and Pennids, which build the main arc of the French, Italian and Swiss Alps from the Riviera coast to the Rhine at the Rhaeticon, and also the Prealps on either side of the Lake of Geneva, with the klippes near Lake Lucerne. The mighty unit so defined contains the most complicated Jurassic geology in the world. Adequate treatment of the Alps would require space at least equal to the whole of this book, and it could be attempted only by one schooled in Alpine geology. Even a condensed exposition of the structure according to the various (often conflicting) theories would alone occupy a long chapter, and it has already been the subject of many books: the best are those by Heim (1921-2), Kober (1923), Staub (1924), Collet (1927), Bailey (1935), Kraus (1951), Cadisch (1953) and Gignoux (1950, pp. 308-40, 387-405).

Although Gignoux (1950, p. 402) has stated that it is only by such a mental process as unravelling the nappes and restoring them to their original positions, so that the various facies produce a coherent palaeogeographical structure, that geology qualifies to be called a science, nothing so exhaustive can be attempted here. It has, indeed, already been attempted with considerable success by Gignoux himself and others, and on an ambitious scale by Kraus (1951). Our present interest being stratigraphy on a global scale, the normal procedure of the Alpine geologists will be reversed. From the formidable complex of nappes which they have unravelled or constructed will be culled the more important stratigraphical data to give a general view of the succession of faunas in the area as a whole and to date the most important intra-Jurassic movements.
From the point of view of Jurassic stratigraphy the western and central Alps, reduced to the simplest terms, may be resolved into two parallel bands: the main geosyncline occupied by the great ‘comprehensive series’ of the schistes lustrés, and the highly diversified and largely calcareous deposits accumulated on the outer or foreland edge of the geosyncline. The line dividing these two bands is vague and often uncertain, and it does not coincide with the trace of the Pennid thrust which separates the Pennids from the Helvetids on Staub’s beautiful tectonic map (1923). It is only the inner (southern and eastern) part of the Pennids that consists of schistes lustrés. The outer half comprises the Briançonnais geanticline and a smaller trough outside it (zone subbrianconnaise), in which the deposits are transitional to the Helvetids. The Briançonnais geanticline was comparable with those which now form the composite crystalline autochthonous massifs (Mercantour, Pelvoux, Belle Donne, Mt. Blanc, Aiguilles Rouges, Aar), from above and between which the Helvetid Mesozoic cover has been peeled and squeezed to form the High Limestone Alps. Moreover, the Jurassic of the Briançonnais geanticline corresponds so closely with that of the Prealps (Gignoux, 1950, pp. 400-1) that there can hardly be any doubt that the Prealp nappes rooted on or behind this geanticline just as those of the High Limestone Alps root between and behind the Mont Blanc-Aiguilles-Aar geanticlines; in other words, the Prealps did not ‘leap-frog’ over the central Alpine geosyncline, but only from an inner zone of its outer margin. Since the Prealps, themselves a giant klippe, are connected by the klippes of Lake Lucerne with the Austrid nappes beyond the Rhaeticon, this stratigraphical observation affects the interpretation of the Eastern Alps and is against the conclusions of the ‘ultranappists’. (See p. 162.)

The southern side of the Alpine geosyncline in the west is buried below the plain of the Po and begins to come in on the south side of the central Alps. It will be considered separately (p. 173).

Any palaeogeographical reconstructions have to allow for a narrowing of the Alps to somewhere around a quarter or a third of the original width of the ground on which they were formed; for measurement of the convolutions of marker horizons in the nappes and folds in all parts of the central Alps shows that on the whole there has been a shortening of between 66 and 75 per cent. In other words the width of the central Alps, now about 150 km., was originally about 630 km. (Cadisch, 1953, p. 287); and, assuming this shortening in the centre to be the maximum, the shape of the original geosyncline and its marginal furrows would have been not a strip as at present, but an ellipse almost as wide as long. Uneven lateral squashing of such a depression can account for the pattern of sweeping curves at either end of the Alps: the swinging round of the schistes lustrés through the Ligurian Alps to Corsica (see p. 218) and the inward virgations of the Apennines and Dinaric Alps.

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The Central Geosynclinal Facies: the Schistes Lustrés or Bündnerschiefer

The monotonous ‘comprehensive series’ of the central geosyncline is 2000-5000 m. thick and consists mainly of mica schists and black and grey phyllites, passing where less metamorphosed into calcareous shales and sandstones. Greenstone intrusions are common and increase southwards: their age is still undetermined, but, from their association with radiolarites, they are believed to be late Upper Jurassic or early Cretaceous (Routhier, 1944).

Despite the prevalent metamorphism, macro-fossils are found in places, especially towards the base. Most of those hitherto found have been of Lower Liassic age—belemmites, Pentacrinus, Gryphaea, Cardinia listeri, distorted Arietitid ammonites, and occasionally corals and logs of silicified wood. Higher in the sequence are Upper Jurassic and Cretaceous radiolarites; and in some places there is gradual upward passage into Eocene flysch, with, locally, nummulites occurring in rock indistinguishable from Schistes lustrés.

The lower limit of the Schistes lustrés is as inconstant stratigraphically as the upper. In some places typical Schistes lustrés begin with the Middle Trias; in other places the lowest layers contain Sinemurian fossils and rest conformably on Upper Triassic quartzite; in others the basal layers are believed to be Pliensbachian. Locally there is a basal conglomerate, and bands of conglomerate and thick breccia may occur higher up in the series. From all this it is inferred that the bottom of the geosyncline from as early as Triassic times was corrugated with rising geanticlinal ridges similar to those on the foreland margin. In the later stages of the Tertiary orogeny the Palaeozoic cores of these geanticlines burst through the Mesozoic sedimentary cover to form the Pennine nappes.

The Foreland Margin

The foreland in the west (Dauphiné and Provence) has already been discussed. For a more comprehensive and detailed structural study reference should be made to Goguel (1944). On the north of both the Swiss and Austro-Bavarian Alps the immediate foreland was the Vindelician (Alemannian) landmass—either a string of islands or an elongated projection from the Bohemian Forest—which divided the Alpine from the Swabian trough of deposition during Liassic times and probably survived at first as islands, later as a submerged swell, through the Middle and Upper Jurassic. Study of the southern margin of this barrier during Liassic times (Frank, 1930; Trümpy, 1949, 1952) has revealed an extremely rapid southerly thickening of the Lias, followed twice by gradual thinning and then repeated rapid thickening. These changes are attributed to a stepwise foundering and outward tilting of strips of the geosynclinal margin, perhaps even under tension, due to profound subsidence of the axial region to the south. Rapid transgression over the Vindelician

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landmass took place during the Toarcian and probably reached its climax with the basal Bajocian (Opalinum Zone) (Trümpy, 1949, p. 178).

The prevalence of breccias in the Alpine Jurassic and the spectacular transgressions, with wedging out of the whole Lias in short distances in Glarus and on the Aar and Aiguilles massifs, suggest rapid movements of orogenic type. Both in the central and eastern Alps, however, the movements are considered to have been essentially epeirogenic, progressive and continuous, though evidently jerky (Brinkmann & others, 1937; Trümpy, 1952). The whole Lias thins out piecemeal against the Vindelician foreland.

The most remarkable of all the evidences for geanticlinal activity during the Jurassic are contained in the Breccia Nappe of the Prealps, where almost the whole Jurassic consists of breccias, to a total thickness of 1600 m. A submarine fault scarp is indicated. Contemporaneous fossils are rare and the breccias have to be dated chiefly by reference to underlying (Rhaetian) and overlying (Albian) beds. Debris from the Prealps nappes in the Tertiaries of the foreland proves that they had reached approximately their present positions, as nappes, before the end of the Oligocene; but where they stood before the nappes began to move, when the breccias were accumulating, it is still impossible to say. The breccias are built up of a series of superimposed submarine slides, which travelled a maximum distance of 5 km. and seem to have slid off the rear of a rising geanticline in the north-west (Kuenen & Carozzi, 1953). The succession in the Breccia Nappe is so remarkable that it merits separate tabulation before considering the general succession in the Alps (Gagnebin, 1934; Schroeder, 1939).

**Succession in the Breccia Nappe, Prealps**

**Flysch**

Albian shales, a few metres thick, micaceous, with glauconitic sandstone, passing up into red beds

Upper Breccia, less coarse on the whole than the Lower Breccia; believed to be Upper Jurassic and Lower Cretaceous: 200-300 m.

Slaty shales with bands of radiolarite: supposed Oxfordian

Lower Breccia, probably representing the Lower and Middle Jurassic, thickening to the north-west, 300-1300 m.

Lower shales, early Lower Liassic, passing up into the breccia

**Rhaetian Beds, in Swabian facies**

**[Berriasian]**

Perhaps the best fauna occurs in the region between Interlaken and Glarus, south of Lake Lucerne, especially between Brunig and Urirottstock, where the Cementstone beds (marls and marly limestones) yield *Berriasella boissieri* (Pict.), *B. callistoides* (Behr.), *B. pontica* (Ret.) *Neocomites occitanicus* (Ret.), *Acanthodiscus euthymi* (Pict.), *A. curelensis* (Kil.), *Spiticeras negrei* (Math.), *S. ducalis* (Math.), and forms such as

Phylloceras calypso (d'Orb.), P. semisulcatum (d'Orb.), Hemilytoceras sutile (Oppel), Berriasella calisto (d'Orb.), which notoriously occur in both Berriasian and Tithonian (Gerber, 1930). Calpionella alpina is most abundant in the Berriasian but also occurs in the Upper Tithonian.

Upper Tithonian

In the same region (Gerber, 1930) in some places Berriasian ammonites begin below the Cementstone beds, in the uppermost layers of the underlying 'Tithonian' limestone. Immediately below, in typical nodular limestone and false breccia is an Upper Tithonian assemblage including Berriasella privasensis (Pict.), B. calisto (d'Orb.), B. delphinensis (Kil.), B. chaperi (Pict.), Dalmasiceras dalmasi (Pict.), Proniceras pronum (Oppel), Spiticeras groteanum (Oppel) [? pseudogroteanum Djan.]. A little lower, in lithographic limestones, is the typical Stramberg fauna, including most of the species above—B. privasensis, B. calisto, B. delphinensis, B. chaperi, D. dalmasi, P. pronum—plus Berriasella oppeli (Kil.), B. richteri (Oppel), B. lorioli (Zittel), Virgatosphinctes transitorius (Zittel.), and Micracanthoceras microcanthum (Oppel). A number of ammonites of this age are figured from the Prealps of the Fribourg area by Favre (1880).

In the Au-Canisfluh area east of the Rhine, south of Lake Constance (Boden See), the top 0.6-1 m. of the Tithonian limestones is a condensed ammonite bed crowded with both Upper Tithonian and Berriasian species (Heim & Baumberger, 1933, p. 161). This occurrence is valuable as additional proof that there is no room for a disconformity and the insertion of other faunas between the central European Upper Tithonian and Berriasian. In the Churfirsten-Alvier group the lower part of the Cementstone beds contains abundant Berriasella richteri (Oppel) and B. lorioli (Zittel), and even at Canisfluh in places B. richteri and B. carpathica (Zittel.) are found with B. calisto in the cementstones immediately above the ammonite bed (Schaad, 1926; Heim & Baumberger, 1933, p. 165); the change from predominantly Tithonian to predominantly Berriasian faunas therefore does not always coincide with the lithological change from Tithonian limestones to Neocomian marls and cementstones.

A Purbeckian phase with Chara has been traced in the Morcles, Aiguilles Rouges and Valais regions (Murat, 1952).

Middle Tithonian

Far away to the south-west, at Col du Lauzon, between Briançon and Château Queyras (Hautes Alpes), another ammonite bed, 10-15 m. thick, occurs near the top of the limestones, here thick false breccias full of Calpionella alpina and formerly worked under the name of Guillestre Marble. The ammonites are extremely abundant and not rolled, but are all small and difficult to identify. It is, however, a decidedly different assemblage and shows marked affinity with the Rogoznik Beds of the Carpathians (Blanchet, 1929). Besides numerous Phylloceratids,
Lytoceratids and Haploceratids, and somewhat doubtful Perisphinctids, a special feature is the presence of Simoceratids: *Simoceras admirandum* Zittel, *Nebrodites pulchellum* (Gem.), *N. aff. agrigentinum* (Gem.), and the peculiar Rogoznik form *Simocosmoceras adversum* (Oppel). Among the Perisphinctids Blanchet records *transitorius*, *contiguus*, *geron* and *pseudocolubrinus*.

The Rogoznik fauna does not agree with that of the Lower Tithonian of the French and Swiss Alps and must therefore fall between the true Upper and Lower Tithonian, namely into the gap already postulated by Mazenot, and indicated in the correlation table on p. 91.

**LOWER TITHONIAN AND KIMERIDGIAN**

The Guillestre Marble contains ammonites (including *Hybonoticeras* and *Epipeltoceras*) which indicate that it includes representatives of the Tithonian, Kimeridgian and Upper Oxfordian, down to the Bimammatum Zone (Blanchet, 1929, p. 50). In the High Limestone Alps also the uppermost Oxfordian, Kimeridgian and Lower Tithonian are represented in a still thicker limestone series, the Quintnerkalk, 300-400 m. thick, at the top of which is the Canisfluh ammonite bed described above. In many places this thick formation is magnificently exposed, but fossils are difficult to find owing to weathering and difficult to extract owing to hardness of the rock. In the Mechtal Alps (near the Sarner See, south of Lucerne), however, about 90 m. from the top of the Quintnerkalk there is another condensed ammonite bed at Hohmatt. It is 10-50 cm. thick and ironshot, and contains at least 3000 ammonites to the cubic metre, but they are all small and difficult to extract (Rod, 1937, 1946). Numerically by far the most abundant are Haploceratids (mainly *H. staszycii* Zeutsch. sp.), after which come a dozen species of Phylloceratids, then, a long way behind, Perisphinctids, with a few Oppeliids, Aspidoceratids and Lytoceratids. As shown by Rod (1946), most of this fauna is a condensed version of the Beckeri Zone, or Acanthicus Beds (upper part) of the Middle Kimeridgian, and he thinks it may even comprise representatives of the Pseudomutabilis Zone and Tenuilobatus Zone (*Streblites tenuilobatus* itself is listed). But in addition Rod believes that the Perisphinctids include *Sublithacoceras cf. dircatus* (Schneid), *S. kyphosus* (Schn.) and *S. cf. calloidiscus* (Schn.) (cf. *dircatus* figured, pl. xiv, fig. 1), all of the Ciliata Zone, Neuburg Beds, and he suggests that these may be precursors of the Franconian type forms. In any case, the difference in age between Beckeri Zone and Ciliata Zone may not be great, according to Roll’s findings (see p. 110). The Hohmatt condensed bed is valuable as showing close connexion between the Neuburg fauna and Kimeridgian faunas and, in contrast, a gap of at least 100 m. (the top of the Quintnerkalk is not reached) up to the Upper Tithonian fauna: a result consistent with the correlation shown on p. 91.

A suite of typical Lower and Middle Kimeridgian ammonites was figured from the French and Swiss Alps by Favre (1877).
The occurrence of *Pygope janitor* Pictet in the Hohmatt ammonite bed (Rod, 1946, p. 189, pl. xiv) confirms observations of Favre (1877, p. 107) in the Alps and Fontannes at Crussol that this striking brachiopod occurs in the Middle Kimeridgian at least as early as the Beckeri Zone and cannot be used as an index fossil for the Upper Tithonian Stramberg Beds.

**Oxfordian**

As remarked above, both the Quintnerkalk in the north-east and the Guillestre Marble in the south-west are believed to embrace at least part of the Upper Oxfordian. Under the Quintnerkalk lies shaly Lower Oxfordian (Heim & Baumberger, 1933, p. 160). The best Upper Oxfordian ammonite faunas figured come from the Prealps. From Mont des Voirons, 9 miles east of Geneva, Favre (1875) monographed an assemblage of the Bimammatum Zone (with a number of ammonites from the Lower Kimeridgian also figured, distinguished in the text only). In the Fribourg Prealps he recognized two assemblages, one in grey nodular limestone which seems to combine the Bimammatum and Transversarium Zones, the other in red nodular limestones and cementstones underneath, which appears to represent the Lower Oxfordian and contains *Creniceras dionysii* (Mayer) (Favre, 1876). A noteworthy fossil from the upper level is a Spiroceratid, *Parapatoceras ischeri* (Favre), the only known Oxfordian uncoiled ammonoid. The Bruns group, south and SE. of Fribourg, has been the subject of an elaborate stratigraphical revision by Horwitz (1940), but the ammonites have not been figured, and from the palaeontological notes it is certain (as he admits, p. 1) that the determinations require revision. The Transversarium Zone is represented, and possibly some early Lower Oxfordian (pp. 62–7). In the Morcles nappe and again in the Jungfrau-Mönch-Eiger range the Cordatum Zone is missing, and in the latter the whole Lower Oxfordian, and the Transversarium Zone rests on an eroded surface and incorporates derived fragments of earlier beds (Collet, 1943, p. 19; Collet & Parejas, 1931, p. 11). A long list of ammonites, mainly *Hecticoceras* and other Oppeliids, and Phylloceratids, from clays below the Upper Oxfordian of the Morcles nappe, does not distinguish species that belong to the Athleta and Mariae Zones, which here as often are developed as a single series of clays.

**Callovian**

Considerable faunas of Lower, Middle and Upper Callovian dates are listed from numerous places, by the authors just cited and others, but figures are lacking. In the Jungfrau range the Lower and Middle Callovian and Bathonian are condensed as ironshot oolite.

**Bathonian**

Scattered records of Upper Bathonian ammonites from various places suggest that the Bathonian in the Alps may be more complete than
usually supposed: e.g. *Oppelia aspidoides* in the Jungfrau range (Collet & Paréjas, 1931, p. 9), *Prohecticoceras retrocostatum* in the Ubaye nappe (Schneegans, 1933); but the so-called ‘Bathonien supérieur’ assemblage of the Prealps (Horwitz, 1940, pp. 19-24) with its three species of *Parkinsonia* appears to be Upper Bajocian. Lower Bathonian with the fauna of the Zigzag Zone is well developed about Engelberg (south of Lake Lucerne), whence have been figured numerous *Zigzagiceras*, *Morphoceras*, *Ebrayiceras* and the inflated *Cadomites arbenzi* (Thalmann): a development of the zone similar to that at Toulon (p. 150), in Sicily (p. 208) and on both coasts of the English Channel (Thalmann, 1923, 1924, 1925, 1925a, 1925b, 1925c). *Zigzagiceras* is also recorded from the Bernese Oberland and the Prealps, where also *Nannolytoceras tripartitum* (Rasp.) is common (Horwitz, 1940, pp. 9, 20). Phylloceratids abound, mixed with the extra-Alpine fauna.

In the southern Prealps and the corresponding root zone in the Briançon district to the south, the Bathonian is represented by a peculiar pelecypod-facies without ammonites, the Mytilus Beds (de Loriol & Schardt, 1883). The age is problematic, but is probably Bathonian, perhaps extending some way up into the Callovian, for Upper Callovian with *Quenstedtoceras lamberti* is reported to overlie the Mytilus Beds (Heim, 1922, p. 617). Renz (1935) argued for a Callovian-Upper Oxfordian date; but Dr L. R. Cox, who kindly considered the problem, informs me (in lit., February 1954) that he accepts many of de Loriol’s determinations of pelecypods which were given other names by Gilliéron and Renz, and in particular points out that *Eligmus polytypus* argues for a Bathonian-Callovian date, since *Eligmus* is not known from later beds. The Mytilus Beds transgress on to Lias.

**Bajocian**

As remarked above, the ‘Upper Bathonian’ Parkinsonids of the Fribourg Prealps, if correctly determined (Horwitz, 1940, p. 21), are Upper Bajocian, Parkinsoni Zone. A *Parkinsonia* of this age has also been figured from the Petersgrat (Hügi & Collet, 1951) and Parkinsoni, Garantiana and Subfurcatum Zone faunas are all present in the Jungfrau range and the Morcles nappe and elsewhere, though generally the rocks are thin. In the Jungfrau range echinoderm limestone (8 m.) with *Stephanoceras* underlies these faunas and rests directly on Rhaetian (Collet & Paréjas, 1931, p. 7). At other places in the Bernese Oberland, however, occur *Otoites sausei* (Thalmann, 1924) and Sonninids of the Sowerbyi or Sauzei Zone (Thalmann, 1923b), and the Lower Bajocian becomes thickly developed with *Cancelllophyscus* beds and irony sandstones 280-300 m. thick, underlain by 25-30 m. of shales assigned to the Opalinum Zone. *Tmetoceras alpinum* occurs at Mürren (Thalmann, 1923a). The Opalinum shales transgress on to Trias on the Vindelician ridge, as was proved in a boring SW. of Augsburg (see p. 107), and doubtless are continuous with those in the Swabian Alb and the Jura.
Lias

The Lias is relatively rich in ammonites and has been far more closely studied than the rest of the Jurassic. Because its stratigraphy is comparatively straightforward and complete, and for the most part the faunas are closely comparable with those of extra-Alpine Europe, it is impossible to devote space to a stage-by-stage examination. The Prealps have been particularly well studied. There are exhaustive monographs for the Prealps south and west of the Rhone (Peterhans, 1926) and north and east of the Rhone (Hug, 1898-9; Jeannet, 1912-13), and also for the klippes of the Lake Lucerne area (Trauth, 1908). The klippes are closely comparable faunally with the contemporary developments in the Bavarian Alps beyond the Rhine. Jeannet (1912-13, p. 403) stressed the resemblance of the Hettangian of the Tours d'Aï to that of the Southern Alps of Lombardy (Lake Lugano), but since the Hettangian shows few peculiarities, this cannot weigh against the remarkable coincidences between the specialised Middle Jurassic of the Prealps and that of the Briançon district in the French Hautes Alpes (see p. 153). The chief peculiarity in the Lias of the Prealps is the occurrence of thick breccias in the Breccia nappe.

There is also much information on the Helvetid Lias, especially in the Morcles nappe (Collet, 1943, 1947) and the Glarus (Trumpy, 1949). Along the margin of the Aiguilles Rouges and parts of the Aar massifs the Lias is absent (Collet & Parejas, 1931, pp. 5-7), as on the Vindelician foreland farther east.

North-eastern Alps, Vienna Basin and Northern Carpathians

The south-north valley of the upper Rhine, above the entry into Lake Constance, divides the Alps into two very different halves. For once the geological and political frontiers coincide: to the west are the Swiss and French Alps, to the east the Austrian and Bavarian Alps. Fossiliferous Jurassic rocks east of the Rhine occur as discontinuous shreds and patches scattered through the Northern Limestone Alps and Dolomites, which stretch for more than 300 miles to the gates of Vienna and are chiefly built of thick Triassic limestones (Vetters, n.d.). Considering their great length and narrow average width of about 30 miles, the Northern Limestone Alps run remarkably straight, but this simplicity masks a great complexity of structure. The apparently continuous outcrop consists, in fact, of a mosaic of more-or-less eroded, mutually overlapping thrust-sheets, in which the Jurassic rocks are developed in a great variety of facies, often brought together in startling contrast by tectonic movements. To the north, the Limestone Alps are thrust over a continuous belt of flysch, and that in turn is thrust over the Molasse and late Tertiary foreland. Between the Flysch and Molasse belts is a discontinuous, narrow, thrust strip of Helvetid Mesozoics, mainly Cretaceous. (A plan of the component nappes and of the three major tectonic belts referred to is given at the end

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of Schaffer, 1951). It is estimated that in a north-south direction the shortening has been to the present width of 43 km. from about 158 km., or to less than one-third (Spengler, 1952).

In general, along the northern edge of the Eastern Alps (especially towards the east) the Lower and Middle Jurassic are developed in the Gresten facies. The Gresten Beds, which have an outcrop 125 miles long, consist of sandstones, arkoses, clay shales, and dark sandy limestones and marls. In the lower part are coal seams, plant beds and shell beds. The clastic materials are derived from the Bohemian Forest massif and cannot have been formed far south of their present position, despite their thrust margin. The Gresten Beds are normally Hettangian, Sinemurian and Pliensbachian, but in places they embrace everything up to the top of the Bajocian. Southwards they pass into normal dark limestones, or into red cephalopod limestones (Adneth Beds) or spotted marls (Flecken-mergel), which represent different parts of the Sinemurian, Pliensbachian, Toarcian and even Bajocian in different places. From the Bathonian upwards littoral influences are much less marked, and shelly or cephalopod limestones alternate horizontally and vertically with radiolarian cherts, Posidonia shales, aptychus beds, crinoidal limestones, Calpionella limestones, and many other facies familiar all over the Mediterranean-Alpine region and elsewhere. The radiolarian cherts and Calpionella limestones have often been taken for deep-water deposits, but this interpretation is belied by frequent intercalations of shallow-water beds and macro-fossils; more likely they originated in troughs temporarily cut off from supplies of sediment.

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It is evident that the thrust-sheets that build the Northern Limestone Alps have travelled northwards for varying distances from more central zones of the Alps, though there is often also a strong eastward component in the thrusts (Cornelius, 1940). The 'ultranappist' view that they have travelled 60 to 100 miles, right across the central Alps from the south side, however, has been discredited by more recent work (Ampferer, 1940; Klebelsberg, 1941; Schwinner, 1940, and in Schaffer, 1951), though it still has supporters (e.g. Clar, 1953). The variability of facies is to some extent independent of nappes and reflects contemporaneous warpings of the sea floor, but the sorting out of the various facies and 'putting back' of the nappes is probably an unattainable ideal. A detailed description of the Jurassic rocks nappe by nappe has been attempted by Trauth (1922 and 1950; most will be derived from these works by readers with a taste for prose with up to 25 lines to the sentence and new formation-names for almost every exposure).

On approaching the Danube the Alps break down and sink beneath thick Tertiary-Quaternary cover in the Vienna Basin and March Plain, to be continued beyond as the Carpathians. This geographical division does not correspond to the geological frontier, which, as Uhlig pointed out, is more logically to be drawn among the headwaters of the River Theiss, in the eastern Carpathians. The north-western and northern Carpathians are a direct continuation of the Eastern Alps, with certain differences. Beyond the Danube the flysch zone widens and becomes a complex of flat-lying thrust-sheets chiefly consisting of Cretaceous and Tertiary sandstones, the Beskid (with Magura) and Subbeskid nappes. At the outer edge of both the inner and wider Beskid zone, and the narrower outer or Subbeskid zone, is a belt of imbrications. The two belts together form the Outer Klippe Chain. It starts close to the Danube, NW. of Vienna, as a line of 'inselbergs', consisting of Jurassic and Cretaceous limestone hills, partly floating on and partly piercing through the flysch. They are not klippes in quite the same sense as the Prealpine klippes of Switzerland, but rather parautochthonous shavings and chips caught up in the base of the overriding Beskid and Subbeskid nappes and carried forward from their original position on a crystalline swell (Glaessner, 1931). The Upper Jurassic succession in the inselbergs and klippes of Ernstbrunn, Niederfellabrunn, Czetechowitz, Stramberg, etc. is of great interest and some of the small outcrops have become world-famous in this connexion.

Along the south, or inner, boundary of the flysch zone (Beskid or Magura zone of different authors), runs a narrow belt of extraordinary complexity which gives rise to an Inner or Pienid Klippe Chain (Neumayr, 1871a; Andrusov, 1931). This narrow band separates the Beskid nappes from the interior region of the Carpathians, the Tatras and their internal flysch basins. The Jurassic and Lower Cretaceous Inner Klippe Chain represents part of the sedimentary cover of the Tatra nappes, which belong to an earlier (Cretaceous) period of folding. Inside the Inner Klippes
Plate 9a.—Stramberg: the limestone klippe and quarry.

Plate 9b.—Gorge of the Dunajec through the Pienin klippes, northern Carpathians.
the main orogeny was Cretaceous; outside, in the flysch zone, mainly Tertiary.

The Pienid or Inner Klippes of the western Carpathians number about 5000 and range in size from small blocks, some of which have been entirely removed by quarrying, to mountains 7 or 8 miles long. They consist mainly of Jurassic rocks, but Lower Cretaceous is also present, and occasionally Trias. Two contrasted types are represented: a Pienid facies, in which there is a continuous suite from Upper Trias to Neocomian, and a Subpienid, in which Bajocian rests disconformably on Trias or older rocks and the facies is more notably shallow-water, with sedimentary breaks. In the klippes both suites are inextricably mixed, although they must have different origins, in a trough and swell region respectively.

The mode of formation of the Pienid klippes is one of the unsolved problems of geology. Uhlig (1907) considered them remains of a burst anticline. Later authors have regarded them as fragments of a breaking tectonic wave at the brow of an advancing Tatric nappe. In the latest cross-sections (Ksiazkiewicz & others, 1953) they look more like the pips and contents forced from a squeezed tomato—a geosyncline squashed by lateral compression.

Within the inner Carpathians Jurassic rocks also occur in two facies: a thrust-travelled 'Sub-Tatra Series', and a parautochthonous 'High Tatra Series' from which the Lower Jurassic is sometimes missing, as in the Subpienid klippes.

For a clear and factual account of Carpathian geology the classics by Uhlig (1897, 1903, 1907) are still indispensable. More recent syntheses are available by Voitesti (1929) and Stille (1953) and, for readers of Polish, by Ksiazkiewicz & others (1953). The last two works have extensive bibliographies.

**UPPER TITHONIAN**

Stramberg Limestone. Zone of *Virgatosphinctes transitorius* (so named by Neumayr, 1871a, p. 517). The mountain at Stramberg is a triangular mass of white limestone with sides 1.5 km. long, which rises as an exotic block from a Cretaceous terrane in the outer klippe chain of Moravia. The limestone is largely of reef facies although corals are poorly preserved and not always conspicuous, and the occurrence was once explained as an isolated reef which grew up from a buried Jurassic sea floor. It early became famous for its fossils through exploitation of the limestone as a flux in Teschen iron-works. The largest quarry is seen in plate 9a. Collections made by a former director, Hohenegger, were studied by Oppel, who published a catalogue of the ammonites with many new names (Oppel, 1865) but died before finishing his projected monograph, which was completed by Zittel (1868). The gastropods were also monographed by Zittel (1873) and the pelecypods by Boehm (1883). There was an early monograph on the brachiopods by Suess, and other groups have formed the subject of special studies since. A discussion of the fauna.

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as a whole was published by Blaschke (1911), who stated that at that time over 600 species of fossils were known, of which about one-third had been found nowhere else and another third were confined to other Tithonian occurrences in the Alpine and Mediterranean province.

On account of the work of Oppel and Zittel the Stramberg ammonite fauna is considered the type assemblage for the Upper Tithonian. Besides species of *Phylloceras, Calliphylloceras, Macrophyloceras, Ptychophylloceras, Lytoceras, Pterolytoceras, Hemilytoceras, Protetragonites* and *Haploceras*, for the most part familiar in other regions and usually of little value for precise dating, the Stramberg fauna has a number of remarkable forms of greater significance. In the following list the species figured in Zittel's monograph (1868) and a few others are assigned to their modern genera.

*Cyrtosiceras macrotelum* (Op.) (type of Hyatt's genus)
*Substreblites zonarius* (Op.) (type of Spath's genus)
*Semiformiceras fallauxi* (Op.) (type of Spath's genus)
*Spiticeras pseudogroteanum* Djanelidze (type, Zittel's pl. xvi, figs. 3, 4)
*Spiticeras zitteli* (Djan.) (type Zittel's pl. xiv, fig. 2)
*Proniceras pronum* (Op.) (type of Burckhardt’s genus)
*Micracanthoceras microcanthum* (Op.) (type of Spath’s genus)
*Micracanthoceras uhligi* (Blaschke)
*Himalayites kollikeri* (Op.)
*Himalayites symbolus* (Op.)
*Berriasella moravica* (Op.)
*Berriasella carpathica* (Zit.)
*Berriasella lorioli* (Zit.)
*Berriasella richteri* (Op.)
*Berriasella oppeli* Kilian (type Zittel, pl. xx, figs. 1-4)
*Berriasella (Pseudargentiniceras) abscissa* (Op.) (type of Spath's genus)
*Berriasella (Dalmasiceras) progenitor* (Op.)
*Virgatosphinctes transitorius* (Op.)
*Aulacosphinctes fraudator* (Zit.)
*Aulacosphinctes eudichotomus* (Zit.)
*Pseudovirgatites scruposus* (Op.) (type of Vetters’ genus)
*Pseudovirgatites seorsus* (Op.)
*Sublithacoceras senex* (Op.)
*Aspidoceras rogoznikense* (Zeusch.) (type of Zittel's genus)
*Simoceras volanense* (Op.)

Suess, Oppel, Zittel and Blaschke were all convinced that the Stramberg quarries were worked in a single zone, but Mojsisovics (quoted in Zittel, 1868, p. 13) recognized three horizons, and unfortunately there is a grave suspicion that at least the last five items of the foregoing list belong to an earlier zone and were confused with the main Stramberg fauna by Hohenegger or other early collectors on account of identity of matrix. The occurrence of earlier beds in identical matrix is confirmed by

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Blaschke’s additions to the fauna: for his *Simoceras remesi* (Blaschke, 1911, pl. 1, fig. 9) seems to be a Middle or Lower Kimeridgian *Aspidoceras* (*Pseudoaegagenia*) aff. *microplum* Oppel sp., closely similar to a form figured by Herbich (1878, pl. xiv-xv, 4) from Transylvania, and as Spath (1933, p. 849) has rightly pointed out, Blaschke’s big Perisphinctids (*steinachneri* and *kittli*) are irreconcilable with an Upper Tithonian age and undoubtedly belong to an earlier Kimeridgian zone.

Eastwards from Stramberg similar limestone occurs in the outer klippe chain as far as Cracow, and some of the fauna is also recorded from the inner klippes, from limestone overlying the Rogoznik Beds (see below). White limestones with *Calpionella* are widespread in the Eastern Alps (Trauth, 1950, pp. 175-6, etc.) and the Carpathians (Passendorfer & Książkiewicz, 1950, pl. vii), but the occurrences are mainly Berriasian or not precisely dated.

**MIDDLE TITHONIAN**

Rogoznik Beds. Zone of *Semiformiceras semiforme* (so named by Neumayr, 1871a, p. 517). The principal source of the ammonites figured in Zittel’s second monograph (1870) was a red lumachelle or crinoid limestone in one of the klippes of the inner klippe chain at Rogoznik, near Neumarkt. In several exposures it is seen to underlie a greyish-white limestone full of ammonites of the Transitorius Zone as found at Stramberg (Neumayr, 1871a, pp. 479-80), and it overlies red nodular limestones which yield various Kimeridgian faunas. The ammonites (listed also by Neumayr, 1871a, pp. 496-8) comprise numerous Phylloceratids, Lytoceratids and Haploceratids, largely identical with those in the Transitorius Zone, but the assemblage as a whole differs as follows: (1) by the presence of a crowd of remarkable Oppeliids, largely with a ventral groove on the body-chamber, belonging to the genus *Semiformiceras*; (2) by the occurrence of several *Taramelliliceras*; (3) by the rarity of *Berriasella*; (4) by the presence of other Perisphinctids such as *Lithacoceras geron* (Zit.), *Subplanites contiguus* (Cat.) and the Portlandian-like *P. pseudocolubrinus* Kilian (Zittel, 1870, pl. 33, fig. 6, pl. 34, figs. 4-6); (5) by the presence of a curious genus *Simocosmoceras* (*sinum, adversum, catulloi*, Zittel, 1870, pl. 31); (6) by the presence of uncoiled ammonoids, *Bochianites guembeli* and *gracile* Zittel (pl. 36, figs. 1-3). These characteristics justify recognizing a separate zone. *Lithacoceras geron* was suggested as index by Kilian in 1887, and *Subplanites contiguus* by Toucas in 1890, but there seems no reason for abandoning Neumayr’s choice of *Semiformiceras semiforme*, which has priority.

The Semiforme Zone has been recognized to the west with certainty only in the French Alps (see p. 156) and it seems likely that its absence elsewhere is accounted for by the gap postulated by Mazenot between the Upper Tithonian *Berriasella* fauna and the *Subplanites* fauna of Neuburg (see p. 110). It may therefore provisionally be regarded as Middle Tithonian (see table 14, p. 167). Zittel (1870, [http://jurassic.ru/](http://jurassic.ru/))
p. 187, pl. 28, fig. 21) figured from Rogoznik a specimen attributed to the zonal index ammonite *Taramellicerases lithographicum*, but Oppel's original species from the Solnhofen Slates has a smooth, not crenulate, keel and a lateral groove, and is a different species. The Perisphinctids recorded from many places in the Rhone basin as *P. contiguus*, *P. geron*, *P. pseudocolubrinus*, etc., may range through Lower and Middle Tithonian, but until this notoriously difficult group has been monographed, misidentification cannot be ruled out. *P. pseudocolubrinus* has been recorded for nuclei of many different kinds of Perisphinctids.

Zittel (1870, p. 293) considered the Semiforme Zone 'not older than the youngest deposits of the Franconian and Swabian Jura'. The only point which in his wisdom he left open, whether it is equivalent in age or younger, is the only point still in doubt, three-quarters of a century later. Despite a previous tentative assumption that they were equivalent (Arkell, 1946, p. 20) I now believe Rogoznik to be younger than Neuburg (in other words, that the Semiforme Zone is later than the Ciliata Zone).

**LOWER TITHONIAN**

A further puzzle, long and inconclusively discussed, is presented by 'inselbergs' at Niederfellabrunn, Ernstbrunn, Nikolsburg and Klentnitz, which rise out of the March Plain north of Vienna and belong to the western end of the outer klippe chain. Two formations are recognized: white, marble-like Ernstbrunn Limestone, which rests on and is in part replaced laterally by marls and marly limestones, the Klentnitz Beds, which have yielded a sparse but celebrated ammonite fauna at Niederfellabrunn (Abel, 1897; Vetters, 1905; Glaessner, 1931; Trauth, 1950, pp. 150-2). Only one complete, unequivocal, well-preserved ammonite is known from the Klentnitz Beds of Niederfellabrunn, that on which Vetters founded the genus *Pseudovirgatites*, and it is identical specifically with a fragment from Stramberg which was type of *P. scruposus* Oppel (Zittel, 1868, pl. xxiv, fig. 3). The rest of the Niederfellabrunn ammonites being different from anything known from Stramberg, the inference is that *Pseudovirgatites scruposus* was one of the species wrongly mixed with the Upper Tithonian Stramberg fauna and belonging in reality to an earlier zone. The accompanying Niederfellabrunn ammonites, however, although certain earlier than both the Stramberg and Rogoznik assemblage, are poorly preserved, incomplete and difficult to identify. Some of Vetters’ types are lost. The remainder and some others from Klentnitz were borrowed from Vienna and revised by Spath (1933; pp. 844-7), who identified some of them with Russian and English genera of the Lower Volgian and Upper Kimeridgian-Lower Portlandian, such as *Dorsoplanites*, *Zaraiskites* (‘Provirgatites’), *Paclovia* and *?Pectinatites*. It appears from his later writings, however, that Spath would now repudiate most if not all of these generic attributions. Those involving Russian genera seem especially doubtful, as is also the reference of some of Vetters’ forms to the Himalayan-Pacific genus *Aulacosphinctoides*. On the basis

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of Vetter's figures nearly all the ammonites seem best compared with
Franconian forms from the Neuburg Beds, figured by Schneid. For
instance the ribbing of Vetter's pl. xxi, fig. 2, is identical with that of
*Anavirgatites franconicus* Schneid sp. (1915, p. xi, 3), and Vetter's pl. xxii,
fig. 5, could well be a worn cast of *Wheatleyites racemosus* Schneid sp.
(1915, pl. ix, fig. 1); and Vetter's pl. xii, fig. 7, assigned by Spath with a
query to *Pectinatites*, might belong to that genus or still more to *Sublithaco-
ceras* cf. *penicillatus* or *callodiscus* Schneid spp. (1915, pl. iii, fig. 3,

<table>
<thead>
<tr>
<th>Divisions now accepted</th>
<th>Formations</th>
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<th>Correlation with S. England</th>
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<tbody>
<tr>
<td><strong>Upper Tithonian</strong> (= Ardesian)</td>
<td>Stramberg Limestone</td>
<td>Virgatoshphinctes transitorius (Neumayr, 1871)</td>
<td>Upper (and Middle?) Purbeckian</td>
</tr>
<tr>
<td><strong>Middle Tithonian</strong></td>
<td>Rogoznik Beds</td>
<td>Semiformiceras semiforme (Neumayr, 1871)</td>
<td>Lower (and Middle?) Purbeckian and Portlandian</td>
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<tr>
<td><strong>Lower Tithonian</strong></td>
<td>Klentnitz Beds and Lower Tithonian of Saint-Concors &amp; Le Pouzin</td>
<td>ciliata vimineus lithographicum and hybonotum</td>
<td>Upper and Middle Kimeridgian</td>
</tr>
<tr>
<td><strong>Middle Kimeridgian</strong></td>
<td>Acanthicus Beds (Benecke, 1865)</td>
<td>Hybonoticeras beckeri (Neumayr, 1873)</td>
<td>(wanting)</td>
</tr>
<tr>
<td><strong>Lower Kimeridgian</strong></td>
<td></td>
<td>Aulacostephanus pseudomutabilis (Oppel, 1863)</td>
<td>Lower Kimeridgian</td>
</tr>
</tbody>
</table>

Thus the balance of probability (so far as present knowledge goes)
is in favour of an approximate correlation between the Klentnitz Beds
and the Neuburg Beds of Bavaria and the Pectinatus Zone of England
(see Arkell, 1946, pp. 22-3). It remains, however, an awkward fact that
the index fossil of the Klentnitz Beds, *Pseudovirgatites scruposus*, has been
found neither at Neuburg nor in the Neuburg fauna at Saint-Concors;
in fact, nowhere else in the world except Stramberg.

The Ernstbrunn Limestone, which in general overlies the Klentnitz
Beds, presents yet another problem. The fauna has been called a mixture
of those of Stramberg and Kelheim (Abel, 1899, p. 376). The ammonites
borrowed from Vienna by Spath (1933, pp. 847-8) consist (besides a few

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Phylloceras and Lytoceras) of Perisphinctids which he identified with three peculiar forms (Subplanites?) figured by Schlosser from the Kelheim Diceraskalk of Bavaria. These have been found with certainty nowhere else but in the Kelheim reef-limestone, which according to Roll and others is an intercalation in and below the Solnhofen Beds (Lithographicum Zone). Therefore if Spath’s determinations are correct, Ernstbrunn Limestone in some exposures must be older than Klentnitz Marls in other exposures. Considering the observed lateral replacement of the two facies and the acute tectonic disturbance, this solution is not improbable. That the succession in the klippes cannot be upside-down is proved by overlying Cretaceous and Tertiary beds (Abel, 1899, p. 285).

Middle and Lower Kimeridgian

The fauna of the Acanthicus Beds is widespread, usually in rather thin red or varicoloured nodular limestones as in most parts of the Alpine-Mediterranean region, but it is less favourably developed for collecting than in Transylvania and Italy and has thrown no new light on the zonal succession. In some parts of the Eastern Alps a coral reef facies is developed, and in others there is passage into Aptychus beds and radiolarites which are said to range in age from Oxfordian to Tithonian (Trauth, 1950, pp. 176, 185, 203, 207). Alleged transgression of the Kimeridgian on to Lias and Trias, reported by early authors, probably has a tectonic explanation. The red nodular facies is widely distributed in the inner klippe chain of the Carpathians (Neumayr, 1873, p. 151; Passendorfer, 1928). An occurrence near Vienna has been lavishly illustrated (Toula, 1907, with 19 plates of ammonites, many new species) but the preservation is so poor that few of the photographs can be interpreted.

Oxfordian

The Upper Oxfordian is also widespread and somewhat thin. Ammonites of both Bimammatum and Transversarium Zones are recorded from many places. Ringsteadia is reported from both the Eastern Alps (Trauth, 1950, p. 176) and the Carpathians—R. vicaria Moesch sp. (Neumayr, 1873, p. 152). In the Eastern Alps radiolarites are extensively developed; they have many shallow-water intercalations and are unlikely to have been formed at great depths (Trauth, 1950, pp. 185, 190).

An Oxfordian occurrence of outstanding interest is the limestone klippe of Czetechowitz in the outer klippe chain of Moravia (Neumayr, 1870a; Neumann, 1907). Here 4 m. of nodular limestone have yielded a remarkable fauna comprising a mixture of the abundant Phylloceratids proper to the Alpine-Mediterranean province with a host of Perisphinctids and Cardioceratids which could occur anywhere in NW. Europe, and in England in particular. The beds are known in the literature as Cordatus Beds but, as Neumann (1907, p. 60) rightly pointed out, the fauna comprises representatives of both late-Cordatum and Transversarium Zones. In fact, probably all the Cardioceratids figured are of the English Plicatilis
Zone, as are all the Perisphinctids and part of the Aspidoceratids. Only the Peltoceratids and *Euaspidoceras ovale* are of the Cordatum Zone judging by the much thicker and more complete standard succession in England. The resemblance to the Plicatilis Zone fauna, especially around Oxford, is so extraordinary that the following nomenclatural revision of Neumann's figured ammonites is worth bringing together (based on Arkell, 1935-48, where discussions will be found, and omitting a few forms figured from later beds):

*Perisphinctes* (? *Perisphinctes*) orbignyi de Loriol (ii, 5) (*healeyi* Neum. obj. syn.)

*Perisphinctes* (*Arisphinctes*) plicatilis (Sow.) (i, 3)

*Perisphinctes* (*Arisphinctes*) ? helenae de Riaz (i, 4)

*Perisphinctes* (*Arisphinctes*) uhligi Neum. (i, 1) (pathological?)

*Perisphinctes* (*Arisphinctes*) fragment indet. (i, 2)

*Perisphinctes* (*Kranaocephalites*) promiscuus Buk. (iii, 9, 11)

*Perisphinctes* (*Kranaocephalites*) trifidus (Sow.) (iv, 12)

*Perisphinctes* (*Kranaocephalites*) methodii Neum. (v, 15)

*Perisphinctes* (*Dichotomosphinctes*) cf. *stenocycloides* Siem. (iii, 10)

*Perisphinctes* (*Dichotomosphinctes*) sp. indet. (ii, 7)

*Aspidoceras* (*Euaspidoceras*) vettessiannum Neum. (vi, 19)

*Aspidoceras* (*Euaspidoceras*) ovale Neum. (vi, 20)

*Peltoceras* (*Peltoceratoidea*) interruputum Neum. (vii, 26)

*Peltoceras* (*Peltoceratoidea*) pseudocontrainii Prieser (type, viii, 27)

*Peltoceras* (*Peltoceratoidea*) sp. (vii, 25)

*Peltoceras* (*Parmacekindia*) pauli Spath. (type, vii, 21; ? also 22, 23)

*Cardioceras* (*Cardioceras*) neumanni Maire (type, iv, 13, pathological)

*Cardioceras* (*Vertebriceras*) dieneri Neum. (v, 16, 17)

*Cardioceras* (*Vertebriceras*) sp. indet. (iv, 14)

*Goliathiceras capax* (Young & Bird) (v, 18, *lambertoide* Neum. syn.)

This list shows so much closer affinity with England and NW. Germany than with South Germany that a sea-connexion across or north of the Bohemian massif is indicated. But the crowd of Phylloceratids brings Czetechowitz within the Alpine-Mediterranean province.

The seaway postulated probably passed through the Dresden outcrops monographed by Bruder (see p. 140) and those near Brunn (Brno), which lie in the Carpathian foreland less than 30 miles west of Czetechowitz. From both places large Oxfordian *Peltoceratoidea* have been described. Near Brunn Phylloceratids still occur but are less abundant. At Olomut-schan is a Transversarium Zone fauna of approximately the same age as that at Czetechowitz but with other elements added (Uhlig, 1881), and at the Schwedenschanze (Oppenheimer, 1907) there is in addition an interesting fauna of the Bimammatum Zone, with special small Perisphinctids, *Epipeltoceras, Taramelliceras, Amoeboceras*, and what appear to be species of *Ringsteadia* (Oppenheimer, pl. xx, fig. 20) and *Decipia* or *Pseudarispinctes* (pl. xxi, 13).

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The Mariae Zone appears to be unrecorded from the whole area of the Eastern Alps, Vienna Basin and Northern Carpathians.

**Callovian**

Callovian faunas are richly represented but inadequately figured and scarcely enable conclusions to be drawn. Most appear to be Middle Callovian. *Peltoceras athleta* may occur in the Tatra according to an old record often repeated (Passendorfer, 1928) and Uhlig (1878; 1881a) figured and described some other Callovian ammonites from the inner klippe chain. In the Eastern Alps Callovian faunas are better preserved and more abundant, but the Macrocephalus Zone so often quoted (e.g. Trauth, 1922, pp. 184, 222) appears to be misidentified; superb specimens of *Reineckeia tyranus*, *R. greppini* Oppel sp. (= *oxyptycha*) and *Indosphinctes patina* figured by Neumayr (1870) from near Gosau in the Salzkammergut belong to late-Lower or early-Middle Callovian.

In the eastern Carpathians, near the headwaters of the Theiss, *Lissoceras voulense* (Op.) and five species of *Phylloceras* considered to be Callovian have been figured as derived limestone casts from a volcanic tuff in one of the klippes (Swiderski, 1938).

**Bathonian**

The Klaus Beds, red or brownish ammonite limestones passing locally into marls with or without *Posidonia* (Zell Beds), widely developed in the North-Eastern Alps, yield important Lower, Middle and Upper Bathonian faunas, but they have not been differentiated (Jüssen, 1890; enlarged lists in Trauth, 1922, pp. 191-5, 220 ff.). Typical Bathonian Phylloceratids and Lytoceratids abound, with the principal Bathonian genera of central and NW. Europe, including peculiar Perisphinctids, of which *P. ybbsensis* Jüssen appears to be a *Choffatia* and *P. seminudus* Jüssen probably is a *Wagnericeras* or *Graclisphinctes*. Upper Bathonian is indicated by *Epistrenoceras contrarium* (d'Orb.) and Lower Bathonian by *Lissoceras psilodiscus* (Schloenb.) and *Morphoceras multiforme*. Trauth (1922, p. 195) considers that these beds extend from Upper Bajocian to Lower Callovian, but allowing for a few obvious misidentifications in his list, there is no evidence for anything but Bathonian.

In the Tatra Mountains there is the same mixture of Phylloceratids and Lytoceratids with northern and western genera (Uhlig, 1897, p. 671; Passendorfer, 1935, 1938). The indications of Lower Bathonian are *Lissoceras psilodiscus*, *Oppelia fallax* Guér. sp. (1938, pl. xii, fig. 2), *Procerites* spp., and a single fragment of *Parkinsonia* (1935, pl. iii, fig. 8). Apart from these the assemblage is overwhelmingly Middle and Upper Bathonian. Passendorfer figured *Cadomites rectelobatus* Hauer sp., a small *Tulites* (Rugiferites) aff. *angulicostatum* Lissajous sp. (pl. iv, 3, 4), *Schwandorfia lucasi* de Gross. sp., *Sphaeroptychius buckmanni* Lissajous (or *Schwandorfia* sp.?), *Oecotraustes* cf. *nodifer* Buckman, *Wagnericeras arbustigerum* (d'Orb.), *Choffatia* aff. *recuperoi* (Gem.), and various...
**Prohecticoceras** including *P. retrocostatum* (de Gross.), *P. fuscum* Quenst. sp. (1938, pl. xii, figs. 5, 6) and *P. costatum* Roemer sp. (pl. xii, 3, 4). The bed yielding this fauna belongs to the parautochthonous 'High Tatra Series' (not to the thrust-travelled 'Sub-Tatra Series'); it is only 20 cm. thick, and is said to rest in some places on crinoidal limestones probably of Bajocian age, but in other places, without visible unconformity, on Triassic limestones. It thus falls into line with evidences of Bathonian transgression in many other parts of the world.

**Bajocian**

In the Eastern Alps in some places the Gresten and Adneth facies both embrace the whole Bajocian; the zonal indices recorded are *Opalinum*, *Murchisonae*, *Bradfordensis*, *Humphriesianum*, *Blagdeni*, *Garantiana* and *Parkinsoni* (Trauth, 1909; Hahn, 1910, p. 378; Schmidtill & Krumbeck, 1938, pp. 321-3). Collections from the Humphriesianum and later zones revised by Schmidtill & Krumbeck include many *Stephanoceras*, *Stemmatoceras*, *Teloceras*, *Normannites*, *Strenoceras* and *Garantiana*, chiefly from Ober St Veit and Hohenauer Wiese. The connexions with Franconia are so many and so close that a direct sea-connexion must be postulated. In other parts of the Eastern Alps the Fleckenmergel facies of the Lias passes up to include the Opalinum Zone (Böse, 1894).

In the Carpathian inner klippen Fleckenmergel with *Leioceras opalinum* and shaly clay with *Ludwigia murchisonae* occur (Neumayr, 1871a, p. 504), and shales with *Posidonia* yield *Soninia* spp., *Witchellia* spp., *Stephanoceras*, *Teloceras* and *Oppelia subradiata* (Horwitz, 1937). Numerous *Phylloceras* and *Lytoceras* occur throughout the region in the Bajocian, mixed with the northern and western genera, just as in the Caucasus. (Some of the Carpathian Bajocian ammonites are figured by Passendorfer & Ksiązkiewicz, 1951, pls. ii, iv).

**Toarcian**

In the Kammerker group, Eastern Alps, red nodular limestones of Adneth facies, up to 10 m. thick, yield a rich and well-preserved Toarcian fauna from the Bifrons and higher zones, up to the highest horizons with *Erycites*, *Hammatoceras*, *Dumortieria*, *Pleydellia*, etc. (Hahn, 1910). Phylloceratids and Lytoceratids abound, in species and individuals, and the usually-rare genera *Paroniceras* and *Frechiella* are well represented (Renz, 1925). *Posidonia* shales occur at the base (Hahn, 1910, p. 368). As remarked already, in other places Gresten and Fleckenmergel facies persist through the Toarcian. In the Carpathians also there are thick beds of Toarcian Fleckenmergel, red nodular limestones and crinoidal limestones, with a rich ammonite fauna (Goetel, 1917, p. 17).

**Pliensbachian**

This stage is perhaps best differentiated in the Kratzalp near Salzburg where it consists of red cephalopod limestones (Adneth facies). The base is defined by a *Crucilobiceras* fauna of the Taylori Subzone (basal

Jamesoni Zone) and the faunas continue up into the Margaritatus Zone, with rich and varied assemblages of Eoderoceratids, Liparoceratids, Polymorphitids, Arieticeratids, etc., etc. (Rosenberg, 1909). Much the same faunas are represented in other places in the true Adneth Limestones and in Fleckenmergel (see especially Mojsisovics, 1868; Geyer, 1893; Hauer, 1854a; Hahn, 1910, pp. 366 ff; Schröder, 1925; Vortisch, 1939). In the Kammerker group there is crinoidal limestone with Pleuroceras spinatum (Hahn, 1910, p. 369). Similar faunas, including P. spinatum, occur in the inner klippe chain of the Carpathians (Andrusov, 1931; Horwitz, 1937).

**Sinemurian and Hettangian**

These stages are developed in a bewildering variety of facies, of which the best-known names are Gresten Beds (predominantly sandy and shaly near-shore facies bordering the Bohemian massif, but with intercalations of dark sandy limestones and marls), which embrace from Hettangian up to the top of the Bajocian, as already stated (Trauth, 1909); Hierlatz Limestone (type locality Hierlatz near Halstatt; also Kratzalp near Salzburg, etc.) which is Upper Sinemurian, corresponding to the Obtusum, Oxynotum and Raricostatum Zones (Rosenberg, 1909); Adnet or Adneth Limestones (from Adnet near Hallein), red nodular cephalopod limestones, typically Pliensbachian but occasionally including some of the Sinemurian; and Fleckenmergel (predominantly spotted, multi-coloured or banded marls, up to 250 m. thick, sometimes with bands crowded with Posidonia alpina) which embrace from Lower Sinemurian to Bajocian (Rothpletz, 1886; Böse, 1894; Schröder, 1925, 1927).

The ammonite faunas from these beds are some of the richest in the world. Those of the Hettangian are the best-illustrated and most varied of the period known, thanks to monographs by Neumayr (1879), Wähner (1882-98) and Lange (1952). The Sinemurian contains giant Arietitids in size and variety equal to those of the Swabian Alb. (For further figures of Hettangian and Sinemurian faunas see also Hauer, 1854b, 1856; Geyer, 1886; and Rosenberg, 1909; and for stratigraphy, especially Trauth, 1909; Hahn, 1910; Schröder, 1925).

Similar faunas are described from the Carpathians and include Cardinia beds (e.g. Goetel, 1917; Andrusov, 1931, with plates; Slavin, 1950).

**Rhaetian**

The North-Eastern Alps are one of the few places in the world where Rhaetian with ammonites is known. They occur in the Kössen Beds—limestones, marls, and clays—mainly in the Osterhorn group south of St Wolfgang Lake, and in the neighbourhood of Garmisch-Partenkirchen, but occasionally as far as Algaü. The only common genera are Choristoceras and Monophyllites: all the rest are rarities. The assemblage is essentially Triassic and shows practically no affinity with the Hettangian fauna (Pompeckj, 1895).
SOUTHERN ALPS (LOMBARDY, VENETIA, SOUTH TYROL)

The Jurassic outcrop on the south side of the Alps begins near Lake Como and forms a continuous strip from there eastwards through Lombardy and Venetia, separating the piedmont plain from the high Alps. The general dip is to the south, under the plain, from which it is separated by a narrower strip of Cretaceous, while to the north it runs out over a wider strip of Triassic limestones and dolomites. In the region of Lake Garda all the Mesozoic outcrops widen and send a tongue NNE., deep into the Alps of the Trientina; the reason for this is that they are thrown down to the east along the Judicarian fault, which passes through the Judicarian and Brenta Alps on a line about 10 miles west of the lake. At the east end the outcrop passes through the Julian Alps into Slovenia and curves round to the south-east into the Dinaric Alps, which will be described with the Balkan Peninsula (p. 191). Small outliers, mainly of Lias, occur many miles north of the chief outcrop, in the Dolomites of the Tyrol and at a number of other places on about the same latitude.

In facies and faunas the post-Pliensbachian Jurassics of the Southern Alps conform closely to those of the Apennines and Sicily on the one hand and those of the Carpathians and Vienna Basin on the other. The North-Eastern Alps show the influence of proximity to the Bohemian massif during the Lower and Middle Jurassic (Gresten facies, see p. 172), but apart from that the North-Eastern Alps also belong to the same province. The similarities in the Upper Jurassic are striking. With the Swiss and French Alps and the territories beyond, including Provence and Sardinia, there is far less agreement: in fact, contrast almost everywhere after the Lower Pliensbachian. The inference is that these regions were separated on the far side of the Alpine Schistes lustrés geosyncline, and that the geosyncline, which can be first detected in Corsica, did not continue through the Eastern Alps but died out not far east of the Rhine line. Doubts cast on the identity of the Schistes lustrés of the Lower Engadine and Tauern windows (see p. 162, and Schwinner in Schaffer, 1951, pp. 216, 231) are thus supported by the facies and ammonite faunas on the opposite sides and east end of the Eastern Alps.

The chief peculiarities referred to, as characteristic of the Italian-Carpathian region and a wide area of the Mediterranean, are: (1) great abundance of special Hildoceratid ammonites in the Upper Pliensbachian (the Domerian fauna); (2) ammonitico rosso in the Toarcian, with abundance of otherwise rare Bouleiceratid genera; (3) thin, condensed, lenticular Bajocian, Oxfordian, and Lower Kimeridgian; (4) Upper Bajocian, Bathonian and perhaps Callovian developed as Posidonia beds with few or no ammonites; (5) Lower and Middle Kimeridgian as red nodular cephalopod limestones, the Acanthicus Beds; (6) lower part of the Tithonian in same facies as the Acanthicus Beds, and passing up

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imperceptibly into white Upper Tithonian limestone of Stramberg type; (7) imperceptible upward passage into similar white limestones of Berriasian age (Biancone).

The literature of the Southern Alps contains abundant references to overlaps of the Kimeridgian or Tithonian on to Middle and Lower Jurassic and Trias. These statements are still repeated by Heritsch & Kühn (in Schaffer, 1951, p. 253). A special study of the problem in the Lessini Alps, east of Lake Garda, however, led Pia (1920) to the conclusion that in each case an illusion of overlap is created by local passage of underlying Jurassic beds into dolomite which was mistaken for Triassic.

[BERRIASIAN

Biancone. White limestone identical with the Berriasian of Berrias and locally rich in Calpionella (de Lapparent, 1935), passing down into and difficult to separate from the Upper Tithonian.]

TITHONIAN

At the top, white limestones (Majolica, Diphya Limestone) with in the upper part Virgatospinctes transitorius, Micracanthoceras microcanthum, Ptychophylloceras ptychoicum, Holcophylloceras silesiacum and other ammonites of the Stramberg Upper Tithonian. This correlation was made as early as 1844 by von Buch. The lower part of the Diphya Limestone becomes red and nodular and, as in many parts of the Mediterranean area, is extremely hard to separate from the Acanthicus Beds. The succession seems to be identical with that in Sicily, which has been investigated in detail more recently (see p. 204). The lower part of the Diphya Limestone in many parts of the Southern Alps has yielded most of the ammonites of the Rogoznik Beds (e.g. Zittel, 1870, pp. 127-36; Munier-Chalmas, 1891, pp. 6-7). Many were figured in Zittel’s monograph (1870) as Lower Tithonian, but the development of true Lower Tithonian as here understood (see table 14, p. 167) is doubtful. It hangs on some isolated ammonites, such as Hybonoticeras hybonotum (Oppel) figured from near Roveredo by Benecke (1865, pi. xi), which does not seem identical with Oppel’s species. More detailed stratigraphical collecting is required. Long lists of ammonites from the two parts of the Tithonian usually recognized—the red beds below, white above—are given for the province of Verona by Nicolis & Parona (1885, pp. 10, 11), and (more up-to-date) for the Alpi Feltrine, Venetian Alps, by Dal Piaz (1907, pp. 150-3).

MIDDLE AND LOWER KIMERIDGIAN

The Acanthicus Beds, consisting of the usual red nodular limestones crowded with ammonites, were first named from the Alps on either side of the Adige valley by Benecke (1865, p. 129), who listed some of the commonest species. Many subsequent lists and discussions have been

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SOUTHERN ALPS

published, e.g. by Mariani (1899, with figure of *Idoceras taramellii* Mariani sp.), Alessandri (1903), Del Campana (1904, with figures of *Idoceras* sp., *Aspidoceras* and *Holocophylloceras polyolcum* Ben. sp.), and Airaghi (1928). From these beds come most of the ammonites figured in 7 large plates by Del Campana (1905), but as they are all museum specimens without precise stratigraphical data and the illustrations are for the most part inadequate, the new names (particularly of the Perisphinctids) are as difficult to apply as are Toula’s, mentioned above (p. 168). These two works, however, at least give an idea of the wealth of Perisphinctids present in the Alpine Middle and Lower Kimeridgian and awaiting monographic treatment. An interesting species is *Idoceras dedalum* (Gem.) (Del Campana, 1905, pi. i, figs. 16, 17) which belongs to a group with *Ataxioceras*-like ribbing abundant in Mexico. Some virgatotome Perisphinctids were already figured by Catullo (1853).

OXFORDIAN

As in Sicily and other parts of the Mediterranean province (Neumayr, 1871, pp. 355, 359) the Oxfordian appears to be elusive: absent in some places, present in others though condensed. A number of Perisphinctids figured (under wrong names) by Del Campana (1905, pl. ii and perhaps others) are Upper Oxfordian and indicate the Transversarium Zone, as does *Pachyceras* (*Tornquistes*) *nicolesi* Parona sp. from near Verona (Nicolis & Parona, 1885, pi. i, fig. 5—if the drawing can be trusted). The *Gregoryceras* figured by Del Campana (1905, pl. vi, fig. 1), though indeterminable from the photo, is probably *G. toucasi* (Kilian) of the Bimammatum Zone. To this zone also belongs *Amoeboceras* (*Prionodoceras*) *veronense* Parona sp. (Nicolis & Parona, 1885, pl. ii, fig. 1). The occurrence of the two northern genera *Amoeboceras* and *Pachyceras* near Verona is noteworthy.

Lower Oxfordian cannot definitely be recorded but may be represented by Aptychus Beds or Posidonia Beds.

CALLOVIAN AND BATHONIAN

No ammonites belonging unequivocally to either stage seem to be authenticated. It is possible that both stages are represented in the Posidonia Beds, which consist of crystalline red limestone and shale, the red stone sometimes packed with white *Posidonia* shells, forming lumachelles (Benecke, 1865, pp. 118-9—who already dated the beds to the Bathonian; also Pia, 1920, p. 128; Dal Piaz, 1912—no cephalopods; Bettoni, 1904). These beds, however, certainly are early Upper Bajocian at the base (see below).

BAJOCIAN

East of Lake Garda, in the Sette Comuni and at Aque Fredde, the lower part of the Posidonia Beds yields a dwarf fauna including many ammonites which are partly small species, partly nuclei and partly young. The two principal localities, monographed by Parona (1894, 1896), were

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believed by him to be on the same horizon although only *Posidonia* and a few ammonites are common to the two. They were interpreted by Parona as Callovian, but Haug (1910, Traité, p. 1029) pointed out that they are Upper Bajocian. From the plates of Parona’s second monograph (1896, pls. i, ii) it is clear that this is an important assemblage of the Subfurcatum Zone, and the following generic redeterminations are now suggested: *Poecilomorphus* (pl. i, figs. 4, 5, 6), *? Strigoceras* (8), *Oecotraustes* (10, 11, the latter same as ‘*Oppelina umbilicata*’ Buckman?), *Cadomoceras* (12, 13), *Sphaeroceras* (14, 15), *Oecoptychoceras* (16, 17), *Normannites* (19), *Teloceras* (20), *Cadomites* (21), *Caumontisphinctes* (22, and pl. ii, fig. 9), *Strenoceras* (1, 2), *Cleistosphinctes* (3), *Vermisphinctes* (5, 6). *Spiroceras annulatum* (Desh.) is recorded from Aque Fredde.

The Posidonia Beds are said (Parona, 1894, p. 366) to rest either on the Humphriesianum Zone or on a later crinoidal limestone; but although this would be the natural sequence, the presence of a Humphriesianum Zone fauna in this part of the Southern Alps seems unproved, although it is present, with a Sauzei Zone fauna also, in the Feltre region south of the Dolomites (Dal Piaz, 1907); this region has an exceedingly rich fauna of Middle Bajocian ammonites. A specimen of *Skirroceras* cf. *macrum* (Quenst.) in Milan Museum is figured by Alessandri (1903, p. 257), and *Emileia polyschides* is recorded with a *Skirroceras* near Lake Garda by Waagen (see Vacek, 1886, p. 200).

Another focus of interest in the Bajocian of the Southern Alps is an ammonite-limestone only 1 m. thick, which crops out at Cape St Vigilio on the east shore of Lake Garda. It is a condensed bed and contains, as Buckman pointed out (1910, p. 96), representatives of all the Bajocian zones from basal Sowerbyi (Discites Subzone) down to Opalinum, both inclusive, and also *Pleydelliae* of the topmost Toarcian (Aalenian Zone) as shown by Botto-Micca (1893). The bed, discovered by Benecke (1865), was made famous by Vacek’s monograph (1886). A nomenclatural revision is long overdue. Besides numerous Phylloceratids and Lytoceratids, Vacek figured (among others) the following ammonites:—

| Leioceras spp. | pl. vi, figs. 4-16; vii, 11-17; ix, 6, 7, 14 (for some Pleydellia spp. revisions see Botto-Micca, 1893) |
| Ludwigia sp., vii, 4, 8 |
| Brasilia sp., vi, 17; vii, 1-3 |
| Graphoceras sp., viii, 1 |
| Hyperlioceras sp., viii, 2 |
| Protoecotraustes sp., ix, 13 |
| Bradfordia gracililoba (Vacek), x, 1-4 |
| Bradfordia subplicatella (Vacek), xi, 1-5 |
| Bradfordia blumius (de Gregorio) ix, 8-12 |
| ? Hebetoxyites subaspidoides (Vacek), x, 5-7 |
| Eudmetoceras klimakomphalum (Vacek), viii, 16, 17 |
| Eudmetoceras amaltheiforme (Vacek), ix, 1-4 |
| Parammatoceras sieboldi (Oppel), xi, 6, 7 |

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Planammatoceras tenuinsigne (Vacek), xii, 7 (? 6)
Planammatoceras planinsigne (Vacek), xiii
Hammatoceras vaceki Roman non Prinz, xiv, 5-9
Hammatoceras dolium Buckman, xiv, 1-4
Hammatoceras procerinsigne Vacek, xiv, 10-13
Erycites fallax (Benecke non Guéranger), xv, 1-9
Erycites (Abbasites) goniornotus (Ben.), xvi, 9, 10
Erycites (new gen.?) tenax (Vacek), xv, 10-14
Erycites (new gen.?) sagax (Vacek), xv, 15-18
Zurcheria pugnax (Vacek), xvi, 1-4
Zurcheria pertinax (Vacek), xvi, 5-7
Tmetoceras scissum (Benecke), xvi, 15-17
Catulloceras dumortieri (Thiollière), xvi, 11-14
Docidoceras longalvum (Vacek), xvii, 1, 2
Docidoceras sp., xvii, 3
Docidoceras modestum (Vacek), xvii, 4-6
Docidoceras placidum (Vacek), xvii, 7-8
? Emileia punctum (Vacek), xvii, 12, 13

Vacek based on his study of this fauna a survey of the Bajocian of all Europe and drew far-reaching conclusions as to the classification of the Jurassic, but his conclusions are vitiated by his failure to realize the condensed nature of the bed, which he called ‘the Opalinum Zone’. A substantial part of the same fauna occurs farther east, in the province of Treviso (Botto-Micca, 1893).

LIAS (up to 600 m.)

The Lias, especially Toarcian and Pliensbachian, is so extremely rich in ammonites and has produced such an enormous literature, that a seriatim treatment cannot here be attempted. The zonal succession appears to be the same as in the Apennines and Sicily, both of which are treated stage by stage in this book (pp. 209, 217). As a broad generalization, the Toarcian and Pliensbachian consist predominantly of soft grey limestones and shales, the Sinemurian and Hettangian of hard light grey or white limestones, sometimes oolitic; the Hettangian being in places a white dolomite hardly distinguishable from the Rhaetian.

Special interest attaches to the Upper Pliensbachian. The substage name Domerian is named from Monte Domero or Domaro in the Lombardy Alps. Some of the monographs on the Domerian fauna, however, include a number of ammonites which according to the classification now used belong to the basal Toarcian. In some of the most recent and important stratigraphical work this arrangement is still maintained (e.g. Venzo, 1952, pp. 112, 113). In the Upper Toarcian there is a great variety of species which are customarily assigned to a number of different genera set up by Buckman but arbitrarily defined and better considered synonyms: e.g. Chartronia and Denckmannia Buckman do not seem objectively separable from Phymatoceras Hyatt when referred...

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back to the type species. The classification of the Hildoceratidae is also in an unsatisfactory state.

For the Toarcian and Pliensbachian reference should be made to Bettoni (1900), Bonarelli (1894, 1895), Ceretta (1938), Cita (1947), Desio & Airaghi (1934), Fucini (1908), Gregorio (1885), Haas (1913, 1951), Hauer (1861), Lepori (1942), Meneghini (1867-81), Mitzopoulos (1932), Mitzopoulos & Renz (1929), Negri (1934-6), Parona (1892), Renz (1922, 1925, 1925b, 1927), Taramelli (1880), Tausch (1890), Toni (1911-12), Vecchia (1949), Venzo (1952 and monographs in the press).

For the Sinemurian and Hettangian important works are those by Alessandri (1903), Boehm (1884), Bonarelli (1894), Ceretta (1938), Negri (1934-6), Parona (1896-8), Taramelli (1880), Vecchia (1945, 1948, 1949).
CHAPTER 7

THE BALKAN PENINSULA

EASTERN CARPATHIANS, TRANSYLVANIAN ALPS, BANAT

From the headwaters of the River Theiss, in Bukovina, the Carpathian arc turns SSE. and then south, fronted by its own flysch zones with remnants of the klippe chain on their inner edge. At the knee-bend, where eastern Carpathians turn west into Transylvanian Alps, these zones are cut off as it were by a mighty tear system. Under the Wallachian plain there seems to lie a rigid spur which has underthrust WNW. and produced the great loop of mountains in which the Transylvanian Alps on the north and the Balkan Mountains on the south face one another across the lower Danube plain and join at the Iron Gates. Stille (1953) calls this the Wallachian spur and visualizes it as the western tip of a sunk block underlying the Black Sea (the Euxinic Swell of Stille, 1953, p. 156, Pontic Mass of Wilser, 1928, p. 216).

The eastern Carpathians and Transylvanian Alps, and the associated mountains of Banat to the west and SW., enclose the basin of Transylvania (Siebenbürgen, part of which is Szeklerland of the older geological literature), and Jurassic outcrops, important out of proportion to their small size, occur in the mountains on east, south and west sides of the basin. The Jurassic is characterized by patchy Lias, largely in the near-shore Gresten facies, overlain by transgressive Lower Kimeridgian or Tithonian; but in places thin, condensed cephalopod beds of Upper Oxfordian, Middle Callovian, or Bathonian dates begin the transgressive series, after what appears to have been almost complete regression in the Bajocian. Thus the area epitomizes many of the principal transgressions that occurred in many parts of the world. From Bathonian to Oxfordian, both inclusive, there was non-deposition or retarded deposition and condensation, as in many other parts of the Mediterranean region. Strong deposition began only with the Tithonian (reef limestones up to 340 m. thick). The ammonite faunas are all markedly Mediterranean, with abundance of Phylloceratids and Lytoceratids at all levels, but with a strong mixture of north-European forms in the Bathonian, Callovian and Oxfordian.

The clastic materials in the Gresten facies of the Lias are believed to have been derived from a Liassic landmass called by Mojsisovics the Oriental Island (Pompeckj, 1897). It covered the southern part of Transylvania and the southern part of the Hungarian plain (Pannonian basin) and was continued through Serbia to include the south-eastern part of the Balkan peninsula and the Aegean. It is noticeable that the Wallachian-Bulgarian gulf postulated by Pompeckj for Liassic times nearly coincides with the rigid Wallachian spur postulated by Stille (1953) on tectonic grounds. The Liassic outcrops considered by Pompeckj, however, lie

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Fig. 18.—Jurassic outcrops of the northern and central Balkan peninsula, compiled chiefly from maps by Petkovic (1930-31) for Yugoslavia, and Boncev (1936), with modifications from Kamenoff (1947) for Bulgaria.
within the folded and thrust mountain ranges and must have been more or less displaced during the Tertiary movements. His detailed reconstruction of the shoreline of the Oriental Island takes no account of these movements and may therefore be misleading. Nor does it follow that the Wallachian spur was covered by Liassic sea, for according to Stille’s tectonic interpretation it was not moved into its present position until Upper Cretaceous times; and the more easterly parts, now under the Black Sea, are believed, from evidence on the north coast of Anatolia, to have been above sea-level in the Lias. Pompeckj’s map of the Oriental Island is reproduced here (fig. 19) for historical interest and because in essence the concept is probably correct; but its coasts have had to be redrawn to exclude outcrops since discovered in the Stranca Mountains and Argolis, and the easterly connexions have been modified after Wilser.

**TITHONIAN**

Massive white Tithonian limestones form crags and precipitous cliffs here and there throughout the klippe chain of the eastern and southern Carpathians. Some of the most spectacular are the crags of the Nagy-hagymás Mountains between latitude 46° 30’ and 47°, studied by Herbich (1878, p. 190). The thickness here is up to 340 m., but fossils are hard to extract—chiefly corals, *Diceras*, and large gastropods, no ammonites. In the western Transylvanian Alps (Banat) red limestones with *Berriasella richteri* (Op.) and other Perisphinctids are overlain by white cherty Berriasian limestones with *B. boissieri* (Pict.), and in another part of the same area white Diphya Limestone with chert nodules is attributed to the Tithonian (Tietze, 1870). Near the Iron Gates, on the Danube, the Tithonian rests on Bathonian (Tietze, 1872, pp. 72, 74), and in the Transylvanian Alps in some places on Callovian, in others directly on crystalline schists of the basement (Popovici-Hatzeg in Haug, 1910, Traité, p. 1106).

**MIDDLE AND LOWER KIMERIDGIAN**

This is developed in its typical Mediterranean form of red or green and sandy, massive or nodular, cephalopod limestones, the Acanthicus Beds. Neumayr (1873) and Herbich (1878) monographed the ammonites, with a wealth of figures. It so results that these remote and sparsely inhabited mountains yielded the types of genera and species quoted for the Kimeridgian the world over. Unfortunately Herbich’s figures are not up to the standard of Neumayr’s, and his types will have to be refigured before his numerous species can be interpreted. Both authors established the presence of two zones in the Acanthicus Beds: the upper or Beckeri Zone is characterized by abundance of *Pygope janitor* and by the ammonites *Hybonoticeras beckeri* (N.), *H. harpephorum* (N.), *H. verestoicum* (H.), *Aspidoceras microplum* (Op.), *Glochiceras fialar* (Op.), *G. tenuifalcatum* (N.), *Taramelliceras compsum* (Op.), *T. kochi* (H.), *T. pugilis* (N.), *T. mikoi* (H.), *Hemihaploceras schoageri* (N.), *Sowerbyceras loryi* (Munier), etc.
The lower or Tenuilobatus Zone is characterized by Holcophylloceras polyolcum (Ben.), Phylloceras isotypum (Ben.), Taramelliceras trachynotum (Op.), Aspidoceras uhlandi (Op.), A. zeuschneri Zit., A. deaki H., Pseudosimoceras herbichii (Hauer), P. teres (N.), Ataxioceras fasciferum (N.) et spp., Sutneria spp.

Unfortunately the horizon of some of the most interesting forms is still unknown: among them Hemihaploceras nobile (N.) (type of the genus), Semiformiceras darwini (N.), Simocosmoceras nitidulum (N.), Katroliceras acer (N.), Pseudowaagenia haynaldi (H.) (type of the genus), and most of the remarkable Perisphinctids. Many species, including Aspidoceras acanthicum, Lytoceras polycyclum and Phylloceratids, range through both zones. Pygope janitor is confined to the Beckeri Zone.

In the region of the Iron Gates and also in the Transylvanian Alps the Acanthicus Beds are absent, overlapped by the Tithonian.

Oxfordian

Apart from a small collection of Upper Oxfordian Perisphinctids and Euaspidoceras from a locality in Banat (Neumayr, 1871, p. 356) no
Oxfordian seems to be known in the region. However, if Herbich's drawing is accurate, his *P. witteanus* (1878, pl. ix, fig. 2) is more like a *Microbiplices* than a *Prorasenia* and suggests that the top of the Bimammatum Zone may be represented in the Acanthicus Beds. Some of his Perisphinctids, to judge from the drawings (*P. siculus, P. stenonotus, P. oxypleurus*) could also be late Oxfordian.

**Callovian**

This stage likewise is generally absent, but at Valea Lupului, near Rucar, in the Transylvanian Alps, it is present in the form of a red crinoidal limestone intercalated between the crystalline schists and transgressive Tithonian. It yields an ammonite fauna of the Anceps and Athleta Zones (Simionescu, 1898, 1899). Among the few figured species, *Kosmoceras mrazeci* Sim., belonging to the *duncani* group, *Peltoceras subannulare* Sim., and some *Hecticoceras* spp. indicate Upper Callovian, whereas most of the forms recorded but not figured are of the Anceps Zone.

**Bathonian**

No representative of this stage is known in the northern areas, but in the Transylvanian Alps and Banat and across the Danube into the western Balkan Mountains it is present in a number of places, in the form of a thin, condensed, ironshot limestone, packed with well-preserved ammonites. The thickness of the bed does not exceed 1 m. and it occurs only as lenticles here and there at the base of the Tithonian limestones and rests on coarse sandstones attributed to the Lias. The most conspicuous element in the fauna is Lower Bathonian, but Upper Bathonian is also present, as in Sicily (p. 208). The bed was first made known at Swinitza, on the left bank of the Danube near the Iron Gates, where it is 1 ft. thick, and as all the ammonites described in the classic monograph by Kudernatsch (1852) have been renamed, either generically or specifically or both, those figured are here listed under their revised names. The numbers refer to Kudernatsch's plates and figures.

- *Phylloceras subobtusum* (Kud.), ii, 1-3
- *Phylloceras kudernatschi* Hauer, type i, 5-9
- *Calliphylloceras disputabile* (Zittel), i, 1-4
- *Lytoceras adeloides* (Kud.), ii, 14-16
- *Lissoceras ferrifex* (Zittel), type ii, 4, 5
- *Lissoceras psilodiscus* (Schloenbach), ii, 7, 8
- *Prohecticoceras binculptum* (Oppel), type ii, 9, 10
- *Prohecticoceras* sp. nov., ii, 11, 12
- *Bullatimorphites ymir* (Oppel), type iii, 1, 2 (and 3, 4?)
- *Cadamites rectelobatus* (Hauer), iii, 5, 6
- *Siemiradzkia aurigera* (Oppel), iii, 7, 8
- *Siemiradzkia* sp., iii, 9, 10
- *Wagnericeras banaticum* (Kud.), type iv, 1, 2
- *Procerites* sp., iv, 3, 4

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From Mount Strunga, in the Bucegi group, Transylvanian Alps, a more extensive fauna has been published, with many figures (Simionescu, 1905; Popovici-Hatzeg, 1905). It contains typical Procerites of the subprocerus group (Simionescu, pl. ii, fig. 1, pl. iv, fig. 1) and Oxycerites fallax Guéranger sp. (figured by both authors) and many other interesting Oppeliids, such as Prohecticoceras haugi, P. retrocostatum, Paralcidia mariorae, Strungia redlichi, S. binodosa, various Bullatimorphites and allied forms, and a wealth of Phylloceratids.

This fauna is neither wholly Lower Bathonian as stated by Tietze (1872, p. 72) nor Upper Bathonian as stated by Haug (1910, Traité, p. 1030), but a condensed combination of both, with Lower Bathonian elements predominating. Popovici-Hatzeg (1905, p. 23) recorded also two species of Macrocephalites but did not figure them, and in 1954 nothing belonging to this genus could be found in his collection in Paris. Since certainly one and probably both of the 'Macrocephalites' figured from Villany by Loczy (1915, pl. iv) are misidentified generically, the Mount Strunga records should be taken with reserve until confirmed.

BAJOCIAN

In Banat are Posidonia shales believed to be of Lower Bajocian age (Tietze, 1872, pp. 69-70), and at Mount Strunga the Lower Bathonian ammonite bed is underlain by sandstones with pelecypods and brachiopods said to belong to Bajocian species; these repose with a basal quartz conglomerate on the crystalline schists (Popovici-Hatzeg in Haug, 1910, Traité, p. 1030).

TOARCIAN AND PLIENSBACKIAN

Zonal ammonites of the Lower and Upper Toarcian and especially of the Upper Pliensbachian are quoted from all sides of the Transylvanian basin but no sequences of special interest are reported. (See Tietze, 1870, 1872; Herbich, 1878, pp. 120-8; Pompeckj, 1897, pp. 764, 768-9). The beds are developed as sandstones, shales and micaceous sandy limestone, in the Gresten facies.

SINEMURIAN AND HETTANGIAN

In the west and SW. (Banat) and SE. (Kronstadt, = Brasov) areas the near-shore Gresten facies seems to go down to near the base of the Lias, judging by Cardinia and other fossils, but ammonites are absent or rare. The rock-types are chiefly sandstones, grading on the one hand into shales and on the other into conglomerates, and sometimes containing coal-seams. (References as for Pliensbachian).

In the eastern Carpathians, however, in Bukovina (Uhlig, 1900) and Transylvania, especially at Alsorakos in the Persany Mountains on latitude 46° N., there are small outcrops of red ammonite limestone and shale,

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of Adneth facies. The thickness at Alsorakos is only 3 to 6 m. and no sequence is discernible, but at least 73 species of ammonites have been described by Herbich (1878) and Vadasz (1908; with revision of Herbich's types). Ammonites comprise 84 per cent. of the known fauna in numbers of species, but much more in numbers of individuals; and by far the greater part are Phylloceratids. This small outcrop was the richest in Phylloceratids described anywhere, but it is now known to be at least equalled by northern Bakony (see p. 190). From Alsorakos Herbich figured the type species of *Schistophylloceras* Hyatt (pl. XX, G, fig. 2), *Geyeroceras* Hyatt (pl. XX, E, fig. 2), *Dasyceras* Hyatt (pl. XX, G, fig. 3), and *Paradasyceras* Spath (pl. XX, K, fig. 1), also forms of *Juraphyllites* (pl. XX, 1), *Hantkeniceras* (pl. XX, E, fig. 3), and the usually rare *Ectocentrites* (pls. XX, L, fig. 1, XX, B, fig. 3) and *Peltolytoceras* (pl. XX, C, fig. 1). There are also Schlotheimids, Arietitids, *Gagaticeras* (pl. XX, E, fig. 1), *Echioceras*, etc., representing the whole of the Sinemurian and the top of the Hettangian. The beds rest on, and may be enclosed in, volcanic tuffs of post-Jurassic age. Elsewhere similar tuffs enclose erratic blocks of Triassic and Tithonian limestone, and the occurrence farther north of Callovian ammonites in tuffs may be analogous (see p. 170). The explanation is not clear.

The red Lower Lias limestones of Valesacca in Bukovina yield an assemblage consisting mainly of Arietitids (among them four new species) surprisingly different from the fauna of Transylvania, although having a number of common species (Uhlig, 1900). The zones represented here are those of Obtusum, Oxynotum and Raricostatum (Gugenberger, 1936, p. 203).

**BALKAN MOUNTAINS**

The Transylvanian Alps and associated mountains of Banat cross the Danube at and upstream of the Iron Gates, continue southward for a while, then curve round to run west-east through the Stara Planina and Balkan ranges, completing a perfect U-bend around the plain of Wallachia or Lower Danube basin. The whole range, from the Danube to the Black Sea, is considered in this section as the Balkan Mountains in the extended sense of the term.* The western and central parts are strongly overthrust towards the Wallachian plain, but farther east, where the mountains decrease in height, the northward movement also dies down and a broadening autochthonous flysch zone comes in; in this eastern sector the cross-section is comparable with that across the chain-Jura and plateau-Jura where they approach the foreland of the Black Forest—the foreland here being a sunk block beneath the plains, which comes to the surface in Dobrogea (see p. 188). Shortly before striking out into the Black Sea, the remaining Balkan structures take an east-south-easterly turn, pointing towards the northern ranges of Anatolia, in which they are continued (Kockel, 1927; Wilser, 1928).

* In a tectonic sense this usage would appear to be unjustified (see Boncev, 1938).
Numerous disconnected outcrops of Jurassic occur all through the Balkan Mountains, especially in the west, where they are scattered over the whole width between the valleys of the Danube and Morava Rivers and nearly surround the granitic and palaeozoic core of the Stara Planina. (See Boncev, 1936.) Kimeridgian and Tithonian outcrops also cover extensive areas farther west in the neighbourhood of Belgrade, where they were mapped as Neocomian (Gocanin, 1938). Considerable outcrops are now also known in the Stranca Mountains, which diverge SE. towards the Bosphorus (Cohen, 1946).

TITHONIAN

Tithonian limestones in reef and off-reef facies are thickly developed, especially in the west. Uhlig (1884) already recognized their resemblance to Stramberg limestone on the right bank of the Danube at Golubac. From here southward they spread out in long north-south lines and blend inseparably with Berriasian limestones in similar facies, the whole mass 500-700 m. thick. The N-S linear arrangement is thought to be in part original, the reefs having grown along the east shore of the Oriental Island. The fauna is rich in gastropods, corals, etc., and also yields Phylloceratids, Lytoceratids and Perisphinctids (Petkovic, 1949). A Perisphinctid from the Tithonian near Petrovac, SE. of Belgrade and about 25 miles south of the Danube gorge, has been identified with a New Zealand species, Aulacosphinctoides brownei Marshall sp. (Petkovic, 1938); but although the specimen is poor and the figure not clear, so far as it can be seen it looks more likely to be Berriasella lorioli (Zittel), or Aulacosphinctes eudichotomus (Zittel), which was already recorded from Golubac by Uhlig in 1884.

Farther south-east, in the region SW. of Sofia, the reef facies changes into nodular, calcareous and argillaceous sandstones with intercalations of sandy shales, marls, sandy limestones and conglomerates. The thickness of the Tithonian alone still exceeds 150 m. The marly limestones and shales yield a rich ammonite and aptychus fauna, chiefly of the Upper Tithonian but including Neochetoceras steraspis Oppel sp. (Beregov, 1933, 1935; Boncev & Beregov, 1935). (Some figures in Cohen & others, 1946, pls. vii, viii.)

In the Belgrade district there are conglomerates and a slight unconformity between Lower and Upper Tithonian, and a ‘diabase-hornstone formation’ occurs in the Lower Tithonian (Gocanin, 1938).

MIDDLE AND LOWER KIMERIDGIAN

Red or grey and red-spotted nodular marly limestones, marls, and clay shales, sometimes with chert nodules, form typical representatives of the Acanthicus Beds and have yielded a long list of the usual ammonites (Zlatarski, 1908, pp. 221, 228; Beregov, 1935). Two species of Tara melliceras, T. bulgaricum and T. balkanense, were named from a locality
north of Sofia (Toula, 1893, pl. ii, figs. 1, 2). Another list typical for the Acanthicus Beds comes from a locality in the Stara Planina (Kamenov, 1934). The thickness with the Oxfordian amounts to about 50 m.

**Oxfordian**

In the central Balkans marly limestones with black cherts have yielded *Peltoceras arduennense* (d'Orb.) and some Perisphinctids, and farther west shales and false-breccias have produced *Perisphinctes tizianiformis* Choffat (Zlatarski, 1908, p. 227; Beregov, 1935).

**Callovian** has not been established. Ammonites from the Stara Planina figured as from Macrocephalus beds by Boncev & Popov (1935) look more like Bathonian *Procerites* (fig. 2), *Choffatia* (4, 5), *Wagnericeras* (6) and *Oxycerites* (1).

**Bathonian**

The condensed Bathonian ammonite bed of Swinitza continues on the prolongation of the Banat ranges south of the Danube. It is only 10 cm. thick and soon wedges out. It is close above crystalline basement and overlain directly by red nodular limestones ascribed to the Tithonian (Uhlig, 1884). Farther south beds with brachiopods and pelecypods associated with the Upper Bajocian are probably in part Bathonian.

**Bajocian**

In various parts of the Balkan Mountains the zonal index species of the Parkinsoni, Garantiana, Humphriesianum, Sauzei, Murchisonae and Opalinum Zones are recorded, with *Oppelia subradiata*, *Dorsetensia edouardiana*, *Normannites braikenridgei*, *Chondroceras gervillei* and other ammonites, *Spiroceras*, and an extensive fauna of brachiopods and pelecypods (Zlatarski, 1908, pp. 191, 226; Cohen, 1932; Beregov, 1935, p. 108; some figures in Cohen & others, 1946, pls. vi, vii, and in Tzankov & Boncev, 1934). The records show that some zones are present in some parts of the range, others in other parts.

**Toarcian**

This stage is likewise well represented, with *Pleydellia aalensis*, *Dumortieria levesquei* and all the usual Hildoceratids and Dactylioceratids (listed Zlatarski, 1908, pp. 179-80; Toula, 1881; Cohen, 1932). The facies is always clay shales or clayey sandstones.

**Pliensbachian, Sinemurian, Hettangian**

Lower and Middle Lias are widely distributed and take on a great variety of facies—sandstones, shales, marls. Ammonites recorded, if correctly determined, indicate the presence of all three stages, from Spinatum to Angulatum Zones (Zlatarski, 1908, pp. 174-5, 178-9, 223-5; Toula, 1893; Tzankov & Boncev, 1932; Bakalov, 1936).
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DOBROGEA

More than 100 miles north of the outer folds of the Balkan Mountains, where they run out into the Black Sea, and far out in the foreland of both Balkans and Carpathians, Mesozoic and Palaeozoic rocks rise from the alluvial plains and loess in the Dobrogea. The isolated group of hills so formed is enclosed in a peninsula between the sea and the right-angled bends and marshes of the Danube, before it enters the delta. The chief Jurassic inliers protrude from loess across the neck of the peninsula and some are well exposed in cliffs on the Danube near Harsova, and in large quarries worked for cement.

The Jurassic sequence (Simionescu, 1910) rests unconformably on green schists of Lower Palaeozoic age and begins with sandstone and a ferruginous limestone, both of uncertain date: perhaps Lower Oxfordian or Upper Callovian, judging by some echinoids and Rhynchonella thurntanni. Above this comes a thick series of limestones with a wonderful Upper Oxfordian ammonite fauna monographed by Simionescu (1907), passing laterally into sponge limestones and coralline sand, followed without distinct break by similar Lower Kimeridgian limestones which pass laterally and upward into coral limestones. At the top are regularly bedded limestones and dolomites without diagnostic fossils, probably Middle Kimeridgian in date, overlain by Cretaceous conglomerate.

Many of the ammonites figured in Simionescu's excellent monograph have been discussed by me in my monograph on the ammonites of the English Corallian Beds. One of Simionescu's species, Perisphinctes cotoevui, proved to be the commonest and most characteristic form in the English Plicatilis Zone and his name was adopted. Many of the other Perisphinctids are also of this age, though most show subtle differences in some character or other from their closely allied counterparts in Britain and NW. Europe, no doubt due to geographical distance. Many are identical with forms in the similar thick Upper Oxfordian limestones of the Cracow district (p. 479), others with those of Trept (p. 95).

Peltoceras arduennense (d'Orb.), recorded from the basal bed, above the undated ferruginous limestone, indicates that the main limestone series begins with the Lower Oxfordian, and several other ammonites not tied down stratigraphically are also Lower Oxfordian, for instance Protophites christoli (Baud.), Perisphinctes michalskii Buk., Peltoceras cf. constantii (d'Orb.), Euaspidoceras babeiannum (d'Orb.), E. edwardsianum (d'Orb.); but there are no Cardioceratids, and very few Phylloceratids at any level.

The greater part of the fauna, however, belongs to the Bimammatum Zone, which is represented by Epipeltoceras bimammatum (Quenst.), E. berrence (Favre), Euaspidoceras oegir (Oppel), E. hypselum (Oppel), Clambites clambus (Oppel) and remarkable Perisphinctids. Lower Kimeridgian elements are certainly present also, for instance Ataxioceras cf. inconditum (Font.), Physodoceras liparum (Oppel), Aspidoceras cf. uhlandi (Oppel). As indicated by these records, the Bimammatum and

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Tenuilobatus Zones show a marked affinity with SW. Germany. The highest beds, in Plattenkalk facies, assigned by Simionescu to the 'Portlandian', may therefore be approximately equivalent to the Franconian Plattenkalk (Gravesia Zones).

In northern Dobrogea marine Lower, Middle and Upper Trias come in below the Upper Jurassic, but the uppermost Trias is in sandstone and conglomerate facies and discontinuous, indicating the onset of the Lower and Middle Jurassic regression. While the Upper Jurassic is only gently undulated on NW.-SE. axes, the Trias is sharply folded, overturned and imbricated on NE.-SW. axes, parallel to the strike of the Palaeozoic. This occurrence of strongly folded Trias below undisturbed Upper Jurassic is highly anomalous: no parallel can be found for it in any surrounding country in Europe or west Asia. Suess inferred a 'Lower Cimmerian' (post-Trias, pre-Lias) orogeny and assumed that the Dobrogea and Crimea formed parts of a mountain range raised at this time, the 'Cimmerian Mountains'. In fact, however, movements at this period in the Crimea are extremely doubtful (see p. 354) and in the Dobrogea they could have taken place at any time between the Upper Trias and the Upper Jurassic, though the absence of Lower or Middle Jurassic sediments makes an early date most probable. Wilser (1928, p. 180) believed that the distortion of the Trias was caused by disharmonic folding of the less competent Trias beneath the highly competent cover of Upper Jurassic limestones during the Tertiary orogeny; but the strikes are discrepant, and no folding of the Jurassic violent enough to make this probable has been reported. Another possible explanation might be penecontemporaneous slumping. However this may be, the Dobrogea clearly is an upraised part of the foreland of the Balkan and Carpathian arcs. As Wilser emphasized, its stratigraphy, both Palaeozoic and Mesozoic, provides no grounds for assuming continuity with the Crimea and Caucasus, where the sediments appear to have accumulated on the margin of the northern continent in a geosyncline which opened south-eastwards into the Tethys but came to a blind end westwards over what is now the western Black Sea. (See also Stille, 1953, pp. 133-5.)

**Bakony and Mecsec Mountains**

The Bakony Mountains run for about 125 miles SW. from Budapest, north of and parallel to Lake Balaton. The structure is in the main a series of tilted fault blocks or plateaux, consisting principally of Triassic dolomites. Upon the Trias follows a variable thickness of Liassic limestones and shales in many different facies, ranging from Hettangian to Toarcian. The Lias is apparently complete, though certain zones may be missing locally. In the north-east Lower Bajocian up to Murchisonae Zone follows on, developed as red limestones. The Upper Toarcian in the south, Lower Bajocian in the north, are unconformably overlain by white Upper Tithonian limestones with *Berriasella cf. lorioli* (Zit.),

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**THE BALKAN PENINSULA**


The Bakony Mountains are one of the world's richest areas for Liassic ammonites, especially the Phylloceratina; they have been monographed by Prinz (1904), Vadasz (1910) and Kovacs (1942). Kovacs (1939, 1942) undertook a revision of the systematics of the Phylloceratina on the basis of material from northern Bakony, but unfortunately a number of new genera introduced are synonyms of names already current. The nearest comparisons faunally are with Transylvania and the Southern Alps.

Another isolated inlier of Lias and Lower Bajocian occurs in the Mecsec Mountains near Pecs (Fünfkirchen), about 50 miles SE. of Lake Balaton. Much of the sequence here, especially the Lower Lias, is in Gresten facies, sandstones and shales with coal seams (see Pompeckj, 1897, p. 765).

**VILLANY HILLS**

About 115 miles nearly south of Budapest, on the west bank of the Danube and 20 miles SE. of Pecs, limestone quarries in the Villany Hills expose an isolated inlier of Jurassic deposits totally different from those of Bakony and Pecs. Neither Lias nor Tithonian occurs at Villany, but instead there is a development of some of the stages missing at the unconformity between them in Bakony (Fig. 18, p. 180).

In the Villany quarries Triassic dolomite is overlain disconformably by 12-16 m. of grey sandstone passing laterally into conglomerate with derived limestone blocks and into sandy echinoidal limestone. These beds have yielded no ammonites but are rich in Nautilids, and on the basis of these and a few species of brachiopods and pelecypods they have been considered to be Bathonian.

There follows conformably, but with a marked lithological break, a 3 m. ammonite bed: a brown to red, ferruginous, glauconitic, compact marl, crowded with ammonites, which have been sumptuously monographed by Till (1910-11) and Loczy (1915). The preponderant families are Hecticoceratinae, Reineckeidae and Perisphinctids belonging chiefly to *Grossoueria* but also *Subgrossoueria*, *Choffatia*, *Indosphinctes*, etc. *Kosmoceras* is present but rare, and one of the three species is highly peculiar (*K. globosum* Till). From the Reineckeids and *Erymnoceras triplicatum* (Till), *Phlycticeras*, and many of the Perisphinctids, the age of the bulk of the fauna can be dated to Middle Callovian, Anceps Zone, but with representatives of the Upper Callovian (Athleta Zone).

Loczy was unable to establish any succession of ammonites within the 3 m. bed, and accepted the whole fauna as Callovian. Among his figures, however, are a number of ammonites which appear to be Bathonian, and these collectively create a presumption that the bed contains a condensed representative of part of the Bathonian and is in part equivalent to the ammonite bed of Swinitza and Mount Strunga, with which it has some 9 or 10 species in common (not counting most of the Perisphinctids).
which are proverbially difficult to identify with certainty from figures of incomplete material). In the following list of predominantly or wholly Bathonian forms the references are to Loczy’s plates.

Lytoceras adeloides (Kud.) (p. 308)
Phylloceras hudsonmansi Hauer (i, 1-2)
Phylloceras hatzegi Loczy (i, 3)
Ptychophylloceras flabellatum (Neum.) (i, 4, ii, 1)
Calliphylloceras disputabile (Zit.) (i, 2; ii, 3-5; iii, 1)
Prohecticoceras haugi (Pop.-Hatzeg) (v, 1-2)
Prohecticoceras subpunctatum (Schlippe) (iv, 6-7)
Prohecticoceras angulicostatum (Loczy) (v, 4; vi, 1)
Oecotraustes aff. nodifer Buckman (iii, 8, 9, 19, 20)
Paralcidia mariorae (Pop.-Hatzeg) (iii, 14, 15; iv, 5)
[? Clydoniceras cf. tegularum Arkell (iv, 3)]
Cadomites cf. extinctus (Quenst.) (iv, 10)
Tulites (Rugiferites) sp. indet. (iv, 9)
? Tulites (Rugiferites) sp. indet. (iv, 8)
? Wagnericeras banaticum (Kud.) (x, 8)
Procerites aff. subprocerus (Buck.) (p. 425)

Unique and problematic ammonites are Villania densilobata Till (misinterpreted as a Perisphinctes by Loczy) and ‘Aspidoceras’ rollieri Loczy, both of which by their sutures and mode of coiling appear to be new genera of Lytoceratina.

The ammonite bed is disconformably overlain, with a sharp boundary, by thick, hard Upper Oxfordian limestone, which is the rock principally worked in the quarries. Lower Oxfordian is missing, and nothing higher than Upper Oxfordian is exposed or known to occur in the Jurassic sequence.

DINARIC RANGES AND Dalmatia

Like the Wallachian plain, the Adriatic depression is pinched between folded and overthrust ranges which have driven towards it from opposite sides: across the Adriatic Sea the Apennines, in which movement has been to the NE., face the Dinaric ranges, in which movement has been to the SW.

On the Dalmatian side, Istria and the islands and coast ranges are part of the foreland, corrugated by simple folds and faults. Deformation increases in intensity inland and soon folds give place to thrusts (Bourcart, 1922, 1928). At the same time the Mesozoic rocks change in facies. Triassic limestones and dolomites, followed by Jurassic limestones which may represent continuous sedimentation, give place in the inner thrust regions to Triassic geosynclinal deposits with masses of cherts, siliceous shales or hornstones, radiolarites, greenstone intrusives and extrusives (‘ophiolites’), and highly incomplete Jurassic. A number of tectonic zones have been worked out and their connexions with the southern Alps and

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Greece suggested (Nopcsa, 1921; Kossmat, 1924), but the geology is complicated and by no means fully elucidated. According to the latest interpretation (Pilger, 1941) the inner Dinaric ophiolite belt represents a Triassic geosyncline where igneous activity reached its climax in the Ladinian with the intrusion of serpentine batholiths, and where the Jurassic and Lower Cretaceous represented a pause before orogenic movements in the mid-Cretaceous (pre-Gosau movements). The ophiolite series is overlain, with basal conglomerates, in some places by Lias, in others by Tithonian, and in others by the Upper Cretaceous. Thus there appears to have been a westward migration of the trough of deposition after the end of the Trias, as on a much larger scale in the Californian coast ranges after the Nevadan orogeny (see p. 552). Everything has been much complicated by the Cretaceous and Tertiary orogenies.

The age of the hornstone-radiolarite-ophiolite series has been a burning problem. Steinmann considered it Lower Cretaceous. Kossmat (1924) made out a good case for its being Jurassic, and 'Diabase-hornstone beds' have been shown to occur in the Lower Tithonian near Belgrade (Gocanin, 1938). Pilger (1941) and Ledebur (1941), however, are satisfied that in the Dinaric ranges the main suite is Triassic and that probably the whole Trias passes laterally into it, but that in addition there are local, relatively insignificant, developments also in the Jurassic (Ledebur, 1941, p. 489). These later German papers do not seem to have been known to Bourcart (1944), but they confirm his suggestion that the ophiolite series is of different ages in different places, and they explain the conflicting records of ophiolites above and below Upper Trias and overlain in some places by Lias, in others by Tithonian, and in others by Cretaceous with basal conglomerates containing derived greenstone pebbles. Evidently it would be rash to assume even approximate identity of age in regions still farther away, such as the western Alps, Spain or Anatolia, where similar suites are developed.

The only Jurassic fossils known in these mountains with certainty are Lower Jurassic (Lias), basal Bajocian, Kimeridgian and Tithonian, but knowledge is still very incomplete (see Jovanovic, 1951, 1951a). For the Lias, the older literature was analysed by Pompeckj (1897, p. 766). Some Hettangian ammonites are known from red siliceous limestone in Bosnia (Bittner, 1885). In central Dalmatia thick limestones and dolomites with Megalodus and the problematic Lithiotis but no ammonites, and Flecken-mergel, were classed as Lias by Bittner (1907). In Herzegovina, near Sarajevo and in the Zlatibor Mountains, Lias believed to be Pliensbachian in age, with a basal conglomerate, transgresses over and fills pockets in various parts of the Triassic dolomites and limestones down to Werfen Beds (Pilger, 1941, p. 439; Ledebur, 1941, p. 489, some ammonites described and figured, p. 490 ff). Toarcian ammonites occur at Vojnik in Montenegro (Besic, 1948); and at Scutari in northern Albania the Toarcian has already taken on the facies of Ammonitico rosso which

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characterizes it in Greece and the Apennines. Here the red marly limestones also yield some Upper Pliensbachian and basal Bajocian (Opalinum Zone) ammonites (Saxl, 1916; Magnani, 1942). The connexions with Greece were discussed by Renz (1904, 1908, 1927).

The next-youngest dated fossiliferous rocks are the Lemesf Beds of Dalmatia, a thick series of flaggy to fissile, compact limestones (Plattenkalke), overlain by thick-bedded limestones with chert lenses, then 20-30 m. of spotted limestones, and finally unfossiliferous dolomite of unknown age (Furlani, 1910). At the base is a limestone yielding only a coral, *Cladocoropsis mirabilis* (Felix), of interest because it occurs in similar limestone in Cyprus (p. 352). The overlying Plattenkalke strongly resemble those at Solnhofen in Bavaria and contain some of the same species of fossils, including ammonites, and are probably of about the same age. Figured ammonites are *Lithacoceras pseudoulmense* (Furlani) and *Taramellliceras dinaricum* (Furlani), both new species, but 23 other species are recorded, including *Aspidoceras longispinum* (Sow.), *Neochetoceras steraspis* (Oppel), suggesting the Lithographicum and Beckeri Zones. *Virgatosphinctes cf. denseplicatus* (Waagen) alone is a misfit in the list and is probably misidentified.

Limestones ascribed to the Tithonian, but seldom on adequate palaeontological evidence, have been recorded from Croatia (Vogl, 1916) to Albania (Bukowski, 1911; Nopcsa, 1929), sometimes transgressive on the ophiolite series; but some of the occurrences accepted even by Kossmat (1924) are said to be really Triassic (Ledebur, 1941, p. 495; Jovanovic, 1951a).

**GREECE AND THE IONIAN ISLES**

The magic islands and mountains of Greece and the Aegean, the white marble promontories set among blue gulfs, and the outer rampart of Crete, were all blocked out by faulting and minor folding in the Pliocene and Quaternary. The potency of these late movements may be judged from the occurrence of Pliocene deposits at 1700 m. above sea-level in the northern Peloponnese, while off the SW. coast the present sea bed is at 3000 m. below the surface. The existing upraised blocks represent in turn the ruins of a complicated chain of mid-Tertiary fold and thrust mountains which continue the Dinarides in an open curve, first southwards then swinging round SE. and finally east or NE. to join the rias coast of western Anatolia. The highest existing arc of these folds forms the Pindus Mountains, the backbone of central Greece; the outermost forms Crete and swings round to Rhodes.

Facies belts in the Mesozoic and Eocene rocks roughly follow the strike of the mid-Tertiary folds (fig. 20). How far these facies belts reflect original palaeogeography is problematic. Most likely the evidence of Mesozoic and Eocene palaeogeography has been mutilated and falsified beyond hope of reconstruction by thrusting and nappe-formation. The date of the main movements is mid-Miocene. They affect the latest
flysch, which in the Ionian region is Burdigalian (*Miogypsina* limestone), but not the transgressive Upper Miocene, of which the earliest known fossiliferous part is Tortonian. (Renz, 1940, p. 149; 1947.)

The facies belts * and tectonic units deciphered by Renz are shown in fig. 20. Pre-Carboniferous metamorphic rocks (unconformably overlain by Upper Palaeozoic and Lower Triassic formations) occur as three massifs. The ruins of the central massif (1) form the Cyclades Islands, Attica, and southern Euboea. Flanking this are two elongate massifs forming respectively (2) central Peloponnese and northern Crete, and (3) Pelagonia, probably continuous with Lydia and Caria in Anatolia.

Surrounding and overlapping tectonically the edges of the Attica-Cyclades massif are nappes of Mesozoic and Eogene rocks which Renz (1940, p. 146) postulates were squeezed from a now narrow strip pinched between the Attica-Cyclades massif and the Pelagonic massif. These nappes form most of Greece east of the Pindus Mountains. In north and central Greece they override the border of the Olonos-Pindus series, and that series in turn overrides the flysch border of the Adriatic-Ionic series, with the development of imbricate structures which indicate westward movement.

It is the Adriatic-Ionic facies belt which mainly concerns us, representing as it does a part of the autochthonous foreland. The Jurassic sequence in this area closely resembles that in the Apennines and is a direct

* Renz terms these facies and structure belts or tracts 'zones', but it seems preferable to avoid using the word 'zone' in both vertical and horizontal senses in the same context.
continuation of that in Albania. It is characterized by normal ‘foreland’ sedimentation, which appears to have been continuous from Middle Trias to Aquitanian. Farther east, in the Pindus and eastern facies belts, except for the occurrence of Toarcian Ammonitico rosso in Argolis (Renz, 1907) the only horizons identified are Upper Jurassic (Diceras and Acteonina limestones; Lower Kimeridgian Cladocoropsis limestone; Tithonian limestones with Ellipsactinia and Sphaeractinia). These occur in the Parnass-Chiona series, which is a continuation of the high karst region of Montenegro and Croatia, and in it limestones, with dolomite, reach their greatest stratigraphical span. This limestone tract separates two belts where shales and cherts predominate, as in the Viglaes Beds of the foreland.

In the East Hellenic belt the shales and cherts are associated with ophiolitic igneous rocks, especially serpentines, which are overstepped by Upper Cretaceous limestones. This belt is supposed to be a continuation of the serpentine and ophiolite region of inner Albania (Renz, 1940, pp. 105-7). If Renz’s dating is correct, the igneous phase in Greece is Upper Jurassic and Lower Cretaceous; therefore substantially later than farther north in the Dinaric ranges, if Pilger and Ledebur are correct in referring the climax there to the Middle Trias. Direct palaeontological evidence does not seem to be recorded for Greece, but it appears that Renz relied mainly upon correlation with the cherty beds and hornstone series in the more westerly facies belts, where they are definitely dated to the Upper Jurassic and Bathonian (see below). Moreover, a migration of igneous activity into younger formations southward is confirmed by the occurrence of ophiolites in Tertiary flysch, both on the mainland and in Crete, Rhodes and Cyprus (Renz, 1940, pp. 105-6). On the other hand, in Cyprus the radiolarites are Triassic and the pillow-lavas are believed to be Cretaceous (see p. 348).

Our knowledge of Greek geology, and of the Mesozoic rocks in particular, is mainly due to the life’s work of Carl Renz (1876-1951). A complete list of his 126 papers on Greece published down to 1940 is printed in Renz, 1940, pp. 158-66, and a selection of the most important, on which the present account is mainly based, is listed on p. 690. He began his researches in Corfu in 1903 and continued them almost every year thereafter, as a labour of love, bringing a wide experience of many lands from Portugal to the Caucasus to bear on the problems. The sum total of his work is an abiding monument to his memory.*

The following is a summary of the stratigraphy of the Jurassic of western Greece and southern Albania—the Adriatic-Ionian province or facies belt, within which, however, there are several minor changes of facies

* Through the generosity of Frau Renz, all the papers listed on p. 690 are in my reprint collection (making six bound volumes). It may save others fruitless search to state that the ‘Geology and Stratigraphy of Greece’ mentioned in a faulty translation in the Amer. Journ. Sci., vol. 245, 1947, p. 179, does not exist in any language. The reference should read ‘Beiträge zur Strat. u. Pal. des ostmediterranen Jungpalaeozoikum, Teil I, II: Geologie u. Stratigraphie, von C. Renz.’
(Renz, 1910, p. 599). The outcrops occur especially in the Ionian Isles of Corfu, Leucas, Cephalonia and Ithaca, and on the adjoining mainland of Epirus and Acarnania (fig. 21). (For comprehensive summaries see Renz, 1909, 1910, 1913; for Epirus 1913, 1925a, 1927; for Acarnania, 1911b, 1925; for Cephalonia, 1913b; for Kalamos, 1932a; for Leucas, 1905a, 1911a, 1936; for Ithaca, 1911; for Corfu, 1906, 1910, 1926.)

**Fig. 21.—Sketch-map of the Ionian Isles, Hellas and Albania, showing the distribution of facies-types in the Toarcian and Lower Bajocian.** After Renz, 1927.

**TITHONIAN AND KIMERIDGIAN**

Under Cretaceous Rudistid limestones, Eocene limestones and flysch, is a thick series of flaggy limestones and shales with chert, the Viglaes Beds, called after Viglaes Mountain on Corfu. They may embrace most of the Upper Jurassic and part of the Lower Cretaceous, but all the fossils hitherto recorded are Tithonian and Kimeridgian. The only common macroscopic fossils are aptychi: *A. lamellosus* (Park.), *A. punctatus* (Voltz), *A. beyrichi* Oppel, *A. latus* (Park.), *A. laevis* Meyer, *A. obliquus* Quenst.

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Identifiable ammonites are known only from Leucas, where a nest of casts in a greenish-grey marly limestone yielded *Aspidoceras acanthicum* and other spp., *Ptychophylloceras ptychoicum*, *Sowerbyceras*, *Haploceras*, *Lytoceras*, *Perisphinctids*, and a genus recorded as *Peltoceras*, which is probably *Tithopeltoceras*, already figured from the Tithonian of Italy, Majorca and Andalusia. With them occur the Tithonian echinid *Collyrites* (*Tithonia*) cf. *transversa* (d’Orb.). (Renz, 1927, p. 493; 1932a, p. 16).

As remarked above, Upper Jurassic cherty limestones and shales like the Viglaes Beds are widely distributed also in central and eastern Greece, where earlier Jurassic formations have not been found. In the eastern facies belts there are ‘spongiomorph’ limestones with *Cladocoropsis* and associated foraminifera, which mark a Kimeridgian horizon found also in Dalmatia, Cyprus, Anatolia, and the Lebanon (where it comprises part of the Glandarienkalk). Above them follow Tithonian limestones with *Ellipsactinia*. (Renz, 1949.)

**Upper Bajocian and Bathonian**

The Upper Jurassic Viglaes Beds pass down without a break, either palaeontological or lithological, into a series of siliceous flaggy limestones (hornstones) with *Posidonia alpina* Gras (P. *buchi* Roemer, P. *ornati* Quenst.) often massed on the bedding planes. This ‘Posidonien-Hornsteincomplex’ has not yielded ammonites but is presumed to be equivalent to the similar beds of ‘Klaus facies’ in S. Tyrol, Sicily and the Apennines. With the *Posidoniae* occur sporadically small lamellose aptychi and *Rhynchoteuthis*. (Discussion and figures of the *Posidonia* beds in Renz, 1911b, p. 394; 1925a, p. 196, pl. iii.)

**Lower and Middle Bajocian**

In Corfu and on the adjoining mainland the siliceous *Posidonia* beds rest on hard, compact, yellowish, splintery limestones with *Stephanoceras humphriesianum* (Sow.), *Stemmatoceras*, *Skirroceras*, *Chondroceras*, *Oppelia* cf. *subradiata* (Sow.) and other Middle Bajocian ammonites, including *Phylloceras* and *Lytoceras* (Renz, 1910, p. 576, pl. xx; 1926, p. 409). Below this follow greyer, thinner-beded to nodular limestones of the Lower Bajocian with the *Erycites*, *Hammatoceras*, *Tmetoceras*, *Ludwigia* fauna of the Opalinum, Scissum and Murchisonae Zones, already so often listed from the San Vigilio beds of the Alps, Sicily, etc. (Lists in Renz, 1910, p. 574; 1911, p. 475.) There are excellent sections in Corfu and Epirus (Renz, 1910a, pp. 251-60; 1911a, p. 284; 1911b, p. 393, pl. xii; 1906, pp. 752-6; 1907; 1908). In Cephalonia and Acarnania the Middle Bajocian is absent.

**Toarcian**

The Toarcian occurs in two facies: the familiar Mediterranean ‘Ammninitico rosso’, consisting of red or grey or mottled nodular limestones and nodular marls crowded with ammonite casts, and black *Posidonia*
bronnii shales and yellow-weathering or siliceous shales of central European type. In some places (e.g. Kalamos) only the first type occurs; in others there is a transition, with Posidonias disseminated sporadically amongst the nodules. Linkage of the abundant ammonites with the nodular facies recalls the Tithonian. The best sequence of ammonite horizons has been made out on the coast at Alogomandra in Acarnania, where the succession of species is said to be the same as in Canton Tessin and in Umbria (Renz, 1925, pp. 302-3). The Toarcian is the most widespread of all the Jurassic horizons in the Greek archipelago, having been found also in Argolis (Renz, 1907; 1908) and on the island of Rhodes, as Posidonia flags in a relic of a nappe (Renz, 1929, p. 13). Renz has studied the Toarcian ammonites in a long series of papers and short monographs, too numerous to mention. He has revealed the existence, among the swarms of cosmopolitan and common forms, of peculiar and interesting species of Frechiella, Paroniceras, Leukadiella, Polyplectus, etc., etc. The most modern unified list of revised determinations is to be found in Renz, 1927, pp. 484-7. Many plates and figures are scattered through at least a dozen works published in the course of forty years (see bibliography, pp. 690-1). The most important are perhaps Renz, 1910, 1911, 1911a, 1911b, 1925a, 1925b, 1932; Renz & Renz, 1947). Lower, Middle and Upper Toarcian faunas are abundantly represented.

Pliensbachian

This stage has been proved in Epirus and Acarnania and on the Ionian Isles of Corfu, Leucas and Ithaca. It usually comprises the topmost part of the Panto Crater limestones. In Acarnania flags and calcareous shales underlying the Toarcian Ammonitico rosso contain crushed Pleuroceras spinatum, and this has been found also on Corfu (Renz, 1910, p. 564; 1911b, p. 388; 1911c, p. 232). On the coast of Epirus, opposite Corfu, the Toarcian is underlain by whitish-grey limestones with Arieticeras algovianum (Oppel), A. juliae (Bon.), Juraphyllites lariensis (Menegh.), etc.; this is the more usual Panto Crater limestone. Locally, in Corfu, Epirus and Cephalonia, it contains brachiopod beds yielding the Terebratula aspasia fauna of Sicily and Italy (Renz, 1908; 1911, p. 472).

Sinemurian and Hettangian?

The limestones and dolomites forming and called after the crater of the extinct volcano Panto, on Corfu, are Pliensbachian at top and Triassic at base, but palaeontological evidence for Lower Lias is slender, suggested only by brachiopod lenses with pelecypods and some echinoderms found on Cephalonia. The facies is likened to the Dachstein of the Alps. The Panto Crater limestones are thick and more or less subcrystalline and are among the most important mountain-forming rock groups in the Adriatic-Ionian province. They form, for instance, the greater part of the island of Kalamos, but no Liassic fossils have been found in the island. (Renz, 1908; 1932a, pp. 8-9.)

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SARDINIA, SICILY, PENINSULAR ITALY AND CORSICA

Sardinia

Sardinia consists essentially of a Variscan crystalline and Palaeozoic massif with elliptical Variscan granite intrusions. The massif is peneplaned but culminates in a central ridge running S.-N., which is continued through the central and western two-thirds of Corsica. Together these remnants represent the SE. edge of a larger horst or upstanding mass, once probably continuous with the crystalline massifs of Hyères and Mauër's in Provence, and perhaps with the axial ridge of the eastern Pyrenees. All may be relics of an extensive island, or archipelago and shallows in the Mesozoic sea, comparable to the Central Plateau of France and the Spanish Meseta. To the east began the Mesozoic geosyncline of the Alps, in which Schistes lustrés accumulated; a fraction of the southern end survives above sea-level in the NE. corner of Corsica, where it was crushed against the crystalline foreland to the west (p. 218).

The Jurassic rocks of Sardinia represent shallow, epicontinental transgressions over the eastern edge of the massif. Although the area transgressed had been previously peneplaned, outlying remnants of Jurassic and Lower Cretaceous sediments indicate a tendency for the sea to penetrate pre-existing valleys between the Variscan granites (Vardabasso, 1948).

A temporary incursion of the Triassic sea into the massif is proved by the presence of marine Muschelkalk, with Bunter sandstone and Keuper marl, in the Burra peninsula at the extreme NW. of Sardinia. The gypseous Keuper, however, is directly overlain by marine Bathonian. No Lias occurs anywhere on the island. In these north-western outcrops the Mesozoic and Tertiary rocks are let down in a rift valley (Deninger, 1905). In the others, in the SE. centre and on the east coast, the Jurassic rocks are remnants of an almost horizontal layer which once must have covered most of the island and has since been subjected to destructive erosion, following minor germanotype folding and faulting (see many sections in Vardabasso, 1948, p. 62).

In the south-central region the Bathonian transgression was preceded by deposition of Bajocian continental sandstone with at least 31 species of plants, of which 21 are found in the Bajocian deltaic beds of Yorkshire (Tornquist, 1905; Edwards, 1929). Farther north, on the east coast, the Bathonian and Bajocian are overlapped by Upper Jurassic limestones and dolomites, which rest directly on the Variscan basement.
The supposed Bathonian, which is 250 m. thick in the Nurra, consists entirely of limestones and has yielded no ammonites, only at certain levels common pelecypods and brachiopods of the Middle Jurassic of NW. Europe (Dainelli, 1903). On the whole the assemblage is mainly Bathonian, but a few species such as *Pseudamussium pumilum* in the lower half, suggest that Bajocian is included. *Ostrea acuminata*, which comes in near the base, although Bathonian in England, is essentially Upper Bajocian farther south, on the east of the Paris basin, and Deninger (1905, p. 440) states that in hand-specimens some of the oolites are
indistinguishable from the Hauptrogenstein (now known to be Upper Bajocian, not Bathonian).

The Upper Jurassic limestones, up to 200 m. thick, contain some badly preserved small ammonites, but no attempt at even generic identification has been published. The facies is that with *Nerinea* beds and corals, reminiscent of Nattheim and many other places, and contrasting strongly

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<tr>
<th>NW. Coast</th>
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<tr>
<td><strong>NEOCOMIAN</strong></td>
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<td>Limestones with <em>Exogyra couloni</em> and <em>Leopoldia</em>...</td>
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<td>Limestones with <em>Diceras</em>, etc.</td>
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<tr>
<td><strong>UPPER JURASSIC (up to 200 m.)</strong></td>
<td>...</td>
<td>White limestones, Tithonian Nerineidae Dolomite and lithographic slates Sandstone (local) Crystalline basement</td>
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<td>Light-coloured limestones</td>
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<td>Sandy limestones</td>
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<td><strong>MIDDLE JURASSIC (up to 250 m.)</strong></td>
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<td>Grey limestones, <em>Pholadomya murchisonae</em>, etc.</td>
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<td>Grey marly limestones, <em>Pteroperna costatula</em>, etc.</td>
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<td>Limestones with Nerineidae and Rhynchonellids ('concinna')</td>
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<td>Limestones and oolites, <em>Pecten pumilus</em>, etc.</td>
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<td>Limestones with <em>Pentacrinus</em></td>
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<td>Sandstones with plants</td>
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<td>Cherty limestones, <em>Ostrea acuminata</em></td>
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<td><strong>TRIASSIC</strong></td>
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<td>Muschelkalk and dolomites</td>
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<td>Bunter Sandstone</td>
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with the cephalopod-bearing Upper Jurassic and Tithonian of the 'Mediterranean' or 'Andalusian' facies. Most of the outcrops near the east coast, marked as Cretaceous on the International Geological Map and even in the most recent Italian atlas, were found by Deninger to be Upper Jurassic and are so shown in fig. 22.

Table 15 summarizes the Sardinian Jurassic (Deninger, 1907).

**SICILY**

Across the length of Sicily, parallel to the north coast, are dotted numerous small Jurassic outcrops which form part of more or less isolated mountains of Mesozoic limestones surrounded by Tertiaries. The Jurassic limestones are often hard to separate from thick marine Triassic and Cretaceous rocks in similar facies. The outcrops are most numerous

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in the west end of the island, where they extend from coast to coast between Palermo and Sciacca and to the western extremity at Trapani. A thinner belt extends across the neck of the eastern peninsula from the north coast to Taormina, and there is a small patch SW. of Mount Etna. In the south of the island no rocks older than Cretaceous crop out but Jurassic is believed to exist underground. The structure here is mainly tabular, exemplified by the plateau of Ragusa, which is only 90 miles from Cape Bon in Tunisia.

The NE. corner of the island, adjoining the Straits of Messina, consists of the ancient crystalline basement, which is continued across the straits as the massif of Calabria; parts of it were a horst or swell during the Jurassic and probably a median mass in the orogeny. This region will be dealt with in the next section.

The mountains of northern Sicily, in which the Jurassic rocks crop out, are much more complex than the Tellian Atlas and more nearly resemble the Apennines. The stratigraphy is therefore correspondingly difficult, and the difficulties are aggravated by great variability of deposit. Much was done by G. G. Gemmellaro in the nineteenth century to work out and figure the faunas, but many problems of stratigraphy and structure remained unsolved. I have therefore been fortunate for this account of the Sicilian Jurassic to have been able to study several hundreds of ammonites collected in western Sicily by Mr H. R. Warman in 1952-3 for the D'Arcy Exploration Co. I am deeply indebted to him for criticizing the first draft of the account and for much information (Warman & Arkell, 1954).

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Some recent publications portray the Mesozoic mountains of Sicily as all exotic blocks, torn from their roots and moved an unknown distance southward by tectonic sliding of the Tertiary ‘Argille scagliose’ off rising mountain ranges during the Alpine orogeny, as in the Apennines (Fabiani, 1930a; Beneo, 1951, 1951a, etc.). Mr Warman’s extensive field work has led him to conclude that the structure of north Sicily may agree basically with that of the Apennines as described by Beneo and Migliorini (see p. 214), with complex faulting and wedge-formation accompanied by large-scale sliding of incompetent Tertiary cover rocks, but that the individual mountain masses are not erratic blocks. He finds that they are all right-way-up and form an orderly facies-pattern, and none has been proved to float rootless on the Tertiaries as demanded by the ‘erratic’ hypothesis. He regards the strangely isolated mountain blocks as protruding corners and edges of upthrust wedges, riven by faults and often by low-angle thrusts, but as a whole fundamentally autochthonous; whereas the surrounding argillaceous Tertiary cover has slid off the upthrust blocks, much as envisaged by Migliorini and Merla in the Apennines, carrying with it broken masses of the Mesozoic (and sometimes Palaeozoic) limestones. In the eastern Jurassic belt there is particularly severe thrusting with imbricate structure near the border of the Calabrian massif.

The Sicilian Jurassic falls naturally into three broad divisions: the Lias; the Middle and early-Upper Jurassic to Oxfordian inclusive; and the Kimeridgian-Tithonian.

The Lias is very different in the east and west. In the east are grey marly and argillaceous limestones and marls, probably about 300 m. thick, which yield the celebrated Domerian fauna of Taormina. In the west these beds are absent or represented by a few feet of limestones and red marls, or in places perhaps by cherts. Instead, the western outcrops have great thicknesses of white or black, hard, marble-like limestones, with sparse fossils. In places most of these limestones are Triassic. Only at Rocca Busambra (Monte Casale), province of Palermo, has a rich fauna of Hettangian and Sinemurian ammonites been obtained; but Mr Warman thinks that this anomalous massif may be far-travelled.

The Middle Jurassic and early-Upper Jurassic formations to the top of the Oxfordian are highly condensed and together usually measure only about 3 or 4 m., rising to a maximum of 15 m. in the extreme west (Monte Inici to Trapani). Within this small group of beds is an extraordinary variety of faunas. Thin bands of hard pink, red, yellow, grey or black limestone come and go, and each in places is packed with ammonites. So many of the characteristic faunas of European stages and substages have been found by Mr Warman that it would be unsafe to assume that any is absent; though certainly all are not present in any one place. In this group, widespread over most of the island, are volcanic tuffs of Bajocian age, and these sometimes swell the thickness of the

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Middle Jurassic beyond the average. Near Giuliano in west-central Sicily the volcanic beds are at least 60 m. thick and the usual tuffs are accompanied also by agglomerate and pillow-lava. On the other hand, in the Madonie area Mr Warman observed up to 120 m. of bedded chert, jasper and siliceous shales, between Triassic dolomites and supposed Tithonian limestone, but was unable to find any datable fauna. (It is likely that most of these chert beds will turn out to belong to the Domerian, by analogy with Spain.)

The third Jurassic group in Sicily, the Kimeridgian and Tithonian, is widely developed in the ‘Tethyan facies’, nodular pink, white or grey limestones (fausse brèche, Knollenkalk), often crowded with ammonites, in which Phylloceratids predominate. Both the Kimeridgian and the lower part of the Tithonian are developed in this facies and there is no break between them. Higher up the Tithonian passes into compact, fine-grained, bedded white limestones with few macroscopic fossils but many Calpionellidae; and here again there is a perfect transition into the Neocomian and it is often impossible to discern any boundary. In places similar limestones, which had been mapped as Jurassic, are in fact Upper Cretaceous and Eocene (Warman & Arkell, 1954).

In the Madonie Mountains and between them and Palermo the Tithonian takes on a coral and algal facies, which is usually from 10 to 75 m. thick but in one place swells out (as a reef?) to perhaps 300 m.

The following summary of the faunas is based on a combination of published works and my examination of Mr Warman’s collections.

**Tithonian (usually about 10-20 m.)**

Most of the Tithonian ammonites that can be collected come from the nodular limestones and are of Lower Tithonian age. Some have been figured by G. G. Gemmellaro (1868-76) and Di Stefano (1884), and a number of new species were founded on inadequate descriptions and atrocious drawings by Marquis de Gregorio (1922). A promised revision by Renz (1924), based on the collections in Palermo museum, was never published. The most valuable document is a summary of the faunas at a number of localities in the provinces of Palermo and Girgenti by M. Gemmellaro (1922).

Perhaps the only reliable indications of Upper Tithonian collected by Mr Warman are from Monte Bonifato, where he obtained *Micracanthoceras cf. fraudator* (Zittel), *Calliphylloceras kochi* (Oppel) and many poorly preserved Phylloceratids and other ammonites. *Micracanthoceras* sp. was also obtained at Palazzo Adriano (Portella di Gebbia, province of Palermo), but most of this fauna, already listed by M. Gemmellaro (1922, pp. 78-9), is Lower Tithonian. It includes *Virgatospinctes geron* (Zittel), *Spiticeras grotianum* (Oppel), *Promiceras pronum* (Oppel), *Hyboniticeras hybonotum* (Oppel), *H. hamicense* Schopen sp. (1888) and many other ammonites.

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Another assemblage was collected by Mr Warman at Balata. This contains four links with the Tithonian of Andalusia and is worth listing:

- *Holcophylloceras polyolcum* (Benecke)
- *Ptychophylloceras ptychoicum* (Quenst.)
- *Lytoceras polycyclum* (Neum.)
- *Aspidoceras* aff. *hopleisum* (Oppel)
- *Perisphinctes* cf. *falloti* Kilian
- *Berriasella* cf. *fischi* (Kilian)
- *Himalayites cortazari* (Kilian)
- *Protacanthodiscus* aff. *andreaei* (Kilian)

It is probable that intensive stratigraphical collecting in Sicily would establish a sequence of Tithonian and Lower Cretaceous faunas of great value for general correlation. Mr Warman obtained *Neocomites neo-comiensis* (d’Orb.) from one locality and an assemblage of *Spiticeras* of Cretaceous age from another, both in a limestone matrix indistinguishable from the Tithonian. According to Mazenot (1939, p. 267), *P. andreaei* (Kil.) is chiefly Berriasian in France.

**KIMERIDGIAN (up to 15 m.)**

The Kimeridgian of Sicily corresponds to the Acanthicus Beds normal for the Tethyan province, which have been proved to comprise the Lower and early-Middle Kimeridgian up to the base of the Lithographicum Zone (= approximately Gravesiana Zone). G. G. Gemmellaro (1876, p. 241; 1872-82, p. 173) believed that the upper part, or Beckeri Zone, was missing in Sicily. Mr Warman, however, collected at Balata (NW. of M. Inici) from nodular limestones about 100 ammonites which include the zonal indices of this zone in abundance. Among them are 38 specimens of *Sowerbyceras loryi* (which Kilian, 1895, regarded as the zonal index) and 8 specimens of *Hybonoticeras beckeri* (Neumayr) and its associate *H. harpephorum* (Neumayr), as well as *H. pressulum* (Neumayr) and other forms. The remainder of the fauna is:

- *Holcophylloceras polyolcum* (Benecke)
- *Calliphylloceras benacense* (Catullo)
- *Haploceras* cf. *staszycii* (Zeuschner)
- *Haploceras verruciferum* (Meneghini)
- *Lytoceras polycyclum* (Neum.)
- *Taramelliceras pugile* (Neum.)
- *Taramelliceras compsum* (Gem., ? Oppel)
- *Aspidoceras iphicerum* (Oppel)
- *Aspidoceras* cf. *eurystomum* (Benecke)
- *Mesosimoceras* aff. *cavouri* (Gem.)
- *Perisphinctes* cf. *roubyanus* Fontannes
- *Perisphinctes* cf. *subdolus* Fontannes

*Sowerbyceras loryi*, with or without *Haploceras staszycii*, is the dominant

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fossil in collections of somewhat banal composition from several other localities. One of these, from Lucca (Villafranca), is notable for an assemblage of Aspidoceratids, including *A. iphicerum* (Oppel), *A. cyclotum* (Oppel), *A. haynaldi* (Herbich), *A. cf. subbinodiferum* Canavari, *A. aff. microplum* (Oppel), *Physodoceras insulanum* (Gem.) and *Hybonoticeras aff. africamum* (Spath). It appears that all these collections come from the Beckeri Zone. At Lucca, however, were also collected *Himalayites cf. cortazari* (Kilian) and *Rasenia trimera* (Oppel), proving that the section spreads into Lower Kimeridgian and Lower Tithonian, all developed in the same nodular facies.

The richness of the Sicilian Kimeridge may be gathered from the fact that Gemmellaro already in 1876 listed over 40 species of ammonites, and from the figures in pls. vi-ix and xv-xvii of his later work (1872-82). These plates show a wonderful profusion of Simoceratids, *Taramelliceras spp.* and Phylloceratids, which have no place in the Kimeridgian of NW. Europe. For correlation, however, certain other forms are significant and prove the presence of Lower Kimeridgian (Rasenia Zones), notably *Rasenia pancerii* (pl. xvi, 9) and *Idoceras dedalum* (pl. xvii, 3) (the latter close to Mexican forms), as well as Middle Kimeridgian, notably *Subplanites adelus* (viii, 7).

**UPPER OXFORDIAN**

According to Haug (Traité, 1910, p. 1067) the Bimammatum Zone and 'Achilles Zone' are missing in Sicily; but there can be no doubt that the Bimammatum Zone is strongly represented in the so-called 'Zone of *Peltoceras transversarium*' of Gemmellaro (1872-82, pls. xiii, xiv, xx pars). The commonest Peltoceratid in these beds, and also present in Mr Warman’s collections, is *P. (Gregoryceras) fouquei* Kilian (Gemmellaro, 1872-82, pl. xiii, 1, and pl. xx, 16) which the evidence from Andalusia clearly shows to be a species of the Bimammatum Zone (p. 247). This accounts for the peculiar stamp of most of Gemmellaro’s Perisphinctids from these beds, which differ markedly from those of the Transversarium Zone in the Rhone valley and elsewhere; and also for the presence of a *Physodoceras (insulanum* Gem., pl. xiv, 4).

The Transversarium Zone is, however, also represented in these beds, as shown by *Peltoceras (Gregoryceras) riasi* de Grossouvre, a Rhone valley (Trept) species (Gemmellaro, pl. xx, 17). A fauna of Perisphinctids typical of this zone, together with *Euaspidoceras cf. sparsispinum* (Dorn von Waagen) and *E. cf. paucituberculatum* Arkell, has also been found by Mr Warman in a thin bed of hard pink and red limestone resting on the Bathonian at Monte Bonifato (Alcamo).

**LOWER OXFORDIAN**

The presence of vestiges of the Cordatum Zone was suspected from two Peltoceratids figured by Gemmellaro (pl. xx, 18, 19), which appear to be *Peltomorphites*. Mr Warman collected the following typical

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assemblage of the Cordatum Zone in one of the thin limestones at Monte Inici:—

*Calliphylloceras benacense* (Gem.)  
*Phylloceras* spp. indet.  
*Sowerbyceras tortisulcatum* (d'Orb.)  
*Lytoceras* sp. indet.  
*Lissoceras erato* (d'Orb.)  
*Taramellliceram* sp. indet.  
*Euaspidoceras* aff. *babeanum* (d'Orb.)  
*Peltoceratoides* cf. *williamsoni* (Phillips)  
*Perisphinctes* cf. *bernensis* de Loriol  
*Perisphinctes* cf. *alligatus* (Leckenby)  
*Perisphinctes* (*Dichotomosphinctes*, etc.) spp. indet.

**Callovian**

At Rocca che Parra, Calatafimi, Mr Warman found two separate Callovian horizons. The upper held *Indosphinctes* cf. *patina* (Neumayr: cf. Corroy, 1932, pl. xii, 3), *Hecticoceras* cf. *metomphalum* Bonarelli, *Ptychophylloceras* cf. *euphyllum* (Neumayr) and *Holcophylloceras* sp., an assemblage which may belong to the early Middle Callovian, as does perhaps a *Hecticoceras* figured by Floridia (1931, pl. v, 2).

A few feet lower at the same place he obtained the following assemblage:—

*Phylloceras* cf. *kudernatschi* (Hauer)  
*Calliphylloceras disputabile* (Zittel)?  
*Ptychophylloceras euphyllum* (Neumayr)  
*Lytoceras adeloides* (Kudernatsch)  
*Choffatia subbakeriae* (d'Orb.)  
*Choffatia* sp. indet.  
*Reineckea rehmanni* (Oppel)  
*Reineckea* (*Kellawaysites*) *paronai* Petitclerc  
*Reineckea* sp. indet.  
*Bullatimorphites* aff. *bullatus* (d'Orb.)  
*Macrocephalites* aff. *macrocephalus* Zittel

This is evidently a condensed bed representing the Lower Callovian and also a basal part of the Anceps Zone. The *Bullatimorphites* is the form already figured with *Macrocephalites* by Floridia (1931, pl. iv, fig. 1) from Monte Inici. It is very like the typical Bathonian *bullatus*, but similar forms range up into the Callovian in France. Several other species of *Bullatimorphites* were figured from this condensed assemblage at Rocca che Parra by Gemmellaro (1872-82, pls. i-v), as well as *Macrocephalites*, *Paralcidia*, *Choffatia* spp. and *Reineckea segestana* Gem. sp. (1868-76, pl. viii, figs. 1-3).

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ITALY AND CORSICA

BATHONIAN

According to published descriptions (Floridia, 1931) the condensed Lower Callovian at Monte Inici rests on limestones with abundant *Posidonia alpina* and brachiopods, supposed to be Bathonian but yielding no diagnostic ammonites. Mr Warman, however, found two different Bathonian ammonite faunas, both new to Sicily. At Monte Bonifato, from a curious pink, porcellanous limestone containing black-coated irony nodules and encrusted black ammonites, he obtained *Prohecticoceras cf. retrocostatum* (de Grossouvre), *P. cf. subpunctatum* (Schlippe), *P. cf. costatum* (Roemer), *Choffatia cf. ybbisensis* (Jüssen), *Siemiradzkia?* sp. indet. and many poorly-preserved Phylloceratids. This assemblage is Upper Bathonian.

Of still greater interest are many well-preserved ammonites which he obtained from a hard pink limestone at Monte Inici. I determined the following, which comprise an assemblage typical of the Zigzag Zone of NW. Europe, here associated with Mediterranean Phylloceratids.

- *Phylloceras kudernatschi* (Hauer)
- *Phylloceras cf. kunthi* Neumayr
- *Holcophylloceras mediterraneum* (Neumayr)
- *Calliphylloceras disputabile* (Zittel)
- *Ptychophylloceras euphyllum* (Neumayr)
- *Lytoceras adeloides* (Kudernatsch)
- *Lissoceras psilodiscus* (Schloenbach)
- *Paralecidia aff. mariorae* (Popovici)
- *Oppelia (Oxycerites)* spp.
- *Procerites subprocerus* (Buckman)
- *Choffatia aff. uriniacensis* (Lissajous)
- *Parkinsonia württembergica* (Oppel)
- *Morphoceras macrescens* (Buckman)
- *Morphoceras perinflatum* Wetzel
- *Morphoceras aff. pingue* de Grossouvre
- *Morphoceras* sp. nov.

Other Lower Bathonian ammonites occur in other places in strata classed with the *Posidonia alpina* beds, judging by some of Gemmellaro’s figures, namely *Ebrayiceras problematicum* (1872-82, p. xix, 1), *Nanno-lytoceras tripartitiforme* (pl. xix, 9) and *? Zigzagiceras* sp. (pl. xix, 2).

UPPER BAJOCIAN

Most of the ammonites recorded from the *Posidonia alpina* beds, when not equivocal like the Phylloceratids and Oppeliids (pl. xviii), are Upper Bajocian and mostly of the Parkinsoni Zone. Gemmellaro (1872-82) figured *Cadamites daubenyi* (pl. xix, 3), *Leptosphinctes hoffmanni* (pl. xix, 6) and *Parkinsonia ditomplocus* (pl. xix, 8) (though all under other generic names). This dating is borne out by ammonites recorded from these beds near Taormina, which include *Parkinsonia seguenzae* Di Stefano,
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Morphoceras cf. dimorphum (d'Orb.), Sphaeroceras brongniarti (Sow.) and Spiroceras spp. (Di Stefano & Cortese, 1891, p. 230).

As remarked above, subaqueous volcanic rocks of Middle Jurassic age are widespread in Sicily, from near Monte Inici in the west to Monte Judica, near Mount Etna. They consist chiefly of tuffs, but in places include agglomerates and submarine basalts. At one place only, Roccapalumba, near Palermo, have ammonites been found in the tuffs: a Cadomites sp. and an Oppeliid (Fabiani, 1930; Fabiani & Ruiz, 1933, pl. ii, 19, 20). Mr Warman twice searched the tuffs at this locality and sent me from them two good specimens of Cadomites daubenyi (Gemmellaro) or a closely allied species, a fragment of an Oppeliid like that figured by Fabiani & Ruiz, and a fragment of a Perisphinctid. The Cadomites makes an Upper Bajocian date most probable for the volcanic episode.

MIDDLE AND LOWER BAJOCIAN

So many zones have proved to be represented by thin beds in such limited areas that it would be rash to assume that any zone is missing altogether in Sicily. So far, however, no trace has been found of the lower zones of the Upper Bajocian, nor of the upper zone of the Middle Bajocian (Humphriesianum Zone), and this non-sequence in so many places may reasonably be connected with upheaval preceding the volcanic activity.

Beds with Middle and Lower Bajocian ammonites have been found only in the Trapani district, in the west, where they underlie Posidonia alpina beds without the intervention of any volcanics. They consist of dark grey, bedded limestones from which, at the outcrops on Monte San Giuliano (Monte Erice), have been collected some 50 species of ammonites and Nautilids ranging from the Opalinum Zone to the Sauzei Zone inclusive. Phylloceratids are abundant. Of the other ammonites the commonest are Graphoceratids and Hammatoceratids of the Murchisonae Zone. Other important genera are Haplopleuroceras, Zurcheria and other Sonninids, Erycites, Docidoceras longalvum (Vacek), Otoites, the early Oppeliid Bradfordia (including Amblyoxyites and Iokastelia), Tmetoceras, Dumortieria and Leioceras. The whole agrees closely with the San Vigilio formation on Lake Garda. (Gemmellaro, 1886b; de Gregorio, 1886, pls. i, ii; Renz, 1925, revision, lists; Kuhn, 1934; Nautilids figured by Tagliarini, 1901).

TOARCIAN AND UPPER PLIENSBCHIAN (DOMERIAN)

In the west these stages are poorly developed and represented by a few metres of limestone poor in fossils (Renz, 1924) or with brachiopods and some ammonites (Gemmellaro, 1872-82, p. 53, pls. X-XII). The centre of interest shifts to the east, where there are up to 300 m. of grey shaly marls and marly limestone, extremely rich in ammonites, in the neighbourhood of Taormina. Following basic work by Gemmellaro (1885, 1886a, 1886c), Seguenza (1896) and others, the ammonites have been beautifully

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figured in a long series of monographs by Fucini (1919, 1920-35). Despite this thorough systematic work, however, much remains to be done to determine the stratigraphic range of the species and genera. Even the boundary between Domerian and Toarcian is in doubt; for all the fauna figured by Gemmellaro (1885) as of the Upper Lias is Domerian, while many of the Dactylioceratidae figured by Fucini (1935) as Domerian seem to be Toarcian. Unfortunately also, Fucini employed a taxonomic scale out of harmony with that of all other palaeontologists except Buckman, and a number of his genera represent no more than species; further, he erected many new genera without diagnosis or type species, so that it is difficult to determine which are valid nomenclaturally (see Vecchia, 1949; Haas, 1947; 1951). Fucini’s plates suggest that these Sicilian faunas have a strong local element, but work by Dubar in Morocco and by Mouterde in Portugal has thrown important light on these successions.

**LOWER PLEISNABACHIAN**

The best-known fauna of this age is from the beds with ‘Terebratula’ aspasia at Rocce Rosse, near Galati, in the province of Messina. The beds consist of compact grey limestone interbedded with marls and silts. They yield many Phylloceratids, especially Juraphyllitids, including the type-species of Juraphyllites (Rhacophyllites diopsis Gem.) and of Galaticeras (‘Amphiceras’ harspiceroides Gem.), with interesting Polymorphitids, including the type species of Gemmellaroceras (‘Aegoceras’ aenigmaticum Gem.), with Tropidoceras, Eoderoceras, Lytoceratids and other genera (Gemmellaro, 1884). In the province of Palermo and probably elsewhere the so-called Terebratula (or Pygope) aspasia beds are later, Upper Pliensbachian, as shown by the ammonites figured (Gemmellaro, 1872-82, p. 53, pls. x-xii).

**SINEMURIAN AND HETTANGIAN**

These stages probably exist in most parts of the island except perhaps in the west, where it is difficult to separate them from the Trias. In the extreme east and extreme west they are represented by semi-crystalline limestones ranging in colour from black to white and often crowded with a neritic fauna of gastropods, pelecypods and brachiopods. They are best dated at Monte Casale (Rocca Busambra), province of Palermo, whence a wonderful fauna has been figured from a white marble-like crystalline limestone (Gemmellaro, 1872-82, p. 233 ff., pls. xxi-xxxii; gastropods revised by Fucini, 1913, which see for references to works on other groups). The ammonites (Gugenberger, 1936) represent the whole of the Hettangian and Sinemurian, from the Planorbis Zone to the Raricostatum Zone. Of 65 species recognized, Phylloceratids are in a large majority, both in species and individuals (43 per cent., 47 per cent.), followed by Lytoceratids (21 per cent., 20 per cent.) and Arietitids (20 per cent., 17 per cent.). The remainder includes Schlotheimiids, Psiloceratids, Eoderoceratids, and Tethyan Lytoceratina such as Ectocentrites, Pleuro-
acanthites and Fucinites. The assemblage requires direct sea connexion with the Apennines, Alps and SE. Europe, and contrasts with most of the surrounding territories, especially Spain, Tunisia and Algeria.

CALABRIA

The crystalline basement which comes to the surface in the NE. corner of Sicily is continued across the Straits of Messina to form the greater part of Calabria, the 'toe of Italy'. It includes schists and phyllites in some of which traces of Carboniferous plants have been found. Trias is absent. Upon the planed basement, successive stages of the Jurassic transgress from all sides. At Rossano (see fig. 22) are 250-300 m. of Lower Lias limestones locally full of gastropods and brachiopods as in Sicily, with conglomerates containing granite pebbles, and at the base 10-15 m. of red polygenetic conglomerate. The Domerian and Toarcian comprise up to 300 m. of marly and sandy limestones and sandstones, from which characteristic faunas have been obtained, and Eocene overlies this unconformably. At another locality small Upper Toarcian and Lower Bajocian ammonites, including Hammatoceras, Phymatoceras, Polyplectus, Phylloceratids and Lytoceratids, are found in beds resting directly on schists and granite. The succession is the same to the NW., on the 'instep'. (Greco, 1893, 1896, 1898, 1899; Renz, 1924, p. 106).

The palaeontological and lithological facies of the Lias are as in NE. Sicily. The highest fauna yet recognized is the Lower Bajocian assemblage of San Vigilio and Sicily. Farther in towards the centre of the massif, however, Tithonian deposits in turn rest directly on the crystalline basement; they comprise siliceous shales, cherty limestones and calcareous sandstones, with a basal conglomerate, altogether 60-70 m. thick. The only Cretaceous comes in in southern and central Calabria and consists of transgressive Cenomanian and Turonian. (See also Böse & Lorenzo, 1897; Cortese, 1897, and earlier works; above all an admirable summary by Quitzow in Teichmüller & Quitzow, 1935).

Thus the Calabrian massif was on the whole a horst or swell in the Mesozoic. The great thickness of Lias (600 m. rising to 700 m. in the north of the 'instep'), however, shows that at times subsidence of the edges was considerable. Whether the absence of stages between Lower Bajocian and Tithonian was due to non-deposition or subsequent erosions is uncertain; and it is possible that as elsewhere the supposed Tithonian includes in its lower parts representatives of Kimeridgian and even earlier stages which have not yet been (and perhaps owing to poverty of fossils never will be) recognized.

The disposition of the Jurassic rocks near Rossano indicates that the transgressions there came from the east. This fact supports the close correspondence between the facies and faunas of the Apennines and western Greece, pointed out by Renz, in indicating Jurassic sea over at least the southern Adriatic.

There is a noteworthy contrast between the Jurassic transgressions in
Calabria and Sardinia, on opposite sides of the marine trough that connected the central Apennines with Sicily. Lias is absent in Sardinia, complete and very thick in Calabria. In Calabria the Liassic marine cycle ends with ammonitiferous Lower Bajocian, which is about the same age as the continental sandstone that begins the sequence in Sardinia. The predominant formation in Sardinia, transgressive on the basement, is the Middle Bajocian-Bathonian (250 m.), which stages are absent in Calabria. The only feature in common is the transgressive Upper Jurassic, in both regions only vaguely dated but embracing the Tithonian.

The Apennines

Between the small Jurassic outcrops of northern Calabria, on the 'instep' of the Italian 'foot', and the main complex of scattered outcrops higher up the 'leg', in the central Apennines, there is a gap of some 200 miles. On old maps, the gap is to some extent bridged by an inlier of reef-facies limestones assigned to the Tithonian (Viola & Cassetti, 1893), in the core of a dome forming Monte Gargano (the 'spur', on the Adriatic coast). But on the new Geological Survey maps (1928) and Dainelli's atlas (1948) all these limestones have been transferred to the Cretaceous on the strength of more recent palaeontological discoveries (Checchia-Rispoli, 1925). No ammonites occur.

In the central and northern Apennines, especially in Tuscany and Umbria, the Jurassic is thin but complete, or nearly complete, and the Lias is well dated by beds rich in ammonites belonging to all the stages. As pointed out by Haug (1910, Traité, p. 984) in passing north from Calabria we have crossed from a neritic zone to a 'bathyal' zone with marls as well as limestones, and including in the Toarcian Posidonia bronni shales and Ammonitico rosso, extremely rich in cephalopods; they were deposited in a Liassic trough which was certainly continuous from the southern Alps of Lombardy, through the Apennines to Sicily and (as has since been proved) Algeria and Morocco. As in all these places, too, the Upper Bajocian and probably Bathonian are represented by shales with limestone bands and cherts, crowded with Posidonia alpina. Above follow shales and cherts with Aptychus (Lamellaptychus) of uncertain Upper Jurassic age, in part containing Tithonian foraminifera; and locally typical Lower and Middle Tithonian cephalopod limestone with the fauna of Rogoznik.

This succession, first established by Zittel (1869), has been proved over the whole breadth of the peninsula, from Monte Catria, inland from Ancona, to the foothills behind Rome. Particularly good marker formations are the Toarcian Ammonitico rosso and Posidonia bronni shales like those of central Europe, and the Upper Bajocian cherty beds with Posidonia alpina (ornati Roemer) which stretch from the Lombardy Alps to Sicily and Greece; also the Tithonian aptychus and foraminiferal limestones with Cadosina and Stomiosphaera (Renz, 1949).

As in all such large areas there are more or less extensive variations of
facies, and some elements are locally reduced or absent; but on the whole the succession is widely recognizable in the autochthonous or 'limestone Apennines'. In the north-west, however, intense tectonic complication occurs. The autochthon is itself believed by some authorities to be torn from its roots in the form of a vast thrust sheet (the Tuscan nappe, or Tuscanids), and the lower parts at least are metamorphosed regionally (especially in the Apuan Alps—see fig. 22, where the celebrated Carrara marble has been produced from Lower Lias limestone). Above all this, however, there rests with violent structural unconformity a heterogeneous sheet of mixed incompetent rocks, containing exotic blocks of all sizes, known as the Ligurian 'nappe' or Ligurids. The total thickness is up to 1000 m. The principal element in this sheet is a laminated clay, the 'Argilli scagliosi', of Cretaceous and Tertiary age, in which float exotic masses of limestone, sandstone, granite and green igneous rocks, both intrusive and extrusive (the so-called 'ophiolitic series' or 'ophiolites'). These are partly in place and partly transported. At the base of the Ligurids in the north are radiolarian cherts and limestones with Calpionella alpina, which in the Mediterranean area is a reliable index fossil of the Tithonian and Lower Neocomian (Steinmann, 1907, 1913). These rocks rest on all horizons up to Eocene. The Calpionella beds are penetrated and altered by intrusive green igneous rocks, but also contain conglomerates in which have been found pebbles of apparently the same igneous rock. From this it has to be concluded that violent igneous activity in the northern Apennines occurred during the Tithonian or possibly Lower Neocomian (Teichmüller & Schneider, 1935, p. 8).

The Ligurian 'nappe' or 'allochton' is continuous in the Ligurian Apennines of the north, but becomes broken up southwards by erosion of domes and anticlines through which the Tuscanid series protrudes as tectonic windows (as in the Apuan dome), until in Umbria it is reduced to shreds and klippes. (Tilmann, 1926; and a good account also in Kober, 1928, Der Bau der Erde, pp. 195-201).

Steinmann called the radiolarian cherts 'abyssites' because they contain Radiolaria and no macro-fossils, but more recent work in many countries has shown that such rocks are more likely of shallow-water origin and connected with the presence of submarine eruptives; moreover, they contain algae, as Steinmann admitted.

The source of origin of the so-called Ligurian nappe, and the mode of transportation, present capital problems. It may be many years yet before final solutions can be found. Any theory must take into account the widespread occurrence of similar phenomena farther down the Italian peninsula—where, however, only post-Jurassic rocks are involved, so that we are not here concerned with the details—and in Sicily. (For a full discussion of the problems of dating the Argille scagliose see Brueren, 1941. He favours the view that in the north (Etruscan Apennines) it is Cretaceous and perhaps in part even Jurassic, and equivalent to the Schistes lustrés.)
Staub, in a characteristic essay (1932) based on a study of the Apuan dome, was convinced that the movement had been from east to west, but nearly all authors, before and since, agree that it was from west to east (farther north, from SW. to NE.). The source therefore has to be postulated in the sunken region of the Tyrrhenian Sea. Since in Corsica the movement is from the east, against the crystalline foreland in the west (see p. 218), there must be a parting under the sea between Corsica and Elba. This parting probably runs into the coast near Genoa and then under the Po basin (Teichmüller & Schneider, 1935, pp. 46-7). Originally the site of a sinking trough, in the early Tertiary orogeny it was uplifted and shed part of its load of sediments as great sheets which glided off into the fore-deeps on either side, contorting and breaking up as they travelled. The distances moved (100-200 miles) and the incompetence of the rocks, however, make an explanation of the Ligurian ‘nappe’ by means of orthodox nappe tectonics well-nigh inconceivable.

To meet these difficulties Italian geologists have developed the ideas of gravitational sliding put forward from time to time in various parts of the world and expounded with special force by Haarmann (1930). The Italian version, known as the ‘successive landslip theory’, contains special and attractive features and merits most serious attention. (See Migliorini, 1945, 1952; Signorini, 1946; Merla, 1948, 1952; Beneo, 1950). The long distances covered by the incompetent Ligurid materials are accounted for by supposing that the slipped debris was passed on from time to time as successive ranges were formed in order from west to east, new materials being added to the old with each orogenic spasm. The earliest uplift occurred over the Tyrrhenian Sea in the late Cretaceous; the latest ended in the Pliocene on the outer margin of the arc, adjoining the Adriatic coastal plain and the Po basin. The ridges were asymmetric in form, with the longer slip-slope on the outer (eastern) side. They present internally a peculiar pattern of ‘composite wedges’, the ends of which would be liable to be torn off and incorporated with the slipping cover material (chiefly Argilli scagliosi), thus providing the exotic blocks. The slips involved bear close comparison with those proved by intensive drilling in the oilfield on the Pacific coast of Peru and Ecuador, as described in 1938 by Baldry and Barrington Brown. The remarkable structures met with in the Apennine ranges (e.g. Behrmann, 1936, many figures) forcibly recall Haarmann’s book.

The following succession near Perugia, in Umbria, lies near the centre of the whole Apennine area and may be considered typical (Principi, 1909):—

- h. Tithonian grey limestones passing up gradually into Neocomian limestones (Majolica)
- g. Aptychus shales
- f. Posidonia alpina beds
- e. Limestones, greyish-yellow, siliceous, without fossils
- d. Red limestones with Erycites fallax, ‘Aalenian’

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c. Red marls and limestones of the Toarcian
b. Limestones full of ammonites of the Pliensbachian
a. White, massive, crystalline limestones with gastropods: Lower Lias

The following summary gives the principal evidence for dating, with references. The Tithonian is overlain by about 300 m. of Lower Cretaceous limestone.

TITHONIAN

The most celebrated locality for the Tithonian limestone is the Monte Catria and Monte Nerone group, inland behind Ancona (Zittel, 1869, and 1870, p. 137, with many figures; revised by Principi, 1921, and Renz, 1949, p. 551). The limestone, worked in quarries, is 3 to 6 m. thick and contains some layers and nodules of greenish-grey chert. It is rich in perfectly preserved cephalopods. Most of them were assigned by Zittel without hesitation to the Tithonian Rogoznik beds (see p. 165), but he recognized also (p. 142) some of earlier Upper Jurassic date. Some noteworthy forms are Subplanites contiguus (Cat.), Lithacoceras geron (Zittel), Hybonoticeras hybonotum (Oppel), Aspidoceras bispinosum (Zittel), A. rogoznicense (Zeusch.), A. cyclotum (Oppel), with Lytoceras montanum (Oppel) and many Phylloceratids and aptychi. Other localities with similar fauna are described by Principi (1921, pp. 67-9).

Hybonoticeras hybonotum is also recorded in Umbria from the aptychus shales, which generally underlie the Tithonian limestone (Verri, 1884). Aptychi are also common in the Tithonian limestone, in association both with the characteristic Rogoznik ammonites (Zittel, 1869) and with Tithonian foraminifera (Renz, 1949). From the province of Ancona comes a remarkable Himalayitid, Tithopeltoceras moriconii Meneghini sp. (1885, pl. xxii, 2), allied to 'Peltoceras' edmundi Kilian of the Lower Tithonian of Andalusia and Himalayites parakasbensis Fallot & Termier of the Balearic Tithonian.

Berriasella aesinensis, Protacanthodiscus bonarellii and Neocosmoceras heterocosmum, figured by Canavari (1891) as from the Tithonian of the central Apennines, are Berriasian.

KIMERIDGIAN

At Monte Serra, near Camerino (east of Perugia), a few thin beds of limestone have yielded a rich fauna of ammonites of the Lower Kimeridgian Acanthicus Beds (Canavari, 1896-1903). They include Aspidoceras acanthicum and many other Aspidoceratids, Simoceratids, Perisphinctids, Oppeliids (Taramelliceras), Phylloceratids and Lytoceratids. There are a number of species in common with the Acanthicus Beds of Sicily. According to Canavari these beds rest directly on eroded Lower Lias limestone, but Bonarelli (1903, p. 441) states that their position is between the Tithonian limestone and Aptychus Beds. Sicilian Simoceratids have also been figured from Ancona province (Meneghini, 1885).

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The Aptychus Beds consist of marly, greenish or yellowish limestones alternating with bands of chert: the principal species recorded are *Aptychus lamellosus, profundus, laevis* and *punctatus*. The age is undetermined, but Lower Kimeridgian seems the most probable. They appear to be transgressive, resting in different places on Callovian, on *Posidonia alpina* beds, on Lower Bajocian, and on Toarcian, but this relation may be tectonic; Merla (1952) considers that deposition was continuous during the Jurassic.

**Oxfordian**

Evidence for the Oxfordian stage in the Apennines is meagre. It is generally believed, but on insufficient grounds, to be represented in the Aptychus beds (Bonarelli, 1903, p. 437; Principi, 1921, p. 76). *Peltoceras? retroflexum* Meneghini (1885, pl. xx, 1), from the Ancona district, has nothing to do with *P. transversarium* but appears to be a Perisphinctid suffering from a common pathological malformation. (Judging by associated Simoceratids it is probably Kimeridgian.)

**Callovian**

A downward limit to the age of the Aptychus beds is provided at Furlo, in the Pesaro-Urbino province (NW. of Ancona), where 60 m. of the beds overlie a limestone with *Reineckeiae* (Bonarelli, 1903, p. 441). *Indosphinctes patina* (Neum.) was recorded from the same area (Meneghini, 1885, p. 364). This Middle Callovian ammonite bed has not been found elsewhere.

**Bathonian, Upper Bajocian**

Limestones, shales and cherts with *Posidonia alpina*, resembling those in Sicily, the southern Alps and Greece, are widely distributed in the central Apennines (Renz, 1949). Locally they are absent like the Callovian and Lower Bajocian ammonite beds, leaving Aptychus Beds resting directly on Lias. Italian geologists (Bonarelli, 1903, pp. 436-7; Principi, 1909, 1921, p. 66) have usually considered the *Posidonia alpina* beds Callovian, but in this is doubtless seen the influence of Parona’s monograph on the ammonites of these beds in the southern Alps, which he called Callovian, but which can be seen from his plates to be Upper Bajocian as in Sicily (see p. 176). As in Sicily and Algeria, the *Posidonia alpina* beds probably represent also the Bathonian.

**Lower (and Middle ?) Bajocian**

As in western Sicily, the *Posidonia alpina* beds are in many places underlain conformably by thin, richly fossiliferous marly limestones containing condensed ammonite faunas of the Lower Bajocian. This is once more the San Vigilio assemblage of Lake Garda, but less complete, for it lacks properly authenticated Middle Bajocian forms. (Records of *Stephanoceras* in the literature may refer to *Erycites* or *Docidoceras*.)

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The composition of the fauna is otherwise much the same as in Sicily and at Lake Garda and need not be repeated. (Bonarelli, 1893, 1896; Principi, 1921; Zuffardi, 1914; Merla, 1933, 1933-4; Renz, 1949, pp. 553-4.) Unfossiliferous limestones which follow above in some localities (Principi, 1909) may represent the Middle Bajocian. A *Sphaeroceras* is recorded (Merla, 1933, p. 117).

**TOARCIAN**

The Toarcian is ubiquitous and richly fossiliferous. It occurs in two facies: (1) Ammonitico rosso, bright red marls and marly limestones packed with ammonites, and (2) shales with *Posidonia bronni*. The former is a Mediterranean, the latter a central European facies. Owing to the attractive preservation of the ammonites from (1), the literature is enormous, but detailed stratigraphical work still has to be done. Lower, Middle and Upper Toarcian are present, with almost all known Toarcian genera represented, including interesting forms such as *Paroniceras* and *Frechiella* (Parisch & Viale, 1906; Renz, 1933). (The following are other principal references: Bonarelli, 1893, 1899; Desio & Airaghi, 1934; Lippi-Boncambi, 1947; Meli, 1917; Meneghini, 1867 (revised by Bonarelli, 1899), 1874, 1881; Merla, 1933, 1933-4; Principi, 1915; Zuffardi, 1914.) Some Domerian Harpoceratids recorded by Principi (1915) from the Toarcian of Umbria are probably misidentified, if not derived. The Toarcian in Umbria is said to be transgressive on to Lower Lias, Trias, Palaeozoic and crystalline (Lotti, 1926, p. 26); but here again the new tectonic interpretations demand caution.

**PLIENSCHACHIAN**

Rich faunas of Lower and Upper Pliensbachian dates are widespread. The commonest facies is a marly or compact whitish limestone (‘corniola’) alternating with greyish-yellow cherty limestone, but in places there is a more shaly development. Extensive faunas have been published, above all from Monte Cetona in the province of Siena in S. Tuscany (Fucini, 1901-5); also from near Spezia (Fucini, 1896) and the central Apennines (Fucini, 1899-1900; Ramaccioni, 1936; Maxia, 1944), the Gran Sasso group (Zuffardi, 1914) and elsewhere. At Monte Calvi, near the coast opposite the Isle of Elba, *Pygope aspasia* beds like those of Galati in Sicily yield a remarkable fauna with the peculiar dwarf genera *Diaphorites* and *Pimelites* (Fucini, 1896a; Levi, 1896). In the Ligurian Apennines near Spezia and in parts of Tuscany the Lower Pliensbachian is represented by red limestones which are a bridge formation from the Upper Sinemurian (Canavari, 1882, 1888; Fucini, 1897).

**SINEMURIAN AND HETTANGIAN**

The presence of the Planorbis Zone seems to be doubtfully attested, but from the Angulatum Zone upwards there is no reason to suspect important gaps. Moreover, there is often a downward passage from
undoubted Lower Lias into *Megalodon* limestones and dolomites which overlie beds with *Pteria contorta* but are still Triassic (Lotti, 1926). Inclusion of these dolomites in the Lower Lias probably accounts for excessive thicknesses sometimes attributed to the Lias (e.g. Behrmann, 1936, p. 4). Dating of particular outcrops often presents difficulty: for instance, a fauna from white limestone in the Pisa district, recognized by Fucini as Liassic, was not long ago published as Triassic (Vinassa de Regny, 1933) but on revision of the ammonites turned out to be Hettangian and Sinemurian (Arthaber, 1935). In the Apuan Alps difficulties are increased by regional metamorphism. The white Liassic limestone has been converted to Carrara Marble.

Elsewhere the Lower Lias consists typically of compact white limestone (‘corniola’) and subcrystalline limestone (‘marmarone’). In some places, as in the Monte Catria group, the upper part of the Sinemurian is represented by these facies, with ammonites, while the lower part of the Lower Lias comprises a variety of limestones, massive, cavernous, brecciform, semicrystalline, pisolitic and oolitic, with only some pelecypods and gastropods (Principi, 1921).

In Tuscany and near Spezia, on the other hand, the Upper Sinemurian (as stated above) is developed as a ‘Lower Ammonitico rosso’ or ‘Calcare rosse ad Arieti’, which facies in places includes the Lower Pliensbachian. In NW. Tuscany this overlies limestones and shales with small ammonites which have a marked local stamp (Canavari, 1882, 1888). One of the most interesting faunas in the Apennines was described from about 30 m. of alternating compact and subcrystalline limestones exposed not far from Pergola, which yielded many *Arnioceras*, with *Boucalticeras* and remarkable Ectocentritidae, including the peculiar genera *Peltolytoceras* and *Lytotropites* (Bonarelli, 1900). Other assemblages have been published from various localities (e.g. De Stefani, 1887; Fucini, 1906, 1911, 1911a; Zuffardi, 1914; Maxia, 1944).

**Corsica**

The south-western two-thirds of Corsica consist of ancient and crystalline rocks in direct continuity with the central ridge of Sardinia (p. 199). The north-eastern third, on the contrary, consists of Schistes lustrés and other Mesozoic and Tertiary strata in a state of intense deformation on axes running approximately N.-S. This terrain belongs to the Ligurian Apennines and the Alps. The Schistes lustrés have been driven westward against the crystalline foreland in recumbent and isoclined folds, carrying wedges of the foreland with them. A puzzling feature is that in the north-west of the folded area (from Corte to the north coast) there ride upon the Schistes lustrés, which had already been to some extent folded, nappes of unmetamorphosed neritic Trias and Lias, consisting of cavernous dolomites, Rhaetic beds with *Pteria contorta*, and Hettangian to Sinemurian limestones with belemnites. The relations of these rocks led to the inference

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that the Schistes lustrés had been driven in between the crystalline basement and its sedimentary cover to a distance of 30 km. (P. Termier & Maury, 1928; Lutaud, 1930). More likely, however, the sedimentary cover first slid eastwards in early Tertiary times over folding Schistes lustrés, by preliminary disharmonic movements of Pyrenean type connected with early stages in the closing of the Alpine geosyncline that lay to the east of Corsica. Then, in the final stages of the main Alpine orogeny, with uplift of the parting, they were forced back again by the general westerly surge of the Schistes lustrés over the foreland (Parent, 1930). In the final paroxysm the nappes overlying the Schistes lustrés were tightly folded and broken up. In places they stand vertical; and there are wedges of thick Lias limestone, into which have been kneaded shreds of Trias limestone, pinched in among the schists (Parent, 1930a).

South of Corte the intensity of the distortion diminishes, and before the outcrops reach the SE. coast of the island almost all traces of disturbance have died out. Here is thought to be the southern end of the Alpine geosyncline and orogen (Parent, 1930; Parejas, 1929).

Tithonian rocks of three types, belonging to three separate tectonic entities, exist in NE. Corsica. First there are radiolarites (black jaspers) forming part of the metamorphic series of the Schistes lustrés and closely associated with massive volcanic green rocks including pillow lavas (the ophiolites); secondly there are radiolarites associated with ophiolites but also with unmetamorphosed limestones containing Calpionella, and presumed to be lateral equivalents of the first facies; and thirdly there float on the Schistes lustrés klippes of unmetamorphosed white limestones with corals, sandstones and breccia (Termier & Maury, 1928). The last seems to be a continuation of the Tithonian of Sardinia; the first two are a continuation of the Ligurian ‘nappe’ of the northern Apennines. Corsica therefore amplifies the evidence of the northern Apennines and confirms the occurrence of submarine volcanic activity in the geosyncline at the end of the Jurassic.
CHAPTER 9

THE IBERIAN PENINSULA AND BALEARICS

The Pyrenees

Between the basin of the Garonne (Aquitaine) to the north and the basin of the Ebro to the south, the barrier of the Pyrenees stretches for 280 miles nearly east and west, from coast to coast. The western part has a humid Atlantic climate and the foothills are thickly forested; the eastern part partakes of the Mediterranean climate, in which the Jurassic limestones are bare and parched in summer, while the marl and clay outcrops support vineyards and citrus orchards.

In structure and stratigraphy the Pyrenees are much simpler than the Alps. There has been complicated Lower Cretaceous and Tertiary folding and overfolding on both sides, with limited overthrusting, but there are no nappes. No fundamental changes of facies have been observed in the Mesozoic rocks, either longitudinally in the direction of strike or across the range from one side to the other. For most of the length of the range the Mesozoic outcrops are confined to two lateral belts completely separated by the main central ridge of older rocks, which has a width of up to 35-40 miles. This axial zone consists of pre-Permian Palaeozoic rocks strongly deformed by the Variscan orogeny and injected at that time with granites. Much of the boundary is faulted, but in many places Cenomanian sediments are seen to overstep the Jurassic and Triassic formations and rest unconformably on the edges of the Palaeozoic ridge; while near the west end they almost cross it. At first sight it might be inferred that the ridge already existed as a land barrier in the Jurassic sea; but the Variscan ranges were completely levelled before the Trias (Lamare, 1936, p. 441), and the similarity in facies and faunas of the Liassic rocks on opposite sides of the present range makes it more probable that the absence of Jurassic rocks over the central parts is, at least mainly, due to pre-Cenomanian (and pre-Aptian?) folding, uplift and erosion. Even in the outer zones where pre-Cenomanian sediments are preserved it is extremely difficult to disentangle the pre-Cenomanian tectonics from the Tertiary (Casteras, 1933, p. 514). Nevertheless, it is probable that some parts of the central ridge had already been elevated above sea-level before the Jurassic period and were then progressively submerged (Lamare, 1936, p. 430), as were the strikingly similar central core of the High Atlas and the minor Palaeozoic horsts of North Africa.

The splendid monographs by Jacob (1930), Dalloni (1930), Casteras (1933) and Lamare (1936), and on the Lias by Dubar (1925, 1927), establish beyond question that the Pyrenees are a 'plis de fond', or upwarp of the Palaeozoic platform, complementary to the downwarped basins
of the Garonne and Ebro, not a geosynclinal chain of Alpine type, and that they cannot be a continuation of either the Alps or the Betic Cordillera (via the Balearics), as has been suggested. The main Tertiary orogeny, known as Pyrenean, took place in the Upper Eocene (Bartonian-Ludian, Stille, 1928) or Middle Eocene (Lutetian, Jacob, 1930), as compared with Miocene in the Alps. It consisted of movements of the central horst and its satellite horsts, which crushed and deformed the Mesozoic cover rocks. At least in some regions pre-Aptian folding is said to be more important than Eocene (Lamare, 1944).

The facies-changes in the Lias, such as they are, take place from east to west rather than from north to south. The Lias of the central and eastern sectors on both sides agrees with that of Aveyron and Provence, forming part of the deposits of a shallow sea with islands, separating the waters of the Alps and Jura Mountains on the one hand from those of the Aquitaine and Ebro basins on the other. Westward the Lias, while still thin and neritic, becomes somewhat more uniform and richer in ammonites, as if passing into regions where the water was deeper. Since all the Jurassic of the Pyrenees is relatively thin and neritic, and any indications of increasing depth of water are in a direction parallel to the range, there can be no question of a Pyrenean geosyncline, at least in the Jurassic (Dubar, 1925, pp. 209, 303).

Volcanic activity occurred in the Hettangian on the centre of the north
flank (Ariège) and near the west end of the range. In these areas there are basalt flows and volcanic tuffs interbedded in poorly fossiliferous dolomites and limestones attributed to the Lower Hettangian. The rocks are without doubt Jurassic, for in the department of Ariège they overlie Rhaetic lumachelles of *Pteria contorta*. (Dubar, 1925, pp. 215, 225; 1927, p. 587.)

The Lias is well developed and fossiliferous over the whole area, except for the Hettangian and locally the Sinemurian, which are developed as dolomites and poorly fossiliferous limestones. The Aalenian and Bajocian are likewise complete, with all the NW. European faunas. The Upper Jurassic is more sporadic in occurrence. The highest ammonite faunas recorded are Oxfordian, but in parts of the Pyrenees there are thick dolomites of Upper Jurassic age which pass up into Lower Cretaceous limestones, and it is possible that the higher stages of the Upper Jurassic will prove to be represented (Dubar, 1925, p. 252). In the Pyrenees of Lérida there is a gap with unconformity between the Kimeridgian lithographic limestones and Middle Jurassic dolomites without fossils (Dalloni, 1930, p. 170).

**Tithonian**

Borings near the south-western edge of the Aquitaine basin have produced uppermost Jurassic and lowest Cretaceous micro-faunas, and equivalent rocks are present also at outcrop on the north-west flank of the range (Cuvillier & Debourle, 1954).

**Kimeridgian**

On the south of the Pyrenees, near the east end, in the province of Lérida, the lithographic limestones of Montsech contain a mixed land, freshwater and sea fauna and flora, without marine mollusca or any other invertebrates except insects. In facies the fauna resembles those of Solnhofen in Franconia and Cerin in the Dept. of Ain, but the vertebrates are held to indicate a somewhat lower horizon in the Kimeridgian (Vidal, 1915; Broili, 1932). The thickness is estimated at 100 m. and there is an unconformity and big gap below (Dalloni, 1930, pp. 163, 170).

**Upper Oxfordian**

In the extreme west are up to 50 m. of poorly-fossiliferous calcareous sandstones or greywackes attributed to the 'Lusitanian' and probably Upper Oxfordian (Lamare, 1936, pp. 56, 178). On the Spanish side in this western region *Perisphinctes plicatilis* (Sow.) and *Ochetoceras canaliculatum* (v. Buch) have been recorded (Palacios, 1919, p. 63); on the French side in addition *Euaspidoceras perarmatum* (Sow.) and *Taramelliceras flexuosum* Miinst. sp. (Dubar, 1925, p. 252).

**Lower Oxfordian**

Black and grey limestones, 50-100 m., are probably attributable here, but no distinctive ammonites are recorded (Lamare, 1936, pp. 56, 178).
CALLOVIAN

Ammonites of Lower, Middle and Upper Callovian dates are recorded, but their stratigraphical relations remain to be elucidated. At the west end of the range, where they occur, the stage comprises 50-100 m. of alternating fine-grained limestones and sandy marls which are altered to a sand. A record of *Quenstedtoceras lamberti* (Sow.) is noteworthy (Palacios, 1919, p. 63). In several places a good *Hecticoceras* fauna of the Middle to Upper Callovian is recorded, also *Reineckea aniceps*, *Phlyticeras* and several forms of *Macrocephalites*, which will repay closer scrutiny (Dubar, 1930, pp. 594, 606; Lamare, 1936, pp. 56, 86, 178, 183).

BATHONIAN

Up to 60 m. of limestone with thin marly beds and some brachiopods may belong here (Dubar, 1930, p. 593). The only Bathonian ammonites recorded are *Perisphinctes procerus*, *P. arbustigerus*, *Oppelia aspidoides*, *O. cf. subcostaria*, *Sphaeroceras* sp. (Palacios, 1919, p. 63; Dubar, 1925, pp. 247, 251). These specific names imply the presence of the Bathonian genera *Procerites*, *Wagnericeras*, *Oxycerites*, *Paralcidia* and *Bullatinmorphites*.

BAJOCIAN

In the upper valley of the Bidassoa (which runs into the Bay of Biscay on the frontier, between San Sebastian and Bayonne), Dubar (1930) made out a clear sequence of Aalenian and Bajocian faunas, and similar sequences have been published for other places near the western end of the range by Lamare (1936, pp. 189, 191, 338). Some additional ammonites are recorded by Palacios (1919) and Dubar (1925, p. 251). The total thickness is up to 100 m. or more, mostly limestones.

Upper Bajocian is represented by various *Garantiana*, *Parkinsonia*, *Spiroceras*, *Bigoites*, *Lissoceras*.

Middle Bajocian is represented by various *Stephanoceras*, *Chondroceras*, *Sphaeroceras*.

Lower Bajocian is represented by *Ludwigia*, *Brasilia*, *Graphoceras*, *Tmetoceras*, etc. (some figured by Dubar, 1930).

TOARCIAN

Limestones, marly limestones and marls of this age are widespread, almost ubiquitous, and richly fossiliferous. In Lérida, in the SE., Dalloni (1930, p. 170) recognizes the following horizons:

2. Beds with *Leioceras opalinum*, *Pleydellia aalensis*, *Dumorteria radians* and *Grammoceras distans*; with beds of *Gryphaea sublobata* at top, containing no cephalopods.

1c. Beds with *Hammatoceras insigne*, *Grammoceras striatulum*, *G. fallaciosum*, *G. thouarsense*, *Phymatoceras erbaense*, *P. bayani*, *Haugia variabilis*.

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ib. Beds with Dactylioceras commune and D. subarmatum.


In other regions farther west other genera, including Lytoceras, Paroniceras and Polyplectus have been found in the upper beds; approximately the same succession is recognized everywhere. A detailed study of the passage beds from Pliensbachian to Toarcian in Ariège has been made by Dubar (1932).

**UPPER PLIENSCHIAN**

Nodular marly limestones and marls, or dark shales, marls and black limestones, sometimes passing up into hard sandy lighter-coloured limestones, are ubiquitous. Dubar (1925, pp. 117-71) was able to separate two zones as in NW. Europe: the Margaritatus Zone below, in which Liparoceras still occurs, and the Spinatum Zone above, with Pecten aequivalvis and Terebratula punctata, etc. Dalloni (1930, p. 169) also recognizes two zones in Lérida in the SE:

- Beds with Pleuroceras spinatum, Tropidoceras stahli and Proto grammoceras celebrium.
- Beds with Arieticeras algovianum, A. boscense and A. cepellini.

**LOWER PLIENSCHIAN**

Although this substage is usually only 2 or 3 m. thick, Dubar (1925, p. 117) and Dalloni (1930, p. 169) were both able to recognize two zones, those of Uptonia jamesoni and Prodauctylioceras davoei. There are records of various Liparoceratids, also Uptonia, Prodauctylioceras, Tragophylloceras, Acanthopleuroceras, Lytoceras cf. fimbriatum, etc. (Dubar, 1925, 1930; Dalloni, 1930; Lamare, 1936, p. 111). According to Dalloni Protogrammoceras normannianum occurs in the Davoei Zone with P. davoei and A. capricornus.

**SINEMURIAN**

Although believed to be complete, the Sinemurian is mostly represented by poorly fossiliferous dolomites. Occasional finds have been recorded of Sinemurian ammonites such as Metophioceras cf. conybeari (Sow.) and Arietites cf. bisculatus (Brug.) (Palacios, 1919, p. 63), also Vermiceras tardecrescens (Hauer) (Dubar, 1925, p. 114).

**HETTANGIAN**

To this stage are attributed ubiquitous and massive developments of dolomite and hard limestone, which pass up into and cannot be separated from the Sinemurian. Interbedded with them are locally tuffs and lavas.
NORTH-EAST SPAIN

From the east end of the Cantabrian Mountains, south of Santander, a widening triangle of discontinuous outcrops of Jurassic rocks extends south-eastwards through Aragon to the Mediterranean coast between Valencia and the mouth of the River Ebro. Thence northwards it sends an extension along the coast range of Catalonia through the province of Tarragona towards Barcelona.

The main outcrops, in the central region, constitute a large part of the Iberian Mountains, a broad band of parallel folded ranges running NW. to SE., between the Variscan massif of the Spanish Meseta and the sunken Ebro basin, or Basin of Aragon, filled with horizontal Tertiary. The Jurassic and Cretaceous systems were strongly folded and overthrust in the post-Oligocene, pre-Miocene orogeny. This and subsequent folding brought to light two long, parallel ranges of Palaeozoic rocks, against which and over which the Mesozoic cover is broken in complicated secondary structures after the manner of those flanking the Pyrenees. The Palaeozoic culminations end at the town of Montalban, south of which the Jurassic and Cretaceous cover rocks unite to form the high plateau of Teruel.

The topographic nomenclature of this important tract is confusing. Originally the north-easterly range was called the Chaîne Ibérique and the south-westerly the Monts Hespérides; and 'Chaîne Celtibérique' was a later synonym of Chaîne Ibérique (Dereims, 1898, pp. 4-5). Lately the collective term Keltiberikum has been used by the German school for the whole system, including the plateau of Teruel, while Chaîne Ibérique is used in the same sense by the French school (cf. Richter & Teichmüller, 1933, p. 2, and Fallot, 1934a, p. 383).

Towards the coast the Iberian folds turn round sharply at right-angles into the folds and faults of the Catalanian coast range, which run SW.-NE., parallel to the shore. In the extreme south, in the province of Valencia, all are cut across by the later folds of the Betic front, beyond which a major orogeny took place in the late Miocene (post-Burdigalian, pre-Helvetian). In a sense the whole of 'Keltiberikum' is part of the foreland of the Betic orogeny.

As shown by R. Douville (1911) the Jurassic rocks over all this region are essentially epicontinental and contain a succession of faunas similar to those of the Pyrenees, France and extra-Alpine Europe, though some zones have not yet been recognized and are probably missing. As in the Pyrenees and Morocco, the Hettangian is without ammonites, and if it exists it is represented by dolomites. Locally the dolomites extend up to the Middle Jurassic. In most of the north-central region, which is nearest to the ancient Meseta, the succession ends with the Middle Jurassic or at highest Callovian, as in much of the Atlas of Morocco. Southwards higher stages come in as the Mediterranean is approached. The Mediterranean Tethys was doubtless the source of the transgressions

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that overspread the basin of Aragon; but in at least the Lower and Middle Jurassic there was a continuous seaway to the Pyrenees and Asturias and thence no doubt to the Atlantic in the Bay of Biscay.

The main source of detailed information on the Jurassic stratigraphy of the Iberian ranges is still the theses by Larrazet (1896) and Dereims (1898), which were well summarized by R. Douville (1911); and the same information and much more is brought together in the official memoir by Mallada (1902). The structural geology of the region has been investigated in a series of brilliant works by the pupils of Professor H. Stille (Lotze, 1929, Brinkmann, 1931, Richter & Teichmüller, 1933), in which some new stratigraphical data are also included. But the conclusions of these enthusiastic research students need to be read in conjunction with the maturer judgments of Staub (1928) and Fallot (1934a).

For the northern outcrops in the provinces of Burgos, Palencia and Santander, much information has been published since Larrazet’s work by Gutiérrez (1918), Mengaud (1920, 1932), Ciry (1933, 1940), Almela (1944), and Karrenberg (1934).
Farther south, in and about the province of Valencia, besides works mentioned above, there are contributions by Schlosser (1919), Roman (1923), Royo y Gomez (1927) and Bataller (1943), and a monumental work by Darder Pericas (1945). Finally, for the coast ranges of Catalonia there are important stratigraphical and palaeontological studies by Bataller (1922, 1926) and Kilian (1898), and above all the splendid monograph by Fallot & Blanchet (1923) which affords most of the very few published illustrations of Spanish Jurassic ammonites. The structure of the coast ranges has been ably described by Schriel (1929) and by Ashauer & Teichmüller (1935), and the geology in general is summarized by Hahne (1933).

Wealden Facies

In the central regions the Kimeridgian limestones are overlain directly by marine Aptian or later Cretaceous. In two separate basins, in the north (Burgos-Santander) and in the south (Valencia), however, a thick lacustrine, deltaic and 'continental' formation of at least mainly Neocomian age, in typical Wealden facies, comes in between the Jurassic and the Aptian. In places, a similar facies extends up to the Cenomanian, the total thickness then being up to 1000 m. in the northern provinces. The latest marine Jurassic limestones observed beneath these Wealden Beds, and dated by ammonites, are Middle Callovian (Anceps Zone) in the north and Lower Kimeridgian (Tenuilobatus Zone) in the south. The important question, whether any Portlandian or Purbeckian in continental facies is represented in the base of the Wealden, remains open. In any case a major regression during the uppermost Jurassic is indicated over the whole peninsula.

In the northern region (Burgos, Santander, etc.), according to the excellent descriptions by Mengaud (1920, 1932) and Ciry (1940) and the latter's splendid geological map, the sub-Aptian Wealden is Neocomian and evidence for anything earlier is lacking. The beds begin with basal polygenetic conglomerates, which pass up into poorly-fossiliferous current-bedded sandstones, white, red and yellow, alternating with variegated clays and marls. In the lower part of the series locally are beds of lignite and thin bands of impure limestone which yield in abundance a few species of freshwater and brackish mollusca. Some seem to be the same as species in the English and North German Wealden, others are different. Various Unios have been figured from the provinces of Soria and Logrono by Palacios & Sanchez and a very large form from Cantabria was identified as a variety of *U. valdensis* Mantell by Mengaud (1920, p. 81, fig. 12). *Corbula striata* Sowerby is also recorded. Gastropods include *Paraglauconica strombiformis* (Schloth.), which abounds on certain bedding-planes in the Weald Shales of England, and another (figd.: Mengaud, 1920, p. 85) likened to the Spanish marine Aptian *Cassiope renieveri* (Coquand). A large *Viviparus* likened to the English *V. sussexiensis* (Sowerby) (= *V. fluviorum* Sow. sp. *non* de Mont.) is not this species,
judging by the figures by Mengaud (1920, p. 83). Towards the west and south the marine Aptian wedges out and the later beds of similar facies continue up to the Cenomanian and transgress on to Lower Jurassic and Trias.

In the southern basin (Valencia) the Wealden Beds rest on pale grey or white marine limestones of Kimeridgian age, which have yielded *Physodoceras lallierianum* (d'Orb.) of the Tenuilobatus Zone (Schloesser, 1919). An upper limit is firmly imposed by succeeding marine Aptian. The usual thickness is about 150 m., but a section of 410 m. has been measured (Brinkmann, 1931, pp. 16-17). Here the age of the lowest Wealden Beds is more debatable. The lower part contains, near the base, some marine bands with *Trigonia gibbosa* (Sow.) and numerous *Isognomon* and other mollusca, which have been taken to indicate equivalence with the Portland Beds (Royo y Gomez, 1927). With and above these marine beds are freshwater beds with trunks and branches of trees and a rich vertebrate fauna. The vertebrates (saurians, fish, etc.) give no definite indication of age beyond 'Upper Jurassic or Lower Cretaceous.' While Royo y Gomez published only one identification of a gastropod from the marine beds, *Natica elegans*, which occurs in the Portland Beds, Brinkmann (1931, p. 16) identified five species of gastropods (10-38 m. above the base), all *Naticae* of Lower Cretaceous species. On the other hand, in another section and from a higher level, he recorded *Trigonia truncata* Kg., a species of the Gravesia Zones of the Boulonnais (Middle Kimeridgian). This is sufficiently like *T. oviedensis* Lycett to make one wonder whether it was not in fact the Asturian species. There is also considerable resemblance to *T. freixialensis* Choffat (1885, pl. x) of the highest Jurassic of Portugal, the Freixial Beds, which Choffat regarded as Portlandian. High up in the same section Brinkmann found isolated Cidarids and corals.

Near the coast SW. of Barcelona dolomites of unknown date are succeeded by 30 m. of bituminous lacustrine limestone with *Paludestrina*, *Bythinia* and *Physa* (Almera, 1896).

The problems of the Spanish Wealden clearly require much further work (see Saenz Garcia, 1952).

**Kimeridgian**

In the former 'Gulf of Aragon', in the plateau of Teruel and in Tarragona, on both sides of the lower Ebro valley, limestones and dolomites occur with the Lower Kimeridgian fauna typical of Crussol in the Rhone valley (Tenuilobatus Zone). This is the latest Jurassic fauna so far discovered, but similar beds devoid of fossils continue upwards for considerable thicknesses (about 35 m. in the plateau of Teruel), until overlain by Upper Cretaceous or Tertiary formations. In Teruel the lowest 5 m. of limestone yields in abundance the *Ataxioceras* and *Taramelliceras* assemblage of Crussol, with *A. polyplocus* (Rein.), *A. lictor* (Font.), *A. lothari* (Oppel), *T. trachynotum* (Oppel), while the upper 15 m. yields instead an assemblage of Aspidoceratids: *A. acanthicum* (Oppel), *A.
tenuispinatum Font., Physodoceras cf. altenense (d'Orb.) (Dereims, 1898, pp. 147-8). In Tarragona the same zone occurs, with still more of the Crussol Perisphinctids, especially Ataxioceras spp., also large Progeronia progeron (de Lor. non von Ammon) and Physodoceras altenense (d'Orb.) (Fallot & Blanchet, 1923, pp. 215-25; Bataller, 1926, p. 114). As Dereims remarked, there is in these assemblages no sign of Phylloceratids or Lytoceratids, nor of Simoceras nor Hybonoticeras. A little farther south, however, at Chelve in the province of Valencia, Simoceras, Hybonoticeras and Lytoceras occur, together with Ataxioceratids, Physodoceras circumspinosum (Quenst.), the northern Rasenid Involucitceras, and a number of Portuguese Perisphinctids (Schlosser, 1919). *Prorasenia stephanoides* (Oppel) (wrongly assigned by Bataller (1926, p. 115) to Spiticeras) would indicate only Lower Kimeridgian; there seems no proof of the presence of any horizon above the Tenuilobatus Zone. Radioles of *Balanocidaris glandifera* occur in Teruel.

**UPPER OXFORDIAN**

The Bimammatum Zone, with *Epipeltoceras bimammatum*, *Ochetoceras marantianum* and many Portuguese Perisphinctids, occurs in Valencia (Schlosser, 1919), and *O. marantianum* also occurs in Teruel in 6 m. of limestone above the Plicatilis Zone (Dereims, 1898, pp. 133, 147). Elsewhere in Teruel are marls with small pyritized ammonites of this zone (Dereims, p. 132-3). The Transversarium Zone is more strongly developed and widespread. In Valencia a large part of the fauna of Trept in the Rhone valley occurs. These ammonites have been compared by Bataller (1943) with the photographs in De Riaz's monograph. In accordance with the revision of the Trept fauna published by the present author in 1946, the list becomes as follows:

- *Holcophylloceras* aff. *polyolcum* (Benecke) (de Riaz, xvi, 9, 10)
- *Ochetoceras* aff. *henrici* (d'Orb.)
- *Euaspidoceras riazi* (Collot) (de Riaz, xix, 8)
- *Peltoceras* (Gregoryceras) sp.
- *Perisphinctes* (Arispinctes) *plicatilis* (Sow.) (de Riaz, pl. i)
- *Perisphinctes* (Arispinctes) cf. *kreutzi* Siem. (pl. vii, 4)
- *Perisphinctes* (Dichotomosphinctes) *wartae* Buk. (pl. xi, i)
- *Perisphinctes* (Dichotomosphinctes) *pseudocratalinus* Kilian & Guèbhard (pl. vii, 5, 6)
- *Perisphinctes* (Dichotomosphinctes) cf. *antecedens* Salfeld (pl. xii, 1)
- *Perisphinctes* (Dichotomosphinctes) cf. *buckmani* Arkell (pl. xii, 2; pl. viii, 5)
- *Perisphinctes* (Discosphinctes) cf. *idelettae* de Riaz (pl. x, 3)
- *Perisphinctes* (Discosphinctes) *richei* de Riaz (pl. xv, 3)
- *Perisphinctes* (? Kranaosphinctes) aff. *navillei* Favre (pl. xvi, 1)

In Tarragona additional species are described, including *P. schilli* (Oppel),

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**THE IBERIAN PENINSULA**

*P. tarracnonensis* Fallot & Blanchet, etc. (Fallot & Blanchet, 1923). In Teruel Dereims (1898, p. 147) records the same fauna in 8 m. of limestones, with *Ochotoceras canaliculatum* (von Buch) and most of the Perisphinctids in the upper half, and *P. plicatilis* and *Aspidoceras perarmatum* in the lower half. Dereims (1898, p. 143) also observed *Peltoceras* (Gregoryceras) *fouquei* Kilian in a higher bed than *P. plicatilis* and *P. cf. airoldii* Gem. and this agrees with its type area, Andalusia, where it is a species of the Bimammatum Zone (Fallot, 1934).

**LOWER OXFORDIAN**

As in the Rhone valley and North Africa, the presence of Lower Oxfordian is not established with certainty. Dereims (1898, p. 131) and Mallada (1902, p. 401) accepted as Lower Oxfordian half a metre of oolite in Teruel from which Dereims recorded *Sowerbyceras tortisulcatum* (d'Orb.), *Calliphylloceras lodaense* (Waagen) (both Oxfordian), *Perisphinctes* cf. *sutneri* Choffat (Upper Oxfordian) and two Perisphinctids recorded as aff. *bakeriae* (Sow.) and cf. *subtilis* Neum., both of which would be *Grossouvriae*, possibly Lower Oxfordian species such as *Klemostosphinctes vernoni* (Young & Bird). At another locality in Teruel a bed only 20 cm. thick is reported to contain 'numerous varieties of *Perisphinctes plicatilis* as well as *Perisphinctes* cf. *consociatus* (Bukowski), *P. cf. michalskii* (Bukowski), and *P. birmensdorfensis* (Moesch) (Dereims, 1898, p. 141), three species which, if correctly identified, would indicate the Cordatum Zone. There seems to be a complete absence, however, of the typical Cardioceratidae, Oppeliidae and Aspidoceratidae (including Peltoceratinae) normal to the Lower Oxfordian.

**UPPER CALLOVIAN**

The only evidence for Upper Callovian in NE. Spain appears to be a single record of *Peltoceras athleta*, the determination of which was doubted by Dereims (1898, p. 149).

**MIDDLE AND LOWER CALLOVIAN**

The Callovian (less Upper Callovian) is the last of the Jurassic stages that is distributed over the whole area. Nevertheless it is much condensed, consisting of limestones in places only 5 m. thick. It is richly fossiliferous and contains the standard NW. European ammonites (except in the south: see below). Both in Burgos in the north and in Aragon two zones have been recognized almost everywhere: a lower zone with *Macrocephalites macrocephalus* auct. and various 'Sphaeroceras' auct., with *Hecticoceras hcticum*, etc., and an upper zone with *Reinekekea ances* and numerous species of *Hecticoceras* and *Grossouwria* and also *Erymnoceras* (Larrazet, 1896; Dereims, 1898, tabulated in R. Douvillé, 1911, p. 60; Gutiérrez, 1918; and Larrazet reproduced in full by Mallada, 1902, pp. 350-3). In the north Larrazet has been confirmed by Ciry (1940, pp. 49-52), though in one locality he thinks the Callovian is developed in the facies...
of freestones. Eastwards the work of Dereims has been extended into Tarragona by Bataller (1922, 1926) and by Fallot & Blanchet (1923). Monographing of the Macrocephalitids may in future lead to refinement; from the references to figures given by Fallot & Blanchet (1923) and by Ciry (1940, p. 62) it seems that true Macrocephalites and Dolitkephalites of the Macrocephalus Zone are present as well as Pleurocephalites proper to the Koenigi Zone. It is evident also that here, as in France, various Bullatimorphites and perhaps allied genera survive from the Bathonian into the Lower Callovian. The genus Phlycticeras also occurs.

Towards the south the outcrop passes into a region of deeper or more open water, where the Betic geosyncline seems to have extended temporarily farther north than usual. At Sarrión, south of Teruel and NNW. of Valencia, a lenticle of ironstone contains a rich Middle Callovian ammonite fauna in which Phylloceratids and Lytoceratids predominate, in marked contrast with the other outcrops where none are recorded. The species are Ptychophylloceras hommairei (d’Orb.), Holcophylloceras signodianum (d’Orb.), Sowerbyceras deleitrei (Mun.-Ch.) and Lytoceras adloides (Kud.). The rest of the fauna, which includes Macrocephalites canissaroi auctt., Reineckeia lifolensis Stein., R. douvillei Stein., Hecticoceras metomphalum Bonar, H. balinense Bonar., etc., notwithstanding a record of ‘M. macrocephalus’, seems to be typically of the Anceps Zone with some earlier elements of about Koenigi Zone date.

**Bathonian**

In the north (Burgos, etc.) the Bathonian and Callovian together comprise 20-40 m. of fine-grained freestone, rarely oolitic, and compact marlstone. The greater part is Bathonian. Ciry (1940, pp. 48-9, 60) recognized a lower zone with (interpreting his records by the figures referred to) Oppelia fallax (Gueranger), O. favrei (Wetzel), Parkinsonia aff. parkinsoni (Sow.), Procerites cf. clausiprocerus (Buckman), Siemiradzkia aurigera (d’Orb.), Bigotites aff. pseudomartinsi (Siemir.) (a Bajocian species); and a higher zone with Pseudoperisphinctes cf. rotundatus (Roemer), Oecotraustes serrigerus Waagen, ? Prohecticoceras sp. cf. zieteni Tsyt. (a Callovian species) and Posidonia alpina. Morphoceras multiforme and Ebrayiceras pseudoanceps are also recorded, but mixed with Bajocian ammonites (Ciry, 1940, p. 46). Collection failure must be suspected here. Some Lower Bathonian Procerites have also been figured (as Bajocian) from Burgos by San Miguel de la Camara (1952). In Teruel, Dereims (1898, pp. 118-20, 122, etc.) recorded almost the same two assemblages; and in addition he has Bullatimorphites ymir (Oppel), Procerites subprocerus (Buckman) and Cadomites cf. rectelobatus (Hauer) in the lower bed (10 m.), and ? Bullatimorphites microstoma (d’Orb.) in the upper bed (4 m.). B. bullatus (d’Orb.) and Wagnericeras arbustigerum (d’Orb.) are also recorded from Teruel.

In Tarragona the Bathonian may be represented in some places by unfossiliferous limestones and dolomites, but in others it contains many

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brachiopods and ammonites and *Cancellophycus*. The presence of Lower Bathonian is indicated by *Procerites* and *Morphoceras* cf. *multiforme*, but the strongest development is Upper Bathonian, with *Bullatinomorphites* spp., *Choffatia subbakerae* (d'Orb.) and allies, *Oppelia aspidoides* (Oppel) and *Clydoniceras* cf. *discus* (Sow.). (Bataller, 1926, p. 110; Fallot & Blanchet, 1923, pp. 181-3).

The Bathonian of the whole area, therefore, is a continuation of that of France and extra-Alpine Europe.

**Upper Bajocian**

The Upper Bajocian is rich in typical NW. European ammonites over the whole area and its fauna is usually distinct from the earlier and later faunas. In the north, in the province of Alava, SE. of Santander, 10-12 m. of limestone yields an assemblage of the Subfurcatum and Garantiana Zones, with both the index genera, plus *Strigoceras*, *Sphaeroceras*, *Normannites*, *Bigotites*, *Lissoceras oolithicum* (d'Orb.), *Oppelia subradiata* (Sow.) and three species of *Spiroceras* (Almela & others, 1944, p. 10). The underlying limestones have yielded only a single *Stephanoceras*. There are similar records for Burgos, Aragon, Teruel and Catalonia, and in most districts the Parkinsoni Zone is represented also. An interesting development occurs in Burgos and in Tarragona, where the Upper Bajocian takes the form of marls with small pyritized ammonites and ammonoids (*Spiroceras* abundant) as in the Ghar Rouban district of Algeria; and in Burgos as in Algeria this facies persists up into the Lower Bathonian, for, as just mentioned, pyritized *Morphoceras multiforme* and *Ebrayiceras pseudo-aniceps* were collected with the Upper Bajocian forms (Ciry, 1940, pp. 46, 58-9; Bataller, 1926, p. 110; Fallot & Blanchet, 1923, pp. 76, 129 ff., pls. i-iii).

**Middle and Lower Bajocian**

All the zones are present in Burgos, Aragon and Catalonia, with all the principal genera of ammonites; many have been figured from the Middle Bajocian by Fallot & Blanchet (1923). Stephanocerotids are most strongly represented, with *Stephanoceras*, *Skirrocera*, *Teloceras*, *Chondriceras*, *Otoites*, *Normannites*, etc., but also *Witchellia*, *Dorsetensia*, *Sonnia*, *Strigoceras* and Oppeliids. Lower Bajocian is recessive and seems to be only locally fossiliferous, but three zones, Opalinum, Murchisonae and Concavum, have been recognized. Many details from Larrazet, Dereims and others are tabulated by R. Douville (1911, p. 61). The Sowerbyi, Sauzei and Humphriesianum Zones are all represented by fauna but have not been separated satisfactorily in the field. (See, however, Dereims, 1898, p. 122). In the north the strong condensation causes *Tmetoceras scissum*, *Leioceras opalinum* and *Pleydellia aalensis* to be recorded from one marl bed 2 cm. thick (Ciry, 1940, p. 44).
TOARCIAN

Typical Toarcian faunas occur over the whole area. The facies is mainly marly limestones with abundant ammonites, pelecypods and brachiopods. The thickness varies usually between about 20 and 50 m. Most detail is known in Burgos (Larrazet) and the Iberian Ranges with the plateau of Teruel (Dereims), and has been tabulated by R. Douville (1911, pp. 56-7). In the Sierra Palomera, Dereims (1898, p. 103) established five zones, as follows:

5. Zone with rare *Pleydellia aalensis* and *Leioceras opalinum* auct.
4. Zone of *Grammoceras doerntense* and *G. bingmanni*
3. Zone of *Grammoceras fallaciosum*, with *G. thouarsense*
2. Zone of *Hildoceras bifrons* and *H. levisoni*
1. Zone of *Harpoceras falcifer* and *H. levisoni*

Under this come 6 m. of limestones with *Spiriferina rostrata* and *Rhynchosella tetrahedra*, then a bed with *Pleuroceras spinatum*. Larrazet found a similar brachiopod bed in the same position, between the Spinatum and Falcifer Zones, farther north, in Burgos. In the Iberian Ranges, however, Dereims (1898, pp. 105-6) found *Spiriferina rostrata* and other brachiopods to be abundant in the base of the Toarcian limestones with *Hildoceras bifrons*, *H. levisoni*, *Dactylioceras annulatum* and *D. commune*; it occurs in all its varieties, as in the Domerian of Italy, and even ranges up into the Fallaciosum Zone with *Hammatoceras insignis*.

Typical Toarcian faunas are also recorded from many other places by Bataller (1922, 1926), Mallada (1902, p. 397, *Polyplectus* recorded, with *Hammatoceras*, etc.), Ciry (1940) and others.

PLIENSCHABIAN

Pliensbachian faunas are practically co-extensive with the Toarcian and the same references should be consulted. Spinatum and Margaritatus Zones are recognized and separable in many places. Below is a more uncertain zone from which such ammonites as *'Microceras capricornu'* and *'Deroceras armatum'* are recorded, and below this in Burgos is another band of *Spiriferina*. In Aragon, Dereims (1898, p. 105) records *Fuciniceras cornacaldense* (Tausch) and *F. ?boscense* (Reynès) immediately below the beds with *Hildoceras bifrons* and *Dactylioceras commune*, but unfortunately their relationship to any earlier faunas is unknown. *Uptonia* has been found in Tarragona (Fallot & Blanchet, 1923, p. 82).

SINEMURIAN AND HETTANGIAN

In Aragon, Burgos and probably elsewhere, these stages are at least partly represented by 100-180 m. of dolomites and more or less dolomitized limestones in which fossils are mostly destroyed. These were formerly taken for Trias, but occasional finds of pelecypods, especially *Pecten hehli*, point to a Liassic age. In the north (Burgos, etc.) the basal, partly dolomitic, platy, fine-grained limestones have yielded *Isocyprina germari*.

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(Dunker), a small pelecypod of equivocal meaning, since it occurs in both Rhaetian and Hettangian beds elsewhere. Above come marly limestones and marls of typical Liassic aspect, from which the earliest ammonites known are *Vermiceras cf. tardecrescens* (Hauer), *V. solarioides* (Reynès) and *Echioceras raricostatum* (Ziet.), collected about 15 m. above the base (Ciry, 1940, pp. 38-41; see also Gutiérrez, 1919, p. 115, for other Arietitids, etc.). The area was evidently continuous with the Pyrenees and there is also a strong resemblance to the development in Morocco.

**Asturias**

The most westerly and northerly Jurassic outcrops of Spain form a group on the north coast of Asturias (province of Oviedo), near the coastal town of Gijon, where they are exposed in the cliffs. This area has such special and peculiar features that it is here described separately; but it is linked with both the Pyrenees and the Iberian Ranges of Aragon by the intermediate group of outcrops near the north coast but not cut by it, lying in the southern part of the Cantabrian Mountains south of Santander, in the provinces of Santander, Burgos and Palencia.

In the coast sections of Asturias (fig. 26), the Lias is essentially the same as in the Pyrenees and all through the Iberian Ranges (Dubar, 1925, 1925a). It begins with grey dolomites, probably Lower Sinemurian, which at Cape Cervignon support a series of limestones and marls of Upper Sinemurian date, with at the base ‘*Asteroceras stellare*’, higher up large *Oxynoticeras* spp., and finally *Echioceras nodotianum* (d’Orb.) and *Bifericeras*. At Rivadesella two higher ammonite horizons occur: the first with *Androgynoceras* and *Arietoceras algovianum* (Oppel), the second with *Pleuroceras spinatum*, numerous belemnites and *Pecten aequivalvis* (Domerian). The Toarcian yields the usual assemblage of the lower zones: *Dactylioceras, Peronoceras, Hildoceras*, etc.

On the Toarcian at Rivadesella follows a remarkable succession of beds (Dubar, 1925, pp. 253-5):

<table>
<thead>
<tr>
<th>TOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Black shaly marls with septaria; a thick formation, apparently unfossiliferous.</td>
</tr>
<tr>
<td>7. Black marls and sandstones with <em>Exogyra virgula</em>.</td>
</tr>
<tr>
<td>6. Sandstones in thick beds, ripple-marked, and black marls alternating with sandstones. <em>Aspidoceras longispinum</em> (Sow.)</td>
</tr>
<tr>
<td>5. Dark sandstones, one of the upper beds full of <em>Trigonia oviedensis</em> Lycett, <em>T. infracostata</em> Lycett, <em>T. bronni</em> Ag., and other pelecypods... 8 to 10 m.</td>
</tr>
<tr>
<td>4. Shaly and sandy black marls with pelecypods and gastropods of no special dating value passing down into 50 m.</td>
</tr>
<tr>
<td>3. Marly sandstones 6 m.</td>
</tr>
<tr>
<td>2. Marls and sandstones, many colours, with some beds of marly limestone 105 m.</td>
</tr>
<tr>
<td>1. Siliceous conglomerate of quartz pebbles, and crossbedded sandstones, with lignite 14 m.</td>
</tr>
</tbody>
</table>

The fossils of beds 6 and 7 unquestionably point to a late Lower Kimeridgian date (Pseudomutabilis Zone), which suggests that the black marls and sandstones...
shaly marls above may correspond to higher parts of the Kimeridge Clay. Of the Trigonitae in bed 5, *T. bronni* Ag. is a species of the Upper Oxfordian in France. The other two species were described by Lycett (1881) from specimens sent him from Oviedo province with erroneous stratigraphical information that they were of Hettangian age. Bed 4 from its inconclusive fauna appears to be also Upper Jurassic. The underlying 120 m. of beds of ‘continental’ facies are believed by Dubar to be Upper Jurassic, and this interpretation is supported by the succession in Portugal. There the Lower Kimeridgian is transgressive and begins with conglomerates and sandstones (see pp. 237-238). Karrenberg (1934, p. 25), however, mentions a Bajocian conglomerate in southern Cantabria; for which (if he correctly dated it) one would have to seek the nearest analogy in the Crimea (see p. 355).

**PORTUGAL**

On the west side of the peninsula Mesozoic rocks form a coastal strip between Oporto and Lisbon and continue for some distance farther south under the Tertiary and Quaternary basin of the Tagus. South of the Tagus they emerge to form the coastal range of Arrabida, at the mouth of the River Sado, and a group of small inliers 30 miles farther south. They are also developed in a separate coastal strip in Algarve, striking west-east from Cape St Vincent to the Spanish border. Their total area is one-tenth that of Portugal. Of this area the greater part is occupied by outcrops of the Jurassic.

The total thickness of the Jurassic system exceeds 2000 m. The Lower Jurassic consists mainly of dolomites and limestones, the Middle of limestones, the Upper largely of carbonaceous sandstones and shales with coal seams, but locally, especially in the Toarcian, Callovian, Oxfordian and

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**FIG. 26.**—Map of the Jurassic outcrops in Asturias, after Rui-Díaz, 1928, with minor additions after Dubar, 1925.
Lower Kimeridgian, there are important developments of marls and limestones with rich marine faunas. The development in Algarve is somewhat different. Here dolomites continue up into the Bajocian or Bathonian, and the Upper Jurassic contains thick dolomites, also coral limestones and conglomerates.

![Image of the Jurassic outcrops of Portugal.](http://jurassic.ru/)

**Fig. 27.**—The Jurassic outcrops of Portugal.

The Jurassic rocks of Portugal are supposed to have been deposited in a N.-S. gulf between the Meseta and its western continuation, the supposititious North Atlantic continent, which may be represented by the tiny islands of Berlengas and Farilhotes, of ancient granite (Choffat, 1900; da Costa, 1952) (fig. 27). It seems possible, however, that the granitic islands may have been brought to the surface by Tertiary faulting, and Dubar (1927, p. 586) believes that there was at least a Liassic seaway across the Meseta, connecting with Cantabria.
Palaeontologically, the outstanding local feature of the Portuguese Jurassic is a great development of the Upper Oxfordian and Lower Kimeridgian stages, together 1500 m. thick, which Choffat in 1885 united as a Lusitanian stage. This term was adopted and given currency by Haug (Traité, 1910, p. 1049), with consequent restriction of d' Orbigny's Oxfordian and Kimeridgian. It has been the source of much confusion and is a regrettable memorial to the magnificent life's work of Paul Choffat, who almost single-handed unravelled and described the Mesozoic stratigraphy and palaeontology of Portugal. Choffat himself (in Koby & Choffat, 1904-5, p. 148) recognized the purely local value of his Lusitanian stage and he did not consider it applicable even in Algarve (Choffat, 1887, p. 306).

NEOCOMIAN

At Cintra and in eastern Algarve marine limestones and marls are developed from the Berriasian up to the top of the Cretaceous, excepting the Almargem Beds, a continental intercalation with a celebrated land flora, probably of Aptian age. But at a distance of only 5 km. from Cintra the whole Neocomian including the Valanginian seems to pass into sandstones. In the south the Jurassic and Lower Cretaceous are complete. From Torres-Vedras northwards the lowest stages of the Cretaceous are progressively cut out by overlap, and farther north the lacuna involves the Upper Jurassic also, until from about the latitude of Coimbra Middle Cretaceous rests on Middle and Lower Jurassic. The basement beds of the Cretaceous contain great quantities of quartzite pebbles which, like the clastic materials in the Upper Jurassic, diminish in size and quantity westwards, indicating a shoreline in the east, but not nearer than 15 miles (Choffat, 1894, p. 249).

TITHONIAN

Freixial Beds. The highest Jurassic beds cover a large area. North of the Tagus they consist mainly of fine micaceous sandstones with calcareous cement; south of Torres Vedras they are mainly marly limestones. The fossils (e.g. Trigonia freixialensis Choffat) are of little value for correlation. In the Arrabida Range, besides corals, there are Nerinea beds, and in Algarve marls and limestones passing into conglomerates with pebbles of limestone and Palaeozoic rocks. Choffat assigned the Freixial Beds to the Portlandian, and the conglomerates suggest the probability of correlation with Tithonian rocks which elsewhere post-date a phase of Nevadan movements.

KIMERIDGIAN

In various parts of Portugal the Lower Kimeridgian is transgressive on to Callovian and earlier Jurassic rocks and on to the Palaeozoic and crystalline basement, and the transgression coincides with the introduction of vast quantities of coarse clastic material. In Algarve the Kimeridgian

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comprises thick dolomites with intercalations and lenses of coral limestones, *Nerinea* limestones and *Diceras* limestones, and beds of quartzite pebbles at two levels, the upper one becoming in western Algarve a limestone conglomerate with quartzite and lydite pebbles, resting on Upper Callovian. A Lower Kimeridgian ammonite fauna with *Ataxioceras effrenatum* (Fontannes), *Sowerbyceras loryi* ( Munier-Chalmas), *Simoceras herbichi* (Hauer), *S. aff. explanatum* Neumayr, etc., first makes its appearance about 5 m. above the Callovian. There appears to be in some places a condensed representative of the Bimammatum Zone also, for *Epipeltoceras bimammatum* and *Ochetoceras marantianum* are recorded from the same beds (Choffat, 1887, pp. 258-61).

North of the Tagus the Kimeridgian is well developed in the Montejunto Range (Torres Vedras country) between the Tagus basin and the sea. Here the succession is:

‘Pterocerian’. Argillaceous sandstones and marls with local intercalations of limestone, and locally beds of well-preserved *Trigonia lusitanica*, etc. (Choffat, 1885, pls. vii, viii). North of the Montejunto Range marine fossils disappear and all passes into sandstones with plant remains and Unios (Choffat, 1885, 1894). No ammonites are known, but there are corals, from which and the gastropods and pelecypods a ‘Pterocerian’, i.e. Lower Kimeridgian, age is inferred (Koby & Choffat, 1904-5, p. 160). Underneath are similarly undatable beds with *Lima pseudo-alternicosta* and corals, said to form a passage down into the Lusitanian.

**Upper Lusitanian (Abadia Marls), 800 m.** Mainly marls or clays, with intercalated sandstones, conglomerates and pebble beds, the pebbles largely derived from the pre-Cambrian: one such lenticle is 50 m. thick. In the marls are sometimes fossiliferous nodules with many pelecypods and gastropods and some corals. In the middle is an ammonite horizon containing a rich Lower Kimeridgian assemblage (Choffat, 1893, pls. xvii-xix), mainly *Progeronia* spp. (pl. xviii), with *Aspidoceras cf anachicum*, *A. cf. longispinum* and others, *Simoceras* spp. (pl. xvii, 6-10, xix, 4), *Taramelllicereras nimbatum* (Oppel), *T. trachynotum* (Oppel), *Idoceras? guimaraesi* Choffat sp. (pl. xvii, 11), *I. planula* (Hehl), *Prorasenia cf. stephanoides* (Oppel), etc. The exact age of this fauna is difficult to assess, but it is probably somewhat earlier than the *Ataxioceras effrenatum* assemblage of Algarve and may belong to the lower part of the Tenuilobatus Zone.

**Middle Lusitanian pro parte (Upper Montejunto Beds).** The Montejunto Beds, 200-350 m. thick, comprise coralline limestones with here and there beds of different facies, in which Choffat recognized four ammonite horizons. The lowest (1) is certainly Upper Oxfordian and the highest (4) certainly Lower Kimeridgian, but the age of the two middle horizons is debatable. The fauna is listed by Choffat (1893, p. 77, beds 1-4 separated) and any specialist may form his own judgment. Definite Lower Kimeridgian ammonites in the highest horizon (4) are *Enosphinctes*
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bukowskii (Choffat) (pl. vi, figs. 19-26; also in bed 3), *Idoceras montejuntense* Dacqué (Choffat, pl. xi, 2), *Aspidoceras aff. cyclotum* (Oppel) (xv, 5), *Prorasenia aff. witteana* (Oppel) and *P. sp.* (xv, 6, 7), *Sowerbyceras loryi* (Mun.) (xvi bis, 1; also bed 3) and various *Taramelliceras* (xvi, 12-17) and other Oppeliids. The absence of *Pictonia, Rasenia, Ringsteadia* and *Aulacesthephanus* from Portugal make close comparison with NW. Europe precarious, but so many species, especially the local Perisphinctids, are common to beds 3 and 4 that no stage boundary could be drawn between them.

**UPPER OXFORDIAN**

*Middle Lusitanian pro parte (Lower Montejunto Beds).* Bed 1 of the Montejuno Beds (10 m.), with *Perisphinctes (Orthosphinctes) tiziani* (Oppel) var. *occidentalis* Choffat and allies (1893, pl. v, 5-10) is assignable with confidence to the Bimammatum Zone.

*Lower Lusitanian (Upper Cabaco Beds, 300 m.).* Beds with numerous pelecypods and corals in lenticles; ammonites rare, except in a thin bed near the base. From this Choffat obtained ammonites which he rightly recognized as 'indubitably Oxfordian' and of the age of the Transversarium Zone. His plates ii-iv show *Perisphinctes (Arisphinctes)* spp. extremely close to some of those in the Plicatilis Zone of England and NW. Europe, also *Dichotomosphinctes* spp. (pl. v, 1, 2), *Kranaosphinctes* (v, 4), *Mirosphinctes* (vi, 4), *Cardioceras (Plasmatoceras)* sp. (vi, 1, 2) of the style of those in the Arngrove Stone, *Euaspidoceras cabassoense* Spath (type, Choffat, pl. 1), which is close to *E. crebricostis* Arkell, and *Ochetoceras* spp. According to Choffat *Ochetoceras* and *Glochiceras* (*Oppelia subclausa* Oppel sp.) have long ranges, the former from the Transversarium Zone into the Kimeridgian.

*? LOWER OXFORDIAN*

*Lower Lusitanian (Lower Cabaco Beds, 200 m.).* The minimum thickness of beds (limestones) between the Transversarium Zone and the Upper Callovian Athleta Zone is 200 m. The only fossils recorded are pelecypods of a few species without dating value.

**UPPER CALLOVIAN**

In the Montejunto Range and in Algarve this is represented by marly limestones with *Peltoceras athleta, P. arduennense, Grossouwria* spp., *Kosmoceras spinosum* (Sow.) (d’Orbigny, pl. 161: see Choffat, 1893, p. 80), *Paralcidia subcostaria* (Oppel), *Hecticoceras punctatum, Horioceras baugieri* (d’Orb.), *Sowerbyceras tortisulcatum* (d’Orb.), etc. (Choffat, 1880, p. 51; 1887, p. 254; 1893, pp. 2, 80).

**MIDDLE AND LOWER CALLOVIAN**

At Cape Mondego and other places north of the Tagus Choffat (1880, pp. 50, 69) records numerous Lower and Middle Callovian ammonites.

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from over 100 m. of alternating marls and limestones, and still longer lists are published for western Algarve (Choffat, 1887, pp. 247-53). Until the ammonites have been revised and figured nothing useful can be said about the succession. The list from Algarve contains 9 species of Phylloceratids. Among the other genera several anomalies appear: *Am. macrocephalus* and *Am. anceps* are said to occur together from the bottom to the top at Cape Mondego, and *Am. modiolaris* only at the top. A macrocephalitid from the Sharpe collection has been figured as *Nothocephalites mondegoensis* Spath (Cutch, p. 206, pl. xxxvi, fig. 16), and presumably indicates about Koenigi Zone. *Parapatoceras, Cadomites, Erymnoceras, Bullatimorphites, Distichoceras* and other interesting genera are present, to judge by Choffat’s specific records, together with a large fauna of other invertebrates. *Posidonia alpina* occurs throughout.

**Bathonian**

As Choffat considered the Bathonian a facies of the Lower Callovian, it is difficult to disentangle the two from his accounts. In some places north of the Tagus he described up to 70 or 80 m. of white oolites with a Bathonian fauna and no ammonites (1880, pp. 46, 71), but at Cape Mondego the Bathonian seems to be absent. White limestones believed to be Bathonian also occur in Algarve.

**Bajocian**

The Bajocian is fully developed in the country north of the Tagus, comprising up to 80 m. of highly ammonitiferous limestones and marls forming steep scarps. In the south and in Algarve is developed an Alpine facies of homogeneous sybcrystalline limestone, in which mainly Upper Bajocian fossils have been found. In the north Choffat (1880) recognized seven zones:

7. Beds with *Parkinsonia parkinsoni, Strigoceras, Garlandiana, Oppelia, Cadomites, Stephanoceras, Spiroceras, Morphoceras*, etc. (list 1880, p. 43)
6. Horizon of *Skirroceras bayleanum* (Oppel)
5. Horizon of *Teloceras blagdeni* (Sow.)
4. Horizon of *Acrocoelites blainvillei*
3. Horizon of *Otoites sauzei* (d'Orb.)
2. Horizon of *Sonninia sowerbyi* (Sow.)
1. Beds with *Ludwigia murchisonae* and *Leioceras opalinum*

Compared with areas in NW. Europe, the order of 5 and 6 is noteworthy; it seems likely that *Teloceras blagdeni* will turn out to be a misidentified *Stemmatoceeras*. Among other fossils, *Cancellophycus* occurs. *Posidonia alpina* is confined to the southern, or Alpine, facies. No. 1 is not clearly differentiated from the ‘Lower Aalenian’ with *Dumortieriae* and *Hammatoceras* (Choffat, 1908, pp. 156-9, a critical discussion of the ammonites).
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TOARCIAN (150-300 m.)

The Toarcian is best known from Choffat’s detailed work at Thomar, north of the Tagus (Choffat, 1908; brachiopods revised by Dubar, 1932, p. 30). The succession of ammonite horizons is as follows:

Thin bed with *Pecten pumilus* (0.5 m?)

Limestone with *Dumortieria* aff. *dumortieri* (Th.) and numerous *Pleydelia* (‘*Lioceras* belonging apparently to *L. aalense*’). (At least 10 m.)

Marly limestones and limestones with numerous *Rhyncho nella* cf. *cyrncephala*; *Dumortieriae, Leioceras, Brasilia* [?], *Hammatoceras pro-
erinsigne* (Vacek), *H.* cf. *subinsigne* (Oppel). (10 m.)

Marly limestones with *Hammatoceras* insigne and *Polyplectus* cf. *discoides*. (5-8 m.)

Limestone with abundant *H. insigne*, also *Grammoceras fallaciosum* (Bayle), *Polyplectus discoides* (Zieten), *Dumortieria* sp., *Catacoeloceras* cf. *crassum*. (2 m.)

Yellow limestones with a few corals. (7-5 m.).

Middle Toarcian marls, marly limestones and limestones with *Hildoceras* bifrons, *Dactylioceras annulatum* and many other fossils. (70 m.).

Lower Toarcian marls and limestones with *Dactylioceras annulatum*, *D. braunianum* and other spp., *Harpoceras falcifer* (Sow.) and *H. grunowi* (Hauer). *Spiriferina rostrata, Rhyncho nella tetrahedra*, etc. (16 m.)

Thin bed with numerous *Spiriferina rostrata, R. tetrahedra* and *Aulacothyris resupinata*.

At Peniche the basal beds of the Toarcian are as follows (Mouterde, 1953); this is an extremely important sequence, as will be seen.

Bed 16. Marls with small brachiopods and *Dactylioceras helianthoides* Yokoyama, *D. attenuatum* (Simpson), *D. sp.*, *Catacoeloceras* sp.


Bed 15d. No ammonites.

The *P. madagascariense* in bed 15e is noteworthy, since this species occurs with *Bouleiceras* in Madagascar and Arabia. More recently *Bouleiceras* itself has been discovered in Portugal, 3 km. south of Coimbra, again associated with *Protogrammoceras madagascariense* and this time at last dated unequivocally to the Lower Toarcian, since it overlies beds with *Dactylioceras* helianthoides, *D. semicoelatum* and *Leptaena* (Dubar & Mouterde, 1953; Mouterde, 1954). The genera *Peronoceras*, *Paroniceras* and *Frechiella* also occur north of Coimbra (Renz, 1912; Meister, 1914).

PLIENSBACHIAN

The succession at Peniche given above is continued downwards by more marls and marly limestones containing the *Arieticeras* (‘*Emaciati-
ceras*’) and *Canavaria* (‘*Tauromenia*’) fauna of Sicily and the Apennines.

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In Portugal these forms are associated with rare *Pleuroceras* but overlie the main *Pleuroceras* beds, and thus enable the Italian fauna to be accurately dated. The rest of the section is as follows (Mouterde, 1953):

**Bed 15c.** *Canavaria nerina* (Fucini), *C. cf. elisa* (Fuc.), *C. spp. nov.*, *Hildaites cf. kisslingi* (Hug), *H. rapisardi* (Fuc.), *H. sp. nov.*, *? Paltarpites aff. hallinensis* (Haas), *Pleuroceras aff. buckmani* (Moxon).

**Bed 15b.** No ammonites.

**Bed 15a.** *Arieticeras lottii* (Gem.), *A. spp.*

Bed 14. Marly limestones with *Pleuroceras cf. elaboratum* (Simpson), *P. birdi* (Simpson)?, *P. spp.*

At Thomar, Choffat (1908) found in 30-35 m. of beds successive zones of *Uptonia jamesoni*, *Androgynoceras capricornus*, *Protogrammoceras normanianum* and *Amaltheus margaritatus*. A more detailed succession was obtained by Dubar along the coast south of San Pedro de Muel (Mouterde, 1947, 1951):


11. Marls with *Lytoceras sp.*, *Arieticeras cf. domarense* (Meneg.) and allied forms.

10. Marls with some limestone bands containing *Amaltheus margaritatus* Montf. and large *Lytoceras fimbriatum* (Sow.). Near the base *Androgynoceras sp.*, *Tragophylloceras ibex* (Quenst.), and higher up *T. loscombi* (Sow.), *Harpoceras cf. fieldingi* (Reynès), *Protogrammoceras cf. normanianum* (d’Orb.).

9. Marls (1-2 m.). *Harpoceratids of the group of H. portisi* Fucini and *antiquum* Geyer non Wright; *Arieticeras aff. colloti* Lanquine.

8. Marls with beds of limestone (2-3 m.). *Androgynoceras henleyi*? (Sow.), *Oistoceras spp.*, *Metacyntbites centriglobus* (Oppel).


6. Marls with a band of marly limestone: *Tragophylloceras cf. paucicostatum* (Pomp.) and a large smooth ammonite.

5. Marls with thin beds of limestone: *Dayiceras polymorphoides* Spath and nov. var.

4. *Jamesoni Zone*. Marls and limestones (20 m.).

4d. *Uptonia reynardi* (d’Orb.), *U. angusta* (Quenst.), *U. dayiceroides Mouterde.*

4c. *Uptonia ignota* (Simpson), *Tragophylloceras paucicostatum* (Simpson).

4b. *Uptonia jamesoni* (Sow.), *Polymorphites muellensis* Mouterde.


Mouterde assigns beds 4a-d to the Jamesoni Zone, beds 5, 6, 7 to the Ibex Zone (less than 10 m. altogether), and beds 8-12 to the Domerian,
but bed 8 appears to be the Davoei Zone. Some Domerian ammonites are figured by Meister (1914).

**Sinemurian**

Beneath the Pliensbachian at San Pedro de Muel are upwards of 20 m. of marls and limestones with *Apoderoceras leckenbyi* (Wright) and *Oxynoticeras* spp. (Mouterde, 1947, p. 138; Pompeckj, 1906). In other places north of the Tagus, below the Jamesoni Zone, are shales or limestones, or both, with *Echioceras raricostatum*, *E. nodotianum* (d'Orb.), etc. These together form the *Gryphaea obliqua* beds of earlier accounts; but the name was abandoned as inexact. The Middle and Lower Sinemurian, consisting of dolomites, were grouped as the Coimbra Beds (c. 100 m.), but this term was also later abandoned, because the dolomite is only a facies and is largely replaced westwards by limestone and shale (Choffat, 1904, pp. 93-4). From the coast north of San Pedro de Muel are described a number of large *Arietitidae* of the Obtusum Zone. The Middle and Lower Sinemurian is represented by 50 m. of dolomites with *Boehmia exilis*, *Cardinia*, *Promathildia*, etc., but without ammonites (Choffat, 1904).

**Hettangian**

Pereiros Beds. Dolomites (100 m.) overlying sandstones and clays (30 m.), of Triassic facies but underlain by true Trias (sandstones and conglomerates up to 350 m. thick). The Pereiros Beds contain a fauna of small gastropods and pelecypods similar to those of the Hettangian in NW Germany, especially *Isocyprina germari* (Dunker) and *Promathildia turritella* (Dunker) (Boehm, 1901; Choffat, 1904).

**Southern Spain (Andalusia)**

We now complete our circuit of the Variscan massif of the Spanish Meseta with an examination of the Tertiary ranges of the south, the Betic Cordilleras. The Variscan ‘grain’ of the southern part of the Meseta is NW.-SE. Against it the Betic Cordilleras are folded almost at right-angles, in a series of ranges running through the country from Cadiz to Alicante and continued in the Balearic Islands. For the greater part of the distance, in the west and centre, the relations of the two sharply contrasted territories are hidden beneath the Neogene basin of the Guadalquivir. The northern boundary of the basin is a great fault, while to the south the Neogene feathers out, transgressing the earlier Tertiary structures and filling valleys and basins among them.

In the cordilleras both the facies of the Jurassic rocks and the tectonics differ from those of all other parts of the Iberian peninsula and resemble those of the Alps. Although now close to the Meseta, the Andalusian Jurassic appears to have been laid down in an open ocean far from the influence of terrigenous sediments. The whole Lias forms practically
one unbroken limestone and shale series. The Middle Jurassic is but feebly developed but shows a little more variety, for though usually limestone, the Bathonian in some places contains sandy elements. The Upper Jurassic consists almost entirely of nodular limestones (fausses brèches, Knollenkalk), often a mere 30-50 m. thick but reaching a maximum of 350 m.; the Tithonian is strongly developed (up to 250 m.). The Oxfordian and Kimeridgian of the Andalusian facies, from a few metres to 100 m. thick, contrast spectacularly with the 1500 m. of the same stages in their Lusitanian facies in Portugal. Besides nodular structure, a speciality is red colouring, which recurs at several horizons, not only in the Upper Lias, which provides, as elsewhere in the Mediterranean region,

**Fig. 28.—Tectonic sketch-map of the Betic Cordilleras. After Fallot, 1948.**

the typical Ammonitico rosso, but also in the Upper Jurassic and locally in the Lower Lias. The fauna consists almost exclusively of cephalopods, among which are a high proportion of Phylloceratids and Lytoceratids at nearly all levels.

The Andalusian (or, better, Mediterranean) facies has often been called bathyal, but several facts suggest that the sea cannot have been deep. The red colouring is derived from iron oxides intrinsic to the deposits, and this presupposes aeration of the bottom; the microscopic composition of the limestones is not that of deep-sea sediments; and the typical Tithonian, Kimeridgian and Upper Oxfordian nodular limestones are all locally transgressive (Fallot, 1934, p. 111). Nevertheless, the lack of terrigenous sediments indicates deposition in a tranquil and open sea a considerable distance off-shore.

The change of facies from the epicontinental or west European type to the Andalusian or Mediterranean type takes place abruptly along an irregular line running from the southern edge of the Neogene basin of the Guadalquivir eastwards to the sea at Alicante, and is found again

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in the Balearic Islands. This line is interpreted as the front of a complex of nappes (the Subbetic) which has travelled about 20 miles northwards, overriding the autochthonous but often acutely folded foreland (the Prebetic). The Prebetic zone forms the surface in the east, spreading out over the edge of the Meseta and passing north into the Iberian Ranges, but towards the west it sinks gradually beneath the basin of the Guadalquivir.

The Subbetic zone of nappes has an intensely complex structure, including klippes, one of which forms the Rock of Gibraltar (Bailey, 1953), but the Mesozoic rocks of which it is composed are little altered and often highly fossiliferous. To the Subbetic (including a northern zone of nappes formerly known as Penibetic) belong all the best-known fossil localities. The series is complete from Lower Lias to Cretaceous; the whole of it from Pliensbachian to Maestrichtian in Mediterranean facies. At any one locality, however, the sequence is often fragmentary, one or other part cut out by tectonic movements; and the whole pile rests on a sole plane over German-type Trias (plate 10 and figs. 29, 30).

To the south of the Subbetic zone, in a broad marginal band along the coast and including the Sierra Nevada, runs the Betic zone of far-travelled nappes, in which the rocks are more or less metamorphosed. They consist largely of Alpine-type Trias and Palaeozoics. No Jurassic has been recognized. The crystalline schists of the Sierra Nevada show through the surrounding Betic nappes as a tectonic window, eroded on a culmination. Similarly, west of Malaga, windows of Trias belonging to one of the Betic nappes project through a higher Palaeozoic and crystalline nappe. (Fallot, 1930, revised Fallot, 1948.)

Much work remains to be done before the Mesozoic preliminary disturbances of the Alpine storm can be deciphered in detail in this region, but local lacunae within the Middle and Upper Jurassic are suggestive, and early Kimeridgian and Tithonian transgressions certainly occur. Widespread Neocomian transgression in the east, claimed by Brinkmann & Gallwitz (1933), is denied by Fallot (1934, pp. 81-6, 115), who states that the supposed oversteps at the base of the Cretaceous are tectonic contacts. The main formation of the Betic nappes is dated to the Lower Eocene (and is therefore earlier than the Pyrenean folding), but the highest, or Malaga nappe, is believed to be Oligocene, as are the earliest movements in the Subbetic zone. Thereafter there was a widespread Burdigalian transgression, which in some places was initiated in the Aquitanian; and this was followed by a major orogeny between the Burdigalian and Vindobonian in the Subbetic zone. The Vindobonian is everywhere transgressive. Finally, the whole region was broadly refolded in the post-Pontic Pliocene. These latest movements involved all the Betic Cordilleras and adjacent parts of the Meseta. (Fallot, 1944.)

The sound foundations of our knowledge of the Jurassic laid by Bertrand & Kilian (1889) and Kilian (1889) for the west and centre, and by Nicklès (1896) for the east, have been built upon especially by

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Blumenthal and Fallot in numerous works and most ably revised and synthesized by Fallot (1931-4). Fallot gives such a wealth of information, with long lists of ammonites, that it is impossible here to attempt more than a bare outline of his results, laying stress mainly on the ammonite succession and its significance for wider correlations, and omitting any attempt to reproduce his brilliant analysis of the distribution of faunas and facies within the area, with his important tectonic arguments. No one wishing to follow up those lines of enquiry can dispense with his treatise.

[Neocomian]

In the west and centre there is an unbroken passage up from Tithonian into similar Berriasian and Valanginian limestones or marls with Neocomites, Olcostephanus, etc. (Fallot, 1934, pp. 76, 86, 105, 107). In the NE., 'Wealden Beds' up to 100 m. thick unconformably overlie various parts of the Jurassic. The boundary of these beds is shown by Brinkmann & Gallwitz (1933, p. 75, fig. 16), but neither their age nor their relation to the marine Neocomian is established.]

Tithonian (up to 250 m.)

Bertrand & Kilian (1889, p. 439) recognized two subdivisions, linked by numerous ammonites in common, but the lower division containing some Jurassic forms and the upper some Cretaceous. Fallot (1934) defined the two more precisely and recognized also a Middle Tithonian.

Upper Tithonian. Fallot (1934, pp. 90, 91, 100) gives three long lists of forms from different localities, the following being the most important species:

- Phylloceras serum (Oppel)
- Himalayites depressus (Uhlig)
- Phylloceras calypso (d'Orb.)
- Micracanthoceras microcanthum (Oppel)
- Phylloceras semisulcatum (d'Orb.)
- Spiticeras pseudogroteanum (Kilian)
- Lytoceras cf. montanum Oppel
- Neocomicites negreli (Math.)
- Lytoceras sutil Oppel
- Neocomites occitanicus (Pict.)
- Lytoceras liebigi Oppel
- Neocomites cabrensis Kil.
- Lytoceras honnoratianum (d'Orb.)
- Simoceras volanense (Oppel)
- Haploceras elimatum (Oppel)
- Aspidoceras avellanum (Oppel)
- Haploceras caracheis (Oppel)
- Aspidoceras cf. raphaeli (Oppel)
- Berriasella abscissa (Oppel)
- Aspidoceras cf. liparum (Oppel)
- Berriasella carpathica (Oppel)
- Aspidoceras iphicerum (Oppel)
- Berriasella calisto (d'Orb.)
- Perisphinctes sublorioli Kilian
- Berriasella privasensis (Pict.)
- Berriasella chaperi (Pict.)
- Berriasella lorii (Oppel)

In the Penibetic region the Upper Tithonian with Calpionella alpina, developed in some places in the form of red crinoidal limestone with Spiticeras celsum (Oppel), overlaps on to the Palaeozoic (Fallot, 1934, pp. 78, 79).

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PLATE 10.—The Rock of Gibraltar, a kikpe of Liassic limestone. (See Figs. 29 and 30.)

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Middle Tithonian. Fallot (1934, pp. 89, 91, 93, 105) lists the following as Middle Tithonian, but this subdivision should be understood only in a local sense:

- *Phylloceras calypso* (d'Orb.)
- *Phylloceras semisulcatum* (d'Orb.)
- *Sowerbyceras loryi* (Hebert)
- *Lytoceras sutile* (Oppel)
- *Haploceras caractheis* (Oppel)
- *Haploceras verruciferum* (Oppel)
- *Haploceras staszicii* (Zeusch.)
- *Haploceras tithonium* (Oppel)
- *Phylloceras abscissa* (Oppel)
- *Phylloceras chalmasi* (Kil.)
- *Berriasella senex* (Oppel)
- *Berriasella pouzinensis* Toucas
- *Sowerbyceras chalmasi* (Kil.)
- *Perisphinctes senex* (Oppel)
- *Perisphinctes cf. geron* (Oppel)
- *Perisphinctes pouzinensis* Toucas
- *Sowerbyceras loryi* (Hebert)
- *Lytoceras sutile* (Oppel)
- *Perisphinctes cf. geron* (Oppel)
- *Haploceras caractheis* (Oppel)
- *Haploceras verruciferum* (Oppel)
- *Haploceras staszicii* (Zeusch.)
- *Haploceras tithonium* (Oppel)
- *Phylloceras pseudogrotianum* (Kil.)
- *Perisphinctes pouzinensis* Toucas
- *Aspidoceras avellanum* (Oppel)
- *Aspidoceras zeuschneri* (Oppel)
- *Aspidoceras pseudogrotianum* (Kil.)
- *Perisphinctes pseudocolubrinus* Kil.
- *Haploceras staszicii* (Zeusch.)
- *Haploceras tithonium* (Oppel)
- *Phylloceras abscissa* (Oppel)
- *Phylloceras semisulcatum* (d'Orb.)
- *Haploceras caractheis* (Oppel)
- *Haploceras verruciferum* (Oppel)
- *Haploceras staszicii* (Zeusch.)
- *Haploceras tithonium* (Oppel)
- *Phylloceras pseudogrotianum* (Kil.)
- *Perisphinctes pouzinensis* Toucas
- *Aspidoceras avellanum* (Oppel)
- *Aspidoceras zeuschneri* (Oppel)
- *Aspidoceras cycлотom* (Oppel)

Lower Tithonian. The palaeontological division between the Kimeridgian and Tithonian, as in many other parts of the world, is not clear. Fallot (1934, pp. 79, 80, 89, 91) points out that *Simoceras volanense* (Oppel), *Sowerbyceras loryi* and other forms pass up from one into the other. In some places he recognizes a typical Tithonian fauna with *Lithacoceras geron*, *Pygope diphyra* and the 'banal' ammonites of the Tithonian (especially the same Phylloceratids and Lytoceratids as above); in others, as he rightly points out, his lists have 'un cachet Kimeridgien'. *Hybonoticeras hybonotum* (Oppel) occurs commonly, and if correctly identified this indicates the Lithographicum Zone of the Lower Tithonian; and the presence of a possible *Gravesia* is interesting (Fallot, 1934, p. 93).

**LOWER KIMERIDGIAN**

The ammonite fauna of the Acanthicus Beds is strongly represented in Fallot's lists by *A. acanthicum* and allied species, *Hybonoticeras* spp., *Simoceras* spp., *Ataxioceras lothari* (Oppel), *A. effrenatum* (Font.), *Enosphinctes eumelus* (d'Orb.), etc. (Fallot, 1934, pp. 87, 89, 91, 108), but it is often difficult to separate from the Tithonian. Possibly the *Hybonoticeras* often recorded as *hybonotum* is really an earlier species like *H. africanum* (Spath), which occurs in Kimeridgian beds of Tithonian lithic facies in Sicily. *Nebrodites torcalensis* Kilian sp. (1889, pl. xxv, fig. 6) is certainly Kimeridgian. The true Kimeridgian is developed in many places as 'ruiniform' limestones displaying fantastic forms of weathering (Bertrand & Kilian, 1889, pp. 426-7).

**UPPER OXFORDIAN**

One of the most constant marker horizons over the whole area is the assemblage of the Bimammatum Zone, with *Epipeltoceras bimammatum* (Oppel) and *Gregoryceras fouqueti* Kilian (both figured by Kilian, 1889, pl. xxvi), *Tarameliceras hauffianum* (Oppel) and a whole assemblage of Perisphinctids and Aspidoceratids. The Transversarium Zone is also

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present, dated by the index fossil, with *Euaspidoceras perarmatum* (Sow.), *Ochetoceras canaliculatum* (Buch), etc. In the long lists from these two zones (Fallot, 1934, pp. 101-2) there is a remarkable scarcity of Portuguese species. Eight species of Phylloceratids and five of Lytoceratids are recorded from the Upper Oxfordian, out of about 100 species of ammonites from the region.

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**Fig. 29.—Geological map of the Lias klippe of Gibraltar.** Based on Bailey, after Ramsey & Geikie, 1878, modified.

**LOWER OXFORDIAN**

Massive bedded limestones and nodular limestones poor in fossils are believed to represent the Lower Oxfordian but, as in many other places, none of the characteristic ammonites has been found.

**CALLOVIAN**

Limestones, both marly and nodular, up to 15 m. thick, have yielded Callovian ammonites in two places. Besides the ubiquitous Phylloceratids, *Macrocephalites* and *Choffatia*, there are recorded *Phlycticeras* sp., *Cademites extinctum* (Quenst.), *Bomburites* cf. *bombur* (Oppel) and three Hungarian Perisphinctids: *Choffatia villanoides* (Till), *Indosphinctes dreверmanni* (Till) and *Subgrossouervia coronaеformis* (Loczy). (Fallot, 1933, p. 70; 1934, p. 96.)
Bathonian

Traces of the Bathonian so far known are slight but definite. In the western Penibetic, compact limestones with strings of marl have yielded Eligmus polytypus, Terebratula circundata and Rhynchochella cf. varians (Bertrand & Kilian, 1889, p. 424). In the Subbetic are marly limestones with Posidonia alpina, partly Upper Bajocian and partly Bathonian, since they yield Nannolytoceras tripartitum (Raspail), Wagnericeras forticostatum.

Fig. 30.—The Arc of Gibraltar, showing the relationships of the Jurassic of Spain, Gibraltar and the Rif of Morocco. After Bailey.

Bajocian

Though greatly reduced, the Bajocian may be complete, to judge by records of Ludwigia murchisonae, Otoites sauzei, Stephanoceras humphriesianum, Shiroceras bayleanum, Chondroceras, Normannites braikenridgei, etc., and Posidonia alpina beds with Spiroceras, Bigotites and Oecotraustes genicularis of the Upper Bajocian. As in Algeria and elsewhere, the Bajocian is often represented by limestones with Cancellaphycus (Fallot, 1933).
1933). From the Lower Bajocian there is a remarkable number of English species of *Haplopleuroceras*, Graphoceratids and other ammonites as in Morocco (e.g. Fallot, 1932, p. 55).

**Lias**

All stages of the Lias except the Hettangian have been proved by ammonites. A vast amount of detail is known and has been ably brought together by Fallot (1932), but since the succession presents no special novelties no attempt is made to summarize the data here. Fallot believes that the original width of the Liassic sea between the Spanish Meseta and the Sahara Platform has been nearly halved by tectonic compression. He points out that the Lower Lias of the Betic Cordilleras does not differ from that of the rest of Spain and much of North Africa, but that in the Middle Lias (Cisneros, 1923, 1927) many peculiarly Italian ammonites entered; and that, despite the especially Mediterranean facies (Ammonitico rosso), the Upper Lias ammonites are those common almost all over Europe. The presence of Middle Lias cherts in Sicily, the Subbetic Cordillera and Gibraltar is noteworthy (Plate 10).

**The Balearic Islands**

A submarine ridge continues the line of the Betic Cordilleras into the Mediterranean. Upon it stand the delectable islands of Majorca, Minorca, Ibiza, Formentaria and Cabrera (fig. 24). Jurassic rocks occur on all but Formentaria. By far the largest outcrops are those of Majorca, but the succession is usefully supplemented by the other islands.

Structurally and stratigraphically the Balearics are a direct continuation of the Betic Cordilleras, though a change of strike to N.-S. in Minorca has given rise to much discussion (see Stille, 1930, 1934, 1937). The most probable solution is that Ibiza and the main sierra of the north of Majorca, in which the nappes are thrust to the north, belongs to the Subbetic, while Minorca and the centre and south of Majorca belong to the Betic (Fallot, 1945). The apparent westerly direction of the thrusting in Minorca could be due to interference by transverse undulations, the easterly dip of the thrust planes being merely off a culmination, as on the east of the Sierra Nevada or the Malaga nappe. The outcropping of Palaeozoic greywackes in Minorca and their occurrence as pebbles in a Burdigalian conglomerate in the middle of Majorca, and the facies of the Mesozoic rocks (which are not 'Andalusian' in Minorca and southern Majorca) support this interpretation (Fallot, 1945).

In the Majorcan Sierra the Jurassic is as complete as in the Subbetic of Andalusia and in the same facies (Fallot, 1922, 1931-4), but in Ibiza the Lower and Middle Jurassic are absent and Upper Jurassic, beginning with Upper Oxfordian, is transgressive on to Trias (Spiker & Haanstra, 1935). In Minorca no Jurassic ammonites have been found.

In the Majorcan Sierra the Lias begins with dolomites and dolomitic limestones which pass up into massive limestones. An *Arietites* has been

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identified with doubt. The earliest authenticated fauna is Upper Pliensbachian with *Arieticeras*, followed by Toarcian with *Hildoceras levisoni* (Simpson). *Tropidoceras masseanum* and *Juraphyllites* are recorded on Cabrera. The Bajocian of Majorca begins with a cephalopod bed containing the San Vigilio fauna of the Alps and NW. European genera (and even species) of Graphoceratids and *Haplopleuroceras*, and some Phylloceratids and Lytoceratids. The facies is in part an oolitic ironstone. Nodular limestones of Upper Jurassic type set in with the Middle Bajocian, which yields a good *Stephanoceras* fauna (some figured by Fallot & Blanchet, 1923). Then come Upper Bajocian marls with *Parkinsonia* and *Posidonia alpina*, etc. The Bathonian is sparsely documented, but probably represented by sandy *Posidonia* marls with *Phylloceras kudernatschi*, *Wagnericeras arbustigerum* (Nolan, 1895) and *Nannolytoceras*. *Morphoceras multiforme* has also been found (Darder Pericas, 1945, table facing p. 94). The Lower Callovian is proved on Majorca, but after this there is a gap in places until the Kimeridgian and Tithonian. The Oxfordian is represented by a stray record of *Epipeltoceras bimammatum* in Majorca and this and *Gregoryceras fouquei* and other ammonites are present on Ibiza, in limestones overlapping on to Trias. The Kimeridgian is as in Andalusia: *Streblites tenuilobatus* occurs on Ibiza, but in Majorca the zone is probably represented by unfossiliferous limestones (Nolan, 1895). The Middle Kimeridgian with *Hybonoticeras beckeri* and *Gravesia irius* begins the ‘Tithonian’ facies. The true Tithonian is divisible into a lower part (with ‘Perisphinctes contiguus’) and an upper (with *Berriasella privasensis* and *Spiticeras*), and it has yielded several peculiar forms of *Himalayites*, *Berriasella*, etc. (Fallot & Termier, 1923, pl. 1; *?Aulacosphinctes ponti*, fig. 4). *Calpionella* limestone is well developed in the islands (Colom, 1935, 1948).
PART III
AFRICA AND ARABIA
CHAPTER 10
NORTH AFRICA

THE NORTHERN FRINGE OF THE AFRICAN SHIELD: THE SAHARA PLATEAU

Like the present Mediterranean Sea, the European Tethys in the Jurassic was bounded on the south by the African continent. Where the great desert plateau now stretches from the Atlantic coast eastwards for 3500 miles across the Sahara, Libya, Egypt, and Arabia to the Indian Ocean, there extended also in Jurassic times a vast landmass. The southern boundary of the African shield in the Jurassic is unknown. Sea overspread its eastern edge from 500 to 1000 miles farther than at present, and the Tethys overspread its northern margin in places 100-250 miles from the present coast; but in the south and west the present ocean and the ancient shield, or its more recent sedimentary cover, are everywhere in contact, without the intervention of any fringe of Jurassic sediments.

The Jurassic fringe along the north coast is broken by the Gulf of Sidra or Syrtis in Libya. East of the gulf in northern Egypt, Jurassic rocks exist but are deeply buried under Cretaceous and Tertiary marine formations. The few occurrences known, from anticlinal folds and borings, and along the side of the Gulf of Suez rift, will be described in the next chapter. Westwards, from the Gulf of Syrtis through Tunisia, Algeria, and Morocco, the Jurassic formations are brought above sea-level and exposed progressively but intermittently for 1000 miles in the Atlas ranges. The folded ranges coincide with the Jurassic and lower Cretaceous rocks, and the southern boundary of these rocks is also the northern boundary of the Sahara plateau. The projecting land occupied by the Atlas ranges, known collectively as Barbary, is clearly a part of the Mesozoic Tethys, of which much has foundered beneath the present Mediterranean, except in Sicily, southern Italy and Greece.

Both the Sahara plateau and Barbary were intensely folded in the Variscan orogeny and planed in the Permo-Trias. Differentiation of the two areas began some time in the Trias with the gentle subsidence of Barbary and the initiation there of salt lakes elongated east and west. The Sahara plateau, on the contrary, remained above sea-level, or continued to rise, supplying clastic sediments to the Jurassic and Lower Cretaceous seas that invaded and covered up the Triassic lakes of Barbary. It was not until the early Upper Cretaceous (Albian-Cenomanian) that the sea spread southwards over the greater part of the Sahara plateau, probably linking up with the waters of the South Atlantic in the Gulf of Guinea. The resulting Cretaceous sediments remain horizontal or only

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gently tilted over vast areas, proving that there has been no important disturbance of the rigid platform since that time.

The earliest term of the transgressive series, which rests horizontally but with great disconformity on Carboniferous and earlier Palaeozoic and Archaean rocks in the northern Sahara, is a quartzose sand and sandstone formation, with quartz pebbles and fine quartz conglomerates of continental type. The only common fossils are silicified tree trunks (gymnosperms) up to 10 and even 20 metres long, which sometimes litter the desert. Occasionally in clay bands bones of fish (Ceratodus), crocodiles (Dyrosaurus) and saurians (Megalosaurus saharicus) are also found. This formation, which crops out round the great ‘ergs’ or sand seas of the Algerian Sahara, under the name of ‘continental intercalaire’, has commonly been supposed to represent continental equivalents of all the lower and middle Mesozoic formations, including the Jurassic. But in the southern Atlas, where in passing northwards the stratigraphical hiatus begins to be filled, the continental formation extends over fossiliferous Aptian rocks; and since it underlies the widespread marine Cenomanian clays and limestones of the Sahara plateau, its age is Albian (Savornin, 1931, p. 222; de Lapparent, 1947; de Lapparent & Lelubre, 1948). The evidence in Algeria therefore agrees with that in Egypt, where, as will be seen in the next chapter, the equivalent and closely similar Nubian Sandstone has yielded only Cretaceous fossils and passes northward over incoming wedges of first Bathonian, then Upper Jurassic, and finally Aptian rocks. These continental sandstones and grits are the first term of the transgressive Upper Cretaceous marine series. They appear to have been laid down at a time when the subsiding peneplaned continent was just passing below sea-level and immense spaces were covered by fluctuating sheets of shallow water. (de Lapparent & Lelubre, 1948; for Libya see also Kilian & Lelubre, 1946; and Desio, 1951, p. 50.)

Farther south the problem of the ‘continental intercalaire’ begins to show signs of resolution on similar lines, though the difficulties are greatly increased by the presence of Triassic (Karroo) and Tertiary and Pleistocene-Recent (Kalahari) systems of rocks of similar facies. In the central territories of Chad and the Cameroons, however, the Nubian Sandstone with its silicified wood seems to be identifiable with some assurance, in the same facies as in the type area of Nubia and as in the Algerian Sahara, and there is no reason to doubt its Middle or Upper Cretaceous age, although it has not yet been everywhere separated from the underlying Palaeozoic sandstones (Nickles, 1951, pp. 135-7). Again, in Nigeria, Dahomey and the Gold Coast the Mesozoic sedimentary cover begins with clastic rocks of Cretaceous age (Dixey & Willbourn, 1951, pp. 102, 104; Arnaud, 1951, p. 59). The Lualaba Series of the Congo, of which the uppermost beds have sometimes been classed as Jurassic on inadequate evidence, is now regarded as part of the Karroo and Triassic (Furon, 1950, pp. 272-3; Mouta & Cahen, 1951).

Thus it appears that virtually the whole African shield, inside the
northern and eastern ring of Jurassic marine outcrops, was above water level throughout the Jurassic and can be regarded as a source of supply for clastic sediments. In the north the Sahara plateau has been defined as ‘the part of Africa where Jurassic sediments are absent’ (Savornin, 1931; Menchikoff, 1949). The sole exception to this definition is a small area in southern Tunisia and northern Tripolitania.

**THE ATLAS RANGES IN BARBARY**

The boundary between the Sahara plateau and folded Barbary runs in an almost straight line, with only two very gentle sinuosities, from the Atlantic coast of Morocco at Agadir to the Syrtis gulf at Gabes in Tunisia, a distance of about 1200 miles. The boundary is determined by a monocline fold, which is the most continuous of the many parallel anticlines and periclines that constitute the Atlas ranges. On the Sahara plateau there is no Jurassic; in the cores of all the anticlines Jurassic is well developed. The line where the Jurassic wedges out southwards is usually concealed by a Cretaceous cover in Algeria; it is probably often a line of bevel at the plane of Cretaceous transgression, as in Egypt and southern England (Dorset-Devon border). In parts of eastern Morocco, however, a Liassic shoreline is uncovered. Cliffs of Palaeozoic sandstones, slates and more rarely Viséan limestones are exposed, with a Jurassic beach at the foot. Reef corals grew on the rocks or in the shallows of the Middle Liassic sea offshore. In some places there are lenticular deposits of sandstone and clay, representing estuaries of Jurassic wadis, forming small gulfs or lagoons (Menchikoff, 1934, 1949; Choubert, 1952, pp. 142-3 and pl. 11).

The southern boundary of Barbary is therefore at least as old as the Jurassic, although the main period of uplift of the Atlas ranges, for which the boundary became the southern hinge, occurred in the Upper Eocene.
and although movements occurred along it again in post-Miocene and even (at least locally at either end) in post-Pliocene times (Laffitte, 1939).

Owing to a regional tilt or pitch of the whole of Barbary and the adjoining Sahara plateau towards the east, Jurassic outcrops are much more extensive in Morocco and diminish progressively through Algeria, until in Tunisia they consist of only scattered inliers in the crests of anticlines, separated by broad stretches of Cretaceous and Tertiary rocks. To some extent this distribution is due to tilting during the Jurassic, for there is reason to believe that in much of Morocco, in the Middle Atlas region especially, deposition ceased with the Bathonian and no Upper Jurassic ever existed.

The Tertiary folding of Barbary took place at two main periods. There was an extensive Upper Eocene-Lower Oligocene (Pyrenean) phase which has left a predominantly SW.-NE. grain in the High Atlas, Saharan Atlas and Middle Atlas of the south and west, and in the north and east Neogene folding superimposed a predominantly W.-E. grain in the Mediterranean or Tellian Atlas. The reticulate pattern resulting from the two phases of folding, and many local complications (in part due to movements of Triassic salt), have made the geological map of Barbary very complex. In general, however, the folding is simple, consisting of narrow anticlines and periclines, sometimes accompanied by overfolding and local thrusting, separated by relatively broad level tracts. Between the High and Saharan Atlas in the south and the Tellian Atlas in the north is a stable area occupied by the Plateau of the Shotts and high limestone ‘causses’. These areas were almost unaffected by Tertiary folding, except along oblique SW.-NE. lines of the Middle Atlas, and they have been compared to the similar mesetas of Spain.

Thus, with one exception, all the mountains of Barbary belong to the southern autochthonous fold zone of the Alpine orogen.

The exception is the Rif of Morocco, an arcutate belt of major thrusts which continues the Betic Cordillera of Spain in the form of a horseshoe. A masterly monograph by Fallot (1937) shows the main range to consist of autochthonous Triassic dolomites, more than 1000 m. thick and overlain by Lias, thrust outwards (i.e. to the SW.) over Cretaceous and Eocene flysch in a series of small nappes, and in turn overthrust in the same direction by Palaeozoics. This is evidently a fragment of the inner or thrust zone of the orogen. Other fragments may be recognized in the Kabylie and its continuation on the coast each side of Algiers. To account for the horseshoe shape of the Betic-Rif thrust arc it seems necessary to postulate a median mass foundered under the western Mediterranean. The movements occurred mainly in the Neogene (Fallot, 1941).

Within the autochthonous folded zone that comprises most of Barbary the Jurassic stratigraphy is by no means simple or straightforward. There are complex changes of facies, both horizontal and vertical, great variations of thickness, and disconformities, which indicate minor folding, faulting and horst-formation within Jurassic times: movements that

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Fig. 32.—Diagrammatic horizontal section across the region where Barbary abuts against the Saharan platform in southern Algeria and Morocco. After Menchikoff, 1936, redrawn.

1, ancient volcanic rocks; 2, basal Palaeozoic conglomerate; 3, dolomitic limestones (Cambrian?); 4, Cambrian-Ordovician sandstone; 5, Silurian; 6, Devonian; 7, Carboniferous; 8, green rocks; 9, red rocks at base of Mesozoic; 10, Lower and Middle Lias; 11, Upper Lias; 12, Middle Jurassic; 13, pre-Cenomanian sandstone; 14, Cenomanian gypseous marls; 15, Cenomanian limestone; 16, post-Turonian red rocks; 17, Chebkhas conglomerate.

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foreshadowed the Tertiary orogeny as in other regions. A large area in western Morocco, much of it adjoining the present coast, was never submerged in the Jurassic, and there are several similar but smaller areas in central and eastern Morocco. One such horst (though less persistent) in the mountains of the Ghar Rouban district, straddling the Moroccan-Algerian border SE. of Oudjda, has been elucidated in detail in a splendid monograph by Lucas (1942). The core of the horst consists of Palaeozoic rocks, now bounded by faults with throws up to 1500 m., which bring the Palaeozoic outcrops up amongst high plateaux of Upper Jurassic limestones (pls. 11, 12). Lucas shows, however, that the horst was already in existence at the beginning of the Jurassic and was not entirely submerged until the Upper Toarcian, while the Bajocian and Bathonian were deposited over it only in condensed form, the Bathonian in the facies of ironshot oolite only 3-4 m. thick. In neighbouring areas the Bathonian is represented by thick grey marls and clays with Posidonia alpina and pyritized ammonites. With the Callovian such marls extended also over the horst. During the Upper Jurassic, which is thickly developed and perhaps complete, though without ammonites and poorly fossiliferous above the Callovian, erosion on the Sahara plateau was intensified and successive sheets of clastic sediments (especially sandstones) were pushed out ever farther across the subsiding area of Barbary. (See fig. 35.)

Extensive volcanic activity took place in western Barbary in the Permian and locally may have continued during deposition of the Lower Liassic. In the massifs of Zekkara and Beni Snassen in Morocco diabase tuffs are interstratified with supposed Lower Lias (Savornin, 1931, p. 256); in the High Atlas basalts are reported to be interstratified with the base of the Lias (Moret, 1939, p. 21); and Roch (1939, p. 171) considers the whole thickness (200 m.) east of Marrakesh to be of Lower Liassic age. In the Saida area of Algeria, however, limestones reputed to contain Cardinia, which are interbedded with basalts (Flamand, 1911), have proved to be Triassic, the pelecypods being not Cardinia but Anoplophora (Lucas, 1952, p. 55). In the light of this, the other occurrences require re-examination.

Seaboard of South-west Morocco

From the southern boundary of Barbary at Agadir, where the High Atlas breaks down near the Atlantic coast, for about 150 miles northwards there is a series of Upper Jurassic outcrops entirely separated from the rest by the Moroccan meseta. The Jurassic sediments represent the remains of an independent basin or bay of the Atlantic, truncated by the present coast. Inland they change in facies and overlap successively against the Palaeozoic rocks of the meseta, with the development of sandstones, reefs and basal conglomerates. The meseta was never submerged in the Jurassic; it was a rocky promontory extending north from the Saharan land (Roch, 1930).

The maximum thickness of Jurassic and Berriasian rocks is about

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500 m.; the Berriasian is not separable lithologically. The Mesozoic sequence begins with thick Triassic marls and red sandstones, capped by basalt. On this lies the first Jurassic formation, some 80 m. of red and white sandstones and marls with gypsum, known as the Jurassic "lagunaire". It has yielded only indeterminable brachiopods, pelecypods, gastropods and a belemnite, and its age therefore still remains to be established.

There follow up to 100 m. of beds in which marine limestones predominate. They have yielded a rich Upper Jurassic fauna, but very few ammonites. Roch (1930, p. 205) records small Peltoceratids comparable with French Lower Oxfordian forms. Half a Perisphinctid has been figured (Gentil & Lemoine, 1905, pl. iv, fig. 6); it was first identified with a Swiss Upper Oxfordian species of the Transversarium Zone, but Roch thought it Callovian. In my opinion it is highest Upper Oxfordian, Bimammatum Zone, comparable with the group of Perisphinctes fontannesii.

Choffat (1893, pl. ix) and P. lusitanicus Siem. as figured by Wegele (1929, pl. ii, fig. 3) from the Planula Subzone.

Next follow 80 m. of limestones in coralline facies with Nerinea beds, which pass eastwards, towards the shoreline, into dolomitic limestones and finally sandstones. They have yielded no cephalopods but are presumably Lower Kimeridgian. Finally there is a series of 250 m. of limestones and marls with lenticular masses of gypsum up to 100 m. thick. The lower parts have yielded echinoids and lamellibranchs believed to be Kimeridgian, while at the top there is a rich ammonite fauna of the Berriasian, in which species of Spiticeras predominate. Berriasella boissieri (Pictet), zonal index of the lowest Cretaceous, occurs in this assemblage (Roch, 1930, p. 257). These highest 250 m. of beds overlap all the earlier formations and transgress far across the folded Palaeozoics.

**HIGH ATLAS, MIDDLE ATLAS AND SAHARAN ATLAS**

The sediments in the north-eastern part of the basin just described wedge out against the core of the High Atlas, a range of Palaeozoic sediments and granites folded and solidified in the Variscan orogeny and refolded in the

Tertiary, with summits rising above 12,000 ft. to a maximum of 13,665 ft. A beautiful geological map and description by Moret (1930) depict a strip across this central core, from the alluvial plains of Marrakesh eastwards. In the SW. corner the last of the Upper Jurassic and Berriasian deposits described by Roch are seen feathering out upon the folded Palaeozoics and overlapped by Valanginian and successively higher members of the Cretaceous.

On the far side of the range the same succession begins again, here underlain once more by thick Trias with summit basalts, which at Tizimoult are interstratified with the supposed basal Jurassic limestones. At first the formation is indivisible, described as a ‘complexe jurassique très lagunaire’, but it soon thickens towards the east and spreads out into the most extensive Jurassic outcrop in North Africa, the eastern High Atlas and its easterly continuation in the Saharan Atlas. Upper Jurassic occurs close to the granite chain in the area of Moret’s map, but in the 350 miles of outcrops farther east the sequence stops with the Bathonian, and by far the greater part of the area consists of Lias. The same applies to the almost equally large outcrop of Jurassic that forms the adjacent Middle Atlas and the ‘causses’ to the NW. of it.

The Lias, and especially the Middle Lias, of this central region exhibits interesting changes of facies. Along the south, adjoining the Liassic shoreline of the African shield, or separated from it here and there by strips of coastal sediments of the ‘lagunaire’ facies, there runs a fringe of reef-like limestones, poorly bedded and crowded with thick-shelled pelecypods and giant gastropods. North of this, forming the High Atlas and Saharan Atlas, the sediments testify to a deeper trough running parallel to the coast. Northwards again, in the Middle Atlas and the causses plateaux, the facies returns to neritic, with great thicknesses of dolomite and limestones, sometimes recalling the ‘reef’ type of the south and evidently formed upon shallows covering the shelving edge of the Moroccan meseta that lies to the west (Fallot & Roch, 1932; Dubar, 1932, 1934, 1943, 1948; Roman & Russo, 1948).

The immense deposits of dolomite in the Middle Atlas and the causses plateaux bear a strong resemblance to the proved Upper Triassic (Rhaetian) dolomites of the Rif, which underlie a lumachelle of Pteria contorta, and they have been claimed as Triassic (Loczy, 1951); but the few fossils so far found in them point rather to a Lower Lias age, although the characteristic Megalodon and other heavy pelecypods are said to occur in both Trias and Lias (Termier, 1936, and discussion of Loczy, 1951, p. 24). Dolomites, moreover, occur in Morocco and western Algeria in formations proved to be as late as Upper Pliensbachian and in the Pre-Rif Bajocian. The remarkable assemblage of heavy-hinged pelecypods, chiefly giant Opisoma, but comprising also Pachymegalodon, Pachyrisma, Pachymytillus, Myoconcha and many other interesting forms, described by Dubar (1948), is proved by ammonites to be Upper Pliensbachian-Lower Toarcian.

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A wealth of detail upon the Middle Atlas and adjoining regions will be found in the monumental treatise by Termier (1936). For the southern ranges, where the High Atlas is prolonged eastward to the Algerian border and merges into the Saharan Atlas near Figuig, there are important works by Dubar (1932, 1934, 1943, 1948), Menchikoff (1936), Choubert (1937, 1938), Roch (1939), and Verlet & Roch (1940). The following is a summary of the ammonite faunas recorded. For details and up-to-date review of facies and faunas, the most important work is by Dubar (1943). Towards the east and NE., Upper Jurassic stages come in, but these will not be considered in this section. Including these, the total column for the Saharan Atlas in western Algeria is (Cornet, 1952):

<table>
<thead>
<tr>
<th>Stage</th>
<th>Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Jurassic</td>
<td>100 m Kimeridgian reef limestone, with corals, 700 m</td>
</tr>
<tr>
<td></td>
<td>600 m sandstone with echinoids and pelecypods. Below, 1700 to 2000 m</td>
</tr>
<tr>
<td></td>
<td>1000–1500 m of dolomite at the base</td>
</tr>
<tr>
<td>Middle Jurassic</td>
<td>1000 m sandy marls, sandstones and calcareous and dolomitic bands, with in the NW. 1000–1500 m of dolomite at the base</td>
</tr>
<tr>
<td>Lower Jurassic</td>
<td>1000 to 1200 m marly limestones and marls</td>
</tr>
</tbody>
</table>

BATHONIAN

Shallow-water marine limestones, sandstones and green and brown marls overlying the Bajocian contain many pelecypods and brachiopods of NW. European Bathonian species; they are perhaps more than 1000 m thick. In the upper part near El Mers, about 60 miles SE. of Fez, have been found many bones of turtles, Teleosauridae and dinosaurs—a Therapod and a huge Sauropod, perhaps Ceteosaurus. With the bones was found an ammonite identified as Clydoniceras discus by F. Roman (Termier & others, 1940). Similar bone-beds occur in the southern Middle Atlas, with Middle and Upper Bathonian brachiopods, among which Ornithella digona was identified by L. Guillaume (Bourcart & others, 1942). For invertebrate fauna see Termier, 1936, vol. iii, pp. 1343–93; Gardet & Gérard, 1946, pp. 59–66; also, in general, Termier, 1943.) Similar beds with brachiopods are described from the eastern High Atlas (Choubert, 1938; Roch, 1939).

UPPER BAJOCIAN

To this substage probably belongs the fourth Bajocian zone of Termier (1936, p. 894) with Phylloceras cf. kudernatschi, Polypectites or Cadomites (?), and Normannites orbignyi Buckman (Gardet & Gérard, 1946, p. 35), but no ammonites from this zone have yet been figured, except perhaps a true Cadomites indet. (pl. viii, fig. 3; not deslongchampsi). A Strigoceras is recorded from several places in Morocco but associated with Middle Bajocian ammonites (Menchikoff, 1936, p. 142; Verlet & Roch, 1940, pp. 72, 82), and it is therefore probably one of the earlier forms, not S. truellei (d’Orb.); but this remains to be investigated.

The most unequivocal Upper Bajocian fauna so far found is an assemblage of the Subfurcatum Zone in the region of Ain Sefra. The
dominant ammonites of this fauna are *Ermoceras deserti* Douvillé and *E. runcinatum* Arkell, here found 3300 km. west of the nearest known occurrence, in Sinai. In the same beds occur *Cadomites* aff. *deslongchampsi* (d'Orb.), *C. cf. daubenyi* (Gemm.), *C. cf. septicostatus* Buck., *Stephanoceras humphriesiforme* (Roché), *Leptosphinctes cf. leptus* Buck., *Cleistosphinctes cleistus* (Buck.) and *Oppelia subradiata* (Sow.). This fauna occurs at the top of 4-5 m. of limestone which represents a condensed Bajocian, for it is underlain by the Toarcian. Above it follow at least 1000 m. of marls and argillaceous limestones with *Posidonia*, all of which must belong to the Upper Bajocian, since it underlies the Lower Bajocian fauna of El-Harchaia with *Oraniceras*, described by Flamand (see next section). (Arkell & Lucas, 1953.)

**MIDDLE BAJOCIAN**

The Sowerbyi, Sauzei and Humphriesianum Zones all seem to be represented (the 1st, 2nd and 3rd Bajocian zones of Termier, 1936, p. 894), judging by the records and the few figures published by Gardet & Gérard (1946). From the High Atlas of Midelt and near Figuig are recorded numerous *Witchelliae* and *Sonniniae*, *Zurcheria*, *Emileia brocchi* (Sow.), *Otoites sauzei* (d'Orb.), *Skirroceras bayleanum* (Oppel), *Phylloceras* and *Lytoceras* (Dubar, 1934, p. 85; Verlet & Roch, 1940), and from the Middle Atlas the same plus *Chondroceras*, *Stephanoceras*, *Hyperlioceras* and *Dorsetensia* (Termier, 1936, pp. 1343-51), and beds with *Stephanoceras humphriesianum* (Sow.) and other species (Colo, 1951, p. 89). Forms figured by Gardet & Gérard are *Poecilomorphus* cf. *angulinus* Buckman (pl. iii, fig. 11), *Emileia* cf. *brocchi* (Sow.) (pl. iii, fig. 15), *Stephanoceras ptilacanthus* Wermbrter (pl. iii, fig. 24, not *humphriesianum*), *S. cf. rhytus* (Buckman) (pl. viii, fig. 1), and *Skirroceras* cf. *bayleanum* (Oppel) (pl. viii, fig. 2). These beds are transgressive, overlapping locally on to Middle and Lower Lias (Termier, 1936, p. 885; Dubar, 1938). In the eastern High Atlas they pass into the Boulemane Marls (Choubert, 1938, see below), and in the northern Middle Atlas the Humphriesianum Zone overlies thick Sauzei and Sowerbyi Zones developed as marly limestones (Colo, 1951).

**LOWER BAJOCIAN**

The Opalinum, Scissum and Murchisonae Zones are represented by a number of ammonites (Termier, 1936, pp. 1317-20; Choubert, 1937; Verlet & Roch, 1940, pp. 78-9; Colo, 1951): *Leioceras* cf. *opalinum*, *Haplopleuroceras subspinatum* Buckman, *Hammatoceras* spp., *Ludwigia* spp., *Erycites* spp. (Termier, 1936, pp. xxiii, fig. 12; Gardet & Gérard, 1946, pl. iii, fig. 10) and *Tmetoceras* cf. *hollandae* Buckman (Termier, 1936, p. 1318, *non* Gardet & Gérard, which is not a *Tmetoceras*). The whole of the Bajocian passes laterally into the Boulemane Marls, which persist for hundreds of miles to the Algerian border and are said to attain 1200 m. in thickness in the Talsint trough in the eastern High Atlas.

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(Choubert, 1938). In the northern Middle Atlas there is the common difficulty of separating the Concavum and Sowerbyi Zones (Colo, 1951). In the High Atlas of Midelt there are indications of gentle folding and overlap along minor anticlines parallel to the main axes of folding; the first movements were pre-Lower Bajocian, the second pre-Middle Bajocian (Dubar, 1938). There is here an interesting comparison with Buckman's early work in the Cotswolds.

**Upper Toarcian**

Among the ammonites recorded from the Aalenian are a number that belong to the Jurense Zone. More detailed collecting is required to establish their precise stratigraphical position in Morocco. Among these are *Lytoceras ophioneum* Benecke (Termier, 1936, pl. xxiii, figs. 8-11), *Dumortieria* spp. and *Catulloceras* sp. (Gardet & Gérard, 1946, pl. iii, figs. 2-5, not a *Tmetoceras*). Termier (1936, pp. 1310-15) and Dubar (1938) also record many other Upper Toarcian ammonites, including the genera *Paroniceras*, *Grammoceras*, *Pseudogrammoceras*, *Pseudolioceras*, etc.; also *Lytoceras jurense* and *Polyplectus discoides* (Zieten) (but the 'P. discoides' of Gardet & Gérard, 1946, pl. iii, fig. 1, from the Lower Toarcian is not a *Polyplectus* but *Harpoceras* cf. *subplanatum* Oppel sp.). Upper Toarcian ammonites are also well represented near Figueig, where *Cancellophycus* beds occur in the Toarcian and Bajocian, and in the northern Middle Atlas (Pleydellia, *Dumortieria*, *Polyplectus*, etc.; Colo, 1951). Breccias believed to be of seismic origin overlie Toarcian coral reefs near Ain Sefra (Cornet, Galmier & Lucas, 1953).

**Middle and Lower Toarcian**

Termier (1936, pp. 1301-10) and Dubar (1938) recognize a Lower Toarcian with *Harpoceras* cf. *falcifer* and *Hildoceras levisoni*, and a Middle Toarcian with *Hildoceras bifrons* and many other forms. In the limestones of this stage *Cancellophycus* becomes especially abundant. Numerous ammonites are recorded, including many species of *Hildoceras*, *Harpoceras*, *Haugia*, *Phymatoceras*, *Mercaticeras*, *Dactylioceras*, *Peronoceras*, *Praehaploceras*, *Paroniceras* and *Phylloceras heterophyllum*, *P. nilsoni* and *P. lacosteii*. (See also Dubar, 1934; Verlet & Roch, 1940, pp. 70, 76.) At the base of the Toarcian, immediately above the 'reef' limestones at Bou-Dahar, Dubar (1948, p. 39, pl. i, fig. 3) collected *Dactylioceras* cf. *tenuicostatum* (Y. & B.); and Termier (1936, pl. xxiii, figs. 5-7) figures *Dactylioceras athleticum* (Simpson), a fossil of the Acutum Bed at the base of the Toarcian in England. The Italian affinities of these faunas are very striking (see especially Dubar, 1938a).

**Upper Pliensbachian (Domerian)**

The interesting changes of facies have already been mentioned. The dolomite and shelly limestone facies so important topographically is
practically devoid of cephalopods, but it passes laterally into limestones, marly limestones and marls, in which ammonites of the Italian Domerian abound. Especially noteworthy are abundant *Lytoceras fimbriatum* (Sow.) and allied species (Termier, 1936, pls. xx, xxi), Phylloceratids (*Juraphyllites* spp.), *Amaltheus, Pleuroceras* and a swarm of Hildoceratidae which might have come straight from the plates of Fucini and other Italian authors: especially *Arieticeeras* spp., *Fucinicearas* spp., *Protogrammiccas* spp. and *Catacoeloceras* spp. (Termier, 1936, pi. xxii; Dubar, 1936; Russo, 1936; Verlet & Roch, 1940, pp. 69-70, 73-6). Amaltheids have not been found in the High Atlas (Dubar, 1936, p. 223). The dolomite facies of Morocco compares closely in lithology and fauna with the Grey Limestones of the southern Alps (Dubar & Termier, 1932).

**LOWER PLIENSCHABIAN**

The Ibex Zone is indicated by *Liparoceras gallicum* Spath (= *bechei d'Orb. non Sow.*) (Gardet & Gérard, 1946, pl. i, fig. 10, improperly put in the Domerian), and the Jamesoni Zone by *Tropidoceras masseanum* (d'Orb.) and allied spp. and *Polymorphites* sp. (Termier, 1936, p. 1270; Russo, 1936; Dubar, 1938a). Evidence reported from the Figuig area consists of *Platypleuroceras brevispinum* (Sow.) and *Crucilobiceras muticum* (d'Orb.) and some allied species (Verlet & Roch, 1940, pp. 73-4, misplaced in the Domerian).

**SINEMURIAN**

Various species of *Arnioceras* and *Oxynoticeras* have been recorded (Dubar, 1932, 1943; Termier, 1936, p. 1269; Verlet & Roch, 1940, pp. 69-70, 72), and two Sinemurian ammonites have been figured by Daguin (1926, pl. v) from Jebel Ayachi in the High Atlas, but unfortunately without peripheral views or whorl-sections, which renders them unidentifiable. The upper figure appears to be correctly named as 'Asteroceras' cf. *brooki* (Sow.), but the lower figure, in the opinion of Dr D. T. Donovan (in lit.), is more likely to be an *Arnioceras* and no earlier than Turneri Zone. Cf. *turneri* is recorded by Dubar (1943). Beneath the Sinemurian ammonite beds near Figuig are dolomitic limestones up to 200 (or 300 ?) m. thick, with brachiopods, resting on unfossiliferous limestones.

? **HETTANGIAN**

Pink dolomites with *Cardinia* ? at the base may be Hettangian, but no Hettangian ammonite is yet known from North Africa.

**THE RIF**

The Rif proper consists of the bow-shaped range already described (p. 238), parallel to the coast, and made up chiefly of thrust sheets of Triassic dolomite and Palaeozoic rocks (Fallot, 1937). To the south a
THE RIF

roughly parallel belt of anticlines and periclines consisting of Jurassic limestones rise through the surrounding softer Cretaceous and Tertiary rocks to heights of 1500-6000 ft. These constitute the Southern Rif, monographed by Lacoste (1934). Finally, rising from a broad Tertiary and alluvial lowland a few miles north of Meknes and Fez are the last wrinkles of the Rif system, a group of anticlinal hills known as the Pre-Rif (Daguin, 1927a, Gubler, 1938). The dates of the Tertiary folding and thrusting are summarized by Fallot (1941, p. 923 and table).

The Trias of the thrust range of the Rif proper, consisting for the most part of more than 1000 m. of dolomites of Alpine facies, contrasts strongly with that of the Southern Rif, where it is of German type, consisting of variegated saline marls producing salt plugs. During the Jurassic a trough of deposition existed on the site of the Southern Rif and the arcuate depression to the north of it (the Rif trough of Lacoste, 1934, p. 90), but comparison between the Jurassic rocks of the two areas is difficult, because in the Rif proper only Lias exists, whereas the Southern Rif and Pre-Rif consist essentially of Middle and Upper Jurassic and the Lias is poorly exposed. There is evidence, however, that the facies of the Lias is almost as different in the two regions as that of the Trias. The Lias and Bajocian of the Pre-Rif show signs of approaching a southern shoreline, which appears to have been a promontory extending towards the NE. from the western Moroccan meseta (Gubler, 1938).

Fig. 34.—Tectonic sketch-map of the western Rif. After Fallot, 1937.
TITHONIAN

Red and white shaly marls with interbedded hard limestones have yielded *Ptychophyllloceras ptychoicum* and other spp., *Sowerbyceras loryi* Munier-Chalmas, *Haploceras caractheis* (Zeusch.), *Berriasella callisto*, *Spiticeras cf. pseudogroteanum* Djanelidzé, aptychi and *Pygope janitor* Pict.

KIMERIDGIAN

Evidence for this stage is inconclusive. Lacoste (1934, pp. 178-80) assigns several ammonites to the Lower Kimeridgian, of which *Phylloceras cf. canavarrii* Menegh., *Simoceras parateres* Canavari, *Nebrodites doublieri* (d'Orb.) and *Taramelliceras trachynotum* (Oppel) alone may be Kimeridgian.

UPPER OXFORDIAN

To this substage belong *Sowerbyceras tortisulcatum* (d'Orb.) and some Perisphinctids (Lacoste, 1934, pp. 178-80).

LOWER OXFORDIAN AND CALLOVIAN have yet to be found, but Lacoste believes the succession to be continuous. The presence of Callovian not many miles away, in the misnamed 'Eastern Rif' (Marçais, 1931), suggests that he may be right.

LOWER BATHONIAN

At Jebel Arechko, in red marly limestones like the Bajocian, Lacoste (1934, p. 176) obtained *Morphoceras aff. multiforme (= polymorphum d'Orb.),* *Ebrayiceras cf. pseudoanceps* (Ebray) and *Cedomites or Polyplectites.*

MIDDLE BAJOCIAN

At Zerhoun in the Pre-Rif (north of Meknes and west of Fez) and at Mjara in the Southern Rif, a rich Bajocian fauna has been found. At Mjara the facies is red marls and marly limestones; at Zerhoun it is in the form of thick sandstones, oolites, freestones, dolomites and marls, changing rapidly and reminiscent of the English Inferior Oolite of the Cotswolds (Lacoste, 1934, p. 176, Gubler, 1938). The only Upper Bajocian ammonite recorded is *Strigoceras truellei* (d'Orb.), but as this was found associated with many Middle Bajocian ammonites, it was probably one of the earlier species of *Strigoceras.* The other ammonites are *Stephanoceras humphriesianum* (Sow.), *S. plicatissimum* (Quenst.), *Skirroceras freycinati* (Bayle), *Normannites braikenridgei* (Sow.) [*? orbignyi* Buckman], *Otoites contractus* (Sow.), *Sphaeroceras brongniartii* (Sow.), *Dorsetensia subtecta* (Buck.), *Poecilomorphus cycloides* (d'Orb.). At Mjara in the Southern Rif *Holophyllloceras mediterraneum* and its allies are common. In addition to these, some Sonninids of the Sowerbyi Zone are said to occur intimately mixed in the fauna of the Lower Bajocian in the Pre-Rif (Gubler, 1938, pp. 137-8); they are *Sonninia propinquans* Bayle (the type species of the genus), *S. deltafalcata* (Quenst.), *Witchellia sayni* Haug (*corrugata* Douv. *non* Sow.), and *W. crassifalcata* Dorn.
LOWER BAJOCIAN

At Zerhoun well-bedded limestones with a rich silicified fauna yield an assemblage entirely identified with English (Dorset) Inferior Oolite species (Gubler, 1938, p. 137):—Haplopleuroceras subspinatum Buckman, Graphoceras decorum Buck., G. (Ludwigella) concavum (Sow.), micrum (Buck.), arcitenans (Buck.), modicum (Buck.), fastigatum (Buck.). In addition, from the Southern Rif Lacoste (1934, p. 172) records Graphoceras opacum (Buck.), G. elegantulum (Buck.), Leioceras opalinum (Rein.), Pleydellia sp. and Tmetoceras scissum (Benecke), in red marls with sandstone bands.

UPPER TOARCIAN

The Toarcian was the period of maximum submergence, when littoral influences disappeared. It consists of grey marls, sometimes shaly, about 25-30 m. thick in the Southern Rif; Phylloceras and Lytoceras abound. Ammonites of the Jurense Zone include Hammatoceras insigne (Schubl.), Phymatoceras tirolense (Hauer ?), Haugia grandis Buck., Polyplectus discoides (Zieten), Pleydellia sp., etc. (Lacoste, 1934, pp. 168-72). Dumortieria and Catulloceras also occur in the Rif proper (Fallot, 1937, pp. 364-5).

UPPER PLIENSBCHAHIN

In parts of the Pre-Rif this is developed in the facies of ‘Calcare ammonitico rosso’ as in Italy (Daguin, 1927, p. 136); it occurs also in Algeria (see p. 270). The usual assemblage of ammonites is recorded, including Hildoceras bifrons, H. levisoni, Catacoeloceras crassum, Dactylioceras commune, Phylloceras heterophyllum. This fauna and Upper Toarcian forms also occur in the Rif proper (Fallot, 1937, pp. 364-5).

LOWER PLIENSBCHAHIN

has not yet been discovered in the Rif.

SINEMURIAN

In the Rif proper the stage is only a few dozen metres thick but developed in Alpine limestone facies, from which Fallot (1937, pp. 358-9) records a long list of Italian species of Arnicoeras, ‘Deroceras’, Vermiceras and Asteroceras, with Italian and Alpine forms of Ectocentrites, also Phylloceras and Lytoceras. From the Southern Rif only Oxynoticeras cf. lymense Wright is reported.
Hettangian

No ammonites of this stage have been found, but Fallot assigns to it a considerable part of the limestones, with some dolomites, which cap the main mass of the Rhaetian thrust dolomites of the Rif proper. The supposed Hettangian is characterized by Rhynchoellina. In the Southern Rif, limestones with a dwarf molluscan fauna are also referred to the Hettangian, but they are interstratified downwards with variegated gypseous marls of Triassic type.

[Rhaetian

The thick dolomites in the Rif contain lumachelles of Pteria contorta, also Myophoria and many other mollusca.]

Tellian Atlas and Plateau of the Shotts

The Rif trough is continued eastwards through the NE. corner of Morocco and over the border at Oudjda into Algeria, across which it stretches to the east coast of Tunisia, a total distance of about 800 miles. In Algeria it is called the South-Kabylie trough (Glangeaud, 1932). It lies between the fragmented Palaeozoic horsts along the present coast, of which the Kabylie east of Algiers is the largest, and a second line to the south, of which the Ghar Rouban and Saida mountains are the best known in Jurassic literature. This southern line is a continuation of the shallows extending from the promontory south of Meknes and Fez, already mentioned (p. 267); along it the Upper Pliensbachian overlaps on to Trias or Palaeozoic and is in places itself overlapped. During the Trias and Lower Lias the trough was subdivided longitudinally by a narrow ridge, the Chelif anticline, but after the Lower Lias this disappeared and the trough sank as a whole (Roman & Russo, 1948).

The Jurassic sea also extended far south of the South-Kabylie trough, spreading out between, around and at last over, the horsts and covering the stable shelf area now occupied by the high plateaux of the Shotts. Jurassic rocks in many places rise through the Pliocene and Pleistocene blanket that covers the plateaux, brought up in oblique anticlines parallel to the Middle Atlas, to join up with the Jurassic in the more easterly folds of the Saharan Atlas.

The Lias of the South-Kabylie trough is identical in facies with that of the Saharan Atlas, Middle Atlas and High Atlas. In particular, the Domerian and Toarcian ammonite faunas are Italian. The facies testifies to accumulation in water of moderate depth, in direct continuity with southern Europe. The Bajocian, Bathonian and Callovian ammonites show direct faunal continuity with central and NW. Europe. With the Middle or Upper Callovian, uprise accelerated erosion on the Saharan shield, and the trough and shelf seas of Barbary became choked with clastic sediment during the Oxfordian and probably most of the Kimeridgian. The deposits of these dates resemble the sandy Deltaic

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PLATE II.—Upper Jurassic escarpment in the Ghar Rouban, Algeria.
PLATE 12.—Collecting from the condensed Bathonian bed, Deglen, Algeria; Upper Jurassic cliff behind. (See Figs. 35 and 37.)
Series (‘Estuarines’) of Yorkshire, with only occasional ammonite beds where the facies is locally suitable. In the later Kimeridgian and Tithonian, denudation of the shield slackened once more and clear-water limestones became prevalent in Barbary, admitting *Calpionella* (Laffitte, 1937) and ammonite faunas of the Tithonian and Berriasian.

In the block mountains and karstic plateaux of the Tellian Atlas the barren Upper Jurassic sandstones and limestones form rugged country. The high summits are snow-covered in winter and sun-scorched in summer. In more sheltered and less rocky situations a scrub of cistus, juniper, lavender and many other bushes finds a foothold, and many of the slopes and valleys are covered with cork forests (plates II, 12).

![Diagrammatic representation](http://jurassic.ru/)

**Fig. 35.—Diagrammatic representation of the successive stages of sedimentation on the northern margin of the African shield in the Ghar Rouban area, western Algeria. After Lucas, 1942, pl. xxvii.**

East of the longitude of Algiers the general easterly pitch or regional dip of the country (both of Barbary and of the adjoining plateau of the Sahara) carries the Jurassic system for the most part below ground. In this eastern sector of Barbary the continuations of the Tellian Atlas and Saharan Atlas approach closer together and finally tend to merge near the Tunisian border. Most of the country is formed of Cretaceous and Tertiary rocks, but anticlinal cores in the principal mountain masses display the Jurassic. The outcrops still tend to arrange themselves in two main lines. The northern line, near the coast, comprises the mountains of Djurdjura, Babor, the Constantine-Bone area, and (in Tunisia) Jebel Ashkel, SW. of Bizerta and Jebel Zaghoudan, south of Tunis. The southern line includes the ranges of Hodna, Batna, Aurès and (in Tunisia) Jebel Nara, SW. of Kairouan.

Nearly all these mountain groups and ranges have formed the subject
of regional monographs, but from the point of view of Jurassic stratigraphy, tectonics, palaeoecology and palaeogeography by far the most illuminating results have been obtained in the rugged Ghar Rouban area near the western border of Algeria, through the brilliant researches of G. Lucas (1942, 1952). He has pictured the sinking of the troughs and the successive faultings and transgressions round the Palaeozoic horsts, and their eventual submergence under the Upper Jurassic sea. His serial maps reconstruct the progress of these events at each stage of the Jurassic.

[Berriasian]

The ammonite fauna is best known from the classic locality of Lamoricière, about 25 miles east of Tlemcen, where there are poor exposures of a thin band of highly fossiliferous limestone in greenish and grey marls in a small fault block (Pomel, 1889; visited by the writer under guidance of Gabriel Lucas in January 1952). *Lytoceras* is common here, but not *Phylloceras*. On the other hand at the Ouarsenis *Phylloceras* comprises more than half the ammonites, which include also *Neolissoceras grasianum* (d'Orb.), *Neocomites neocomiensis* (d'Orb.), *Killianella*, *Saynoceras*, *Olocostephanus* and *Bochianites* (Dalloni, 1936, p. 14). In the Hodna and Batna groups, where the same faunas occur, the thickness of the Neocomian averages 1500 m. and may exceed 2000 m. (Savornin, 1920, p. 214).

[Upper Tithonian]

A rich Upper Tithonian ammonite fauna almost identical with that of Choméac, Ardèche, has been identified at Oued Soubella and Bou Thaleb in the Sétif district of Constantine (Savornin, 1920, p. 171; Roman, 1936, p. 37) and again at Jebel Nara, SW. of Kairouan in Tunisia (Schoeller, 1937; Breistroffer, 1937; Arnould-Saget, 1951; Castany, 1952, pp. 14-19). It also has numerous links with Stramberg, Switzerland, the Crimea and Spain. The assemblage comprises *Haploceras elimatum* (Oppel), *Neolissoceras grasianum* (d'Orb.), *Proniceras* spp., *Spiticeras pseudogroteanum* Djan., *Virgatosphinctes* cf. *transitorius* (Oppel), *V. cf. senex* (Oppel) and numerous Berriasellids, together with Phylloceratids, Lytoceratids, aptychi, *Pygope janitor*, *Calpionella*, etc. The minute organisms *Calpionella*, now believed to be Infusoria, are recorded from the Tithonian or Berriasian of many places in Algeria and Tunisia (Laffitte, 1937; Durand Delga, 1950).

[Lower Tithonian]

The best-known Lower Tithonian fauna is that of the Djurdjura mountains, ESE. of Algiers, monographed by Roman (1936). It is found in 8-10 m. of red nodular limestone which rests unconformably on Toarcian limestones and is in turn overlapped transgressively by Upper Cretaceous marls. The whole crops out in the north side of the range, which here consists of an isoclinal fold overturned to the south,
away from the metamorphic mass of the Kabylie. The fauna is remarkable
for a high proportion of new species and the strange local genus *Djurjur-
ceras*, which is a specialized Virgatospinctid with peculiar ribbing
reminiscent of some English *Subplanites*. There are a few links
with Tunisia, Sicily and Spain. Genera represented are *Phylloceras*,
*Psychophylloceras*, *Lytoceras*, *Kossmatia*, *Micracanthoceras*, *Corongoceras*,
*Simoceras*, *Aspidoceras*, *Virgatospinctes* (*transitorius* Oppel and *senex*
Oppel), etc. Roman considered this fauna to denote the basal Tithonian,
mainly from the absence of *Berriasella*, *Spiticeras* and *Haploceras*, but its
age in relation to European zones is difficult to assess. It looks like a
mixture.

Farther west the facies is unfavourable for ammonites. The total
thickness of poorly fossiliferous limestones and dolomites attributed on
general grounds to the Kimeridgian and Tithonian exceeds 200 m. in
the Jebel Nador massif and thickens to 600 m. in the Ghar Rouban
area (Lucas, 1942, pp. 401, 402). Limestones with aptychi, belemnites
and *Pygope* occur near Jebel Chenoua, west of Algiers, and derived
Tithonian ammonites are reported in the Berriasian ammonite bed of
Lamoricière (Roman, 1936, pp. 40, 41).

At Jebel Zaghouan in Tunisia the Kimeridgian-Tithonian is developed
in two different facies, one 50-100 m. thick, the other partly ‘reef’ lime-
stone 500 m. thick (Castany, 1950).

**KIMERIDGIAN**

The lower and middle parts of the 900 m. of deposits (including some
of the 300 m. of unfossiliferous ‘Lusitanian’ sandstones) that build the
great cliffs and plateaux in the mountains of Tlemcen, the Ghar Rouban
area (Lucas, 1942, p. 402) and elsewhere, running into eastern Morocco
(Mongin & Monition, 1952), are probably Kimeridgian, but so far no
identifiable ammonites have been found. Farther east there are a few
finds to record: Spath (1913, p. 546) identified Aspidoceratids of the
Acanthicus Beds (Lower-Middle Kimeridgian) near Jebel Zaghouan in
Tunisia; and south of Philippeville in eastern Algeria Deleau (1938,
pp. 106-9) found *Streblites tenuilobatus* (Oppel), *Lytoceras orsinii* Gem.,
*Holcophylloceras* sp. and *Hybonoticeras* sp., 3 m. above the basal conglom-
erate of the Upper Jurassic, which there rests on eroded Lias. ‘Waagenia’
auberti Pervinquière (1907, pl. ii, fig. 8), however, is not a *Hybonoticeras*
and has been made type of a new genus *Aulasimoceras* Spath (1931).
Shales with aptychi occurring in the Babors may be Kimeridgian
(Ehrmann, 1920); such shales can be of more than one date (Glangeaud,
1932, p. 126). *Balanocidaris glandifera*, however, which has been found in
several places, gives a Lower Kimeridgian date.

**UPPER OXFORDIAN**

The Bimammatum Zone, with the index fossil, *Taramelliceras* spp.
and *Perispinctes* spp., is recorded in NE. Morocco (Marçais, 1931) and

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is thickly developed in the Jebel Nador area, judging by records of late-Oxfordian Perisphinctids such as *P. cf. microplicatilis* (Quenst.), *P. cf. divisus* (Quenst.) and *P. cf. grandiplex* (Quenst.) in beds overlying the Transversarium fauna (Deleau, 1948, p. 39). *Peltoceras bimammatum* is also recorded from the Hodna Mountains (Bou-Thaleb: Savornin, 1920, p. 158) and *Ochetoceras marantianum* from Jebel Zaghouan (Solignac, 1947, facing p. 16). Spath's lists of ammonites from Jebel Zaghouan (1913, p. 544) suggest a passage from the Transversarium Zone up into the Lower Kimeridgian, with the Bimammatum Zone well represented though not separated in the field.

The Transversarium Zone is developed in ammonitico rosso facies like the Toarcian (Dalloni, 1936, p. 12) and is extremely rich in ammonites. The assemblage is typical of southern France and the Jura. In the Jebel Nador area the same fauna occurs in black marls with bands of marly

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Fig. 36.—Jurassic outcrops of north-eastern Tunisia. After Solignac (1947) and others.
limestone, and Deleau (1948, p. 36, pl. iii) has already remarked on the identity with Trept. The same beds in red nodular facies crop out in a number of places in northern Tunisia (Solignac, 1947, facing p. 16), among them Jebel Zaghounan, whence a list has been published by Spath (1913, pp. 544-6, pl. lii), including *Peltoceras (Gregoryceras) toucasianum* (d'Orb.), aff. *fouquei* Kilian and *pervinquieri* Spath, and *Perisphinctes kobelti* Neumayr, the type of which came from this locality. (The species of 'Grossourria' and 'Ataxioceras' in Spath's list are incorrectly assigned generically.) Several members of this fauna were also figured mistakenly as from the Tithonian by Pervinquière (1907). The following representative list comprises species determined by me in a collection kindly given me in 1953 by Dr P. E. Kent, who collected them at Jebel Ben Saidane in Tunisia (Pervinquière's chief locality), and others seen by me in Algiers University and the Sorbonne, where there are numerous specimens from Ain el Amra. (BS = Ben Saidane.)

| Phylloceras cf. riazi de Loriol, BS |
| Holcophylloceras polyolcum (Benecke), BS |
| Sowerbyceras tortisulcatum (d'Orb.), BS |
| Lytoceras cf. polyanchomenum de Riaz (Gem.?), BS |
| Lissoceras erato (d'Orb.) |
| Ochetoceras canaliculatum (v. Buch), BS |
| Trimarginites arolicus (Oppel), BS |
| Taramelliceraras sp. |
| Euaspidoceras aff. perarmatum (Favre et auct.), BS |
| Peltoceras (Gregoryceras) spp. |
| Pachyceras (Tornquistes) kobyi (de Loriol), BS |
| Perisphinctes lucingae (Favre), BS |
| Perisphinctes cf. navillei (Favre), BS |
| Perisphinctes prelothari Lee, BS |
| Perisphinctes spp. |

While this book was in the press I was sent for determination a good fauna of the Bimammatum Zone, Planula Subzone, from the Ain Rich area, Saharan Atlas (Emberger, 1954).

**LOWER OXFORDIAN**

It is surprising that the widespread fauna of the Mariae Zone, strongly represented in the Rhone valley and the Lebanon, has not been found in North Africa. The only record of a Cardioceratid is one of 'Cardioceras cordatum' from the Oran side of the Moroccan-Algerian border (Gentil, 1908), in company with *Phylloceras kudernatschi* Hauer and *Sowerbyceras tortisulcatum* (d'Orb.). In the NE. corner of Morocco, Marçais (1931) assigns to the Oxfordian brown shaly marls with *Pachyceras lalandeanum* (d'Orb.) and he also records a specimen of *Peltoceras cf. arduennense* (d'Orb.) (not in situ). Both could be either Lower Oxfordian or Upper Callovian (Lamberti Zone). The same applies to a *Distichoceras*, a *Horioceras* and a *Trimarginites* from Saida in Algiers University museum.
MIDDLE CALLOVIAN

Reineckeia beds of the Anceps Zone, rich in ammonites, are widespread and transgressive. The best development is in the Saida area, where the transgression was already noticed by Flamand (1911), who figured R. richel Flam, from here. The zone is said to consist of 200-250 m. of sandy marls (Flandrin & Clair, 1949). It marks the arrival of an immense sheet of detrital sediment from the Sahara plateau and onset of uniform sedimentation over a wide area (Lucas, 1950a). The beds overlap locally on to Toarcian (Lucas, 1950). In addition to the common Reineckeia, collections from Saida in Algiers University museum contain many large Erymnoceras spp., Pachyceras, Choffatia sp., and a Hectococeras cf. metomphalum Bonarelli identical with a form that occurs in the Reineckeia beds of Persia (Lake Urmia and the Elburz).

In the Ghar Rouban area there is a greater variety of ammonites and Lucas (1942, pp. 364-5) has been able by industrious collecting to draw up a long list of Oppelliids, Hecticoceratids, Reineckieids, Erymnoceras, Pachyceras, Perisphinctids, Phylloceratids and Lytoceratids. The same zone is also rich in ammonites in NE. Morocco (Gentil & Lemoine, 1905; Marçais, 1931) and has been recorded in the Batna and Bougie districts of eastern Algeria (Ehrmann, 1942) and at Jebel Zaghouan in Tunisia (Spath, 1913, pp. 543, 558, pl. iii, figs. 3, 4).

LOWER CALLOVIAN

The Lower Callovian is well represented in the Ghar Rouban area, whence Lucas (1942, p. 365) collected no less than 9 species of Macrocephalitids. In January 1952, at Deglen, he showed me a thin band of ironshot oolite cropping out below the marls and sandy limestones of the Anceps Zone and a few feet above the similar ironshot Bathonian, and from it I was able to collect Macrocephalites in situ. Another interesting list of Macrocephalitids is recorded from Touissit (Lucas, 1952, p. 65). Lucas (1950) also distinguishes Lower Callovian beds with Macrocephalites in the Saida area.

BATHONIAN

The Bathonian shows perhaps greater variations of facies than any other stage: grey marls with Posidonia and pyritic ammonites of the Zigzag Zone (Roman, 1933), sandstones and marly limestones (Agard & others, 1950), grey limestones with Cancellophycus and highly condensed ironshot oolite round the Ghar Rouban horst (Lucas, 1942), and thick dolomites and lithographic limestones forming 'causses' as in the Saida area (Flandrin & Clair, 1949). Lucas (1942, 1952) has discussed in detail the changes of facies and their significance. The ammonite faunas only can be considered here.

The Lower Bathonian marls with small pyritic ammonites of Jebel Sekika near Nemours (Roman, 1933) also occur near Beni Bahdel in the

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Tlemcen mountains. From these two localities M. Lucas and I, in January 1952, collected numerous small Phylloceratids identified as *P. cf. hatzegi* Loczy and *P. cf. kunthi* Neum. (= *P. riazi* Roman, 1933, *non* de Loriol), which as Roman pointed out represent perhaps nine-tenths of the total numbers; also *Holophylloceras zignodianum* (d’Orb.), *H. mediterraneum* (Neum.), *Lytoceras adeloides* (Kud.), *Nannolytoceras pygmaeum* (d’Orb.) (common), *Oppelia fallax* (Guéranger), *O. limosa* (Buckman), *Ocotroniastes pulcher* (Buckman) (common), *O. bomfordi* Arkell, *Ebrayiceras pseudoanceps* (Ebray), *Berbericeras sekikense* Roman, *Siemiradzkia* spp. indet. and *Parkinsonia* (*Oraniceras*) *hamyanense* (Flamand). Roman also figured a *Morphoceras*. The same fauna occurs at the base of the Bathonian near Tourirt, 55 miles west of Oudjda, in NE. Morocco (Agard, Termier & Termier, 1950), and through the kindness of M. G. Colo, of the Direction des Mines, Rabat, I have been sent (1953) about 100 specimens of

![Fig. 37.—Horizontal section through the transgressive Jurassic on the eastern part of the Ghar Rouban horst. After Lucas, 1952.](http://jurassic.ru/)

**Parkinsonia** (*Oraniceras*) *hamyanense* Flamand with associated Lower Bathonian ammonites such as *Parkinsonia* cf. *valida* Wetzel, *Morphoceras* cf. *densicostatum* Thal., *Ebrayiceras vashaldi* (Collot), from a strip of outcrops running for 175 km. SW. from Oudjda. This is evidently the Zigzag Zone with its *Parkinsonia* (*Oraniceras*) fauna developed as in Germany.

In the Ghar Rouban area (Deglen, etc.), where the whole Bathonian is condensed to 3 or 4 m. of ironshot oolites and marls (Lucas, 1942, p. 327), the same forms occur, with later ammonites of certainly Middle and perhaps also Upper Bathonian age (*Clydoniceras*). Middle Bathonian forms have also been figured by Roman (1930) from other places in the Oudjda district. The commonest genera are *Cadomites* (with *Polyplectites*?), *Bullatimorphites*, *Prohecticoceras*, *Oxycerites*, *Siemiradzkia* (plate 12).

Bathonian strata have also been recognized in the Batna and Bougie areas of Constantine (Savornin, 1920, pp. 152, 154; Ehrmann, 1942), and *Oraniceras* is recorded (Durand Delga, 1952, p. 25).
Upper Bajocian

In the Ghar Rouban area the Upper Bajocian occurs as grey marls with small pyritic ammonites, clearly distinguished lithologically and palaeontologically from the underlying strata. Lucas (1942, pp. 265-82) has collected and determined nearly 1000 ammonites, which enable him to recognize two zones, a lower with Strenoceras but without Spiroceras or Strigoceras, which he identifies as the Subfurcatum Zone, and an upper with Spiroceras spinatum predominant and with Strigoceras truellei and Garantiana garantiana, which he identifies as the Garantiana Zone. There are also numerous Bigotites, Leptosphinctes, Cadomites, Oppelia subradiata, Sphaeroceras brongniarti, Morphoceras dimorphum, Phylloceratids and Lytoceratids. In the lower zone Phylloceratids represent 62 per cent. of the total numbers of individuals. It is noteworthy that Teloceras blagendi (Sow.) is recorded from these beds (Lucas, 1942, p. 281).

Upper Bajocian ammonites are also recorded from various localities in the Oudjda district (Jodot, 1923; Roman, 1930, p. 9) and NE. Morocco (Gentil, 1908) and from Saida (Lucas, 1950).

Middle Bajocian

In the Ghar Rouban area the Middle and Lower Bajocian cannot be separated. Lucas (1942, p. 264) lists the following Middle Bajocian ammonites: Emileia polyschides (Waagen), Stephanoceras brodiei (Sow.), Dorsetensia edouardiana (d'Orb.), D. regrediens (Haug), Soninia aff. deltafurcata (Quenst.). Stephanoceras cf. humphriesianum (Sow.) is recorded from Jebel Nador (Deleau, 1948, p. 34) and Beni Snassen in NE. Morocco (Gentil, 1908). True Stephanoceras and Otoites and other ammonites were also figured by Flamand (1911, pl. iv) from the High Plateaux near Mecheria and occur farther east (Deleau, 1938, p. 103).

Lower Bajocian

In the Saida area there is the same mixture of Lower Bajocian ammonites with species of the Sowerbyi Zone already noticed in Morocco. Lucas (1950) lists a rich ammonite fauna including Hammatoceras, Haplopleuroceras, Dumortieria, Hyperlioceras, Reynesella and Graphoceras ('Depaoceras' and 'Ludwigella'), specifically identical with English species figured by Buckman. From the Ghar Rouban area Lucas (1942, p. 264) has also Leioceras, Hyperlioceras ('Toxolioceras'), Ludwigia, Tmetoceras scissum and Phylloceras. From Tourirt, 55 miles west of Oudjda, in NE. Morocco, are recorded Hammatoceras spp., Erycites fallax, Bradfordia praeradiata and Holcophylloceras ultramontanum (Agard, Termier & Termier, 1950). Flamand (1911) also found various Lower Bajocian ammonites which would repay revision; and there are records from the province of Constantine (Deleau, 1938, pp. 80, 90; 1952, p. 16).

Toarcian

The most constant and most ubiquitous and commonest Jurassic ammonite fauna in the Tellian Atlas is that of the Toarcian. It is recorded
in abundance from NE. Morocco (Daguin, 1927; Gentil, 1908, 1908a; Agard, Termier & Termier, 1950) through the Oudjda and Ghar Rouban areas (Lucas, 1942), the Saida area (Dubar, 1932) and Jebel Nador (Deleau, 1941, 1948), the Djurdjura (Roman & Russo, 1948, p. 14), eastern Algeria (Savornin, 1920, pp. 140, 147; Ehrmann, 1942; Deleau, 1938, pp. 80, 90) and Tunisia (Solignac, 1947, facing p. 14). At least three successive zones can be recognized, of which the lowest is known separately only in the Djurdjura, where there is a level with Dactylioceras athleticum (Simpson) as in the Middle Atlas, corresponding to the Tenuicostatum Zone.

By far the most abundant and widespread fauna is that of the Falcifer and Commune Zones, which comprises the Italian fauna and is usually developed in the Italian and Alpine facies of ammonitico rosso, but sometimes as clays with pyritic fossils. The ammonites are too numerous to be listed and are for the most part the same as those already enumerated from the Moroccan Atlas. An interesting addition at Jebel Nador is Leukadiella ionica Renz, a species previously known only in the Toarcian of Greece (Deleau, 1948, pi. ii, fig. 30, wrongly called Bouleiceras nitescens Thevenin). The Upper Toarcian fauna is less abundant but has an equally wide distribution from Morocco to the Djurdjura, and has usually been separated by collectors. Lists are published by the authors cited above. (See especially Lucas, 1942, pp. 239-40; Agard, Termier & Termier, 1950).

UPPER PLIENSBCHIAN

This is co-extensive with the Toarcian but often less favourable for collecting. The thickness varies from 10-70 m. on the belt of horsts to at least 300 m. in the troughs of deposition, where there are thick dolomites of Rif facies (Russo, 1935; Lucas, 1942, p. 184). The ammonite fauna is essentially Italian, comprising many Domerian Arieticeras, Protogrammoceras, Fuciniceras, etc. (Lists will be found in Lucas, 1942, and other papers mentioned under the Toarcian; for critical revisions see Roman & Russo, 1948, and Deleau, 1938, pp. 79-80, 90 ff.; and for figures see Spath, 1913, pl. lli; Deleau, 1938, pl. vi; Deleau, 1948, pl. i.) The brachiopods of Guelma (between Bone and Constantine) have been studied by Dareste de la Chavanne (1920).

LOWER PLIENSBCHIAN

With the Toarcian and Domerian fauna of the Djurdjura were collected some Tropidoceras, Phylloceratids, etc. (Roman & Russo, 1948, p. 14). Elsewhere strata of this age, if present, are without ammonites so far as known; at Tourirt, for instance, their place is occupied by dolomites and hard limestones with chert, yielding brachiopods (Agard, Termier & Termier, 1950). At Jebel Nador also there are dolomites, and in eastern Algeria compact limestones and oolites (Deleau, 1938, p. 90).
NORTH AFRICA

? SINEMURIAN AND ? HETTANGIAN

In the Jebel Nador area and in the province of Constantine beds without ammonites assigned to the Lower Lias on general grounds comprise 500-600 m. of crystalline dolomites thought to be of reef origin, the basal part a dolomitic breccia believed to be the result of destruction of reefs in situ (Deleau, 1938; 1948, p. 32), and in several places *Mytilus psilonoti* Quenst. has been recorded in beds taken to be Hettangian (Savornin, 1920, p. 135). At one locality only in the Ghar Rouban area, Lucas (1942, p. 156) recognizes regularly bedded grey limestones with a band of brachiopods which he assigns to the Lower Lias. In the Hodna there is a level with *Dimyopsis intusstriata* (Savornin, 1920, p. 139). In the province of Constantine beds with *Rhynchonellina* occur, as in the Rif and in the Alps and Sicily (Dubar & Delga, 1952). Records of Sinemurian ammonites from Tunisia require verification (see Spath, 1913, pp. 541-2).

[TRIAS

From the upper part of about 50 m. of limestones and dolomites in the Djurjura range, previously referred to Infra-Lias, *Pteria contorta* has been obtained (Lambert, 1937). *Myophoria vulgaris* occurs in the province of Constantine (Deleau, 1938, p. 64).]

SOUTHERN TUNISIA AND TRIPOLITANIA

From the most southerly Jurassic outcrop of the Atlas system in Tunisia, at Jebel Nara, SW. of Kairouan, there is no other outcrop for about 120 miles southwards to near Medenine, SE. of Gabes. Then there begins a continuous strip which runs south and gradually curves round SE., crosses the frontier into Tripolitania (Libya) and fades out running W.-E. This outcrop is about 125 miles long. It is continued east under Quaternary deposits and comes to the surface again for a short distance SW. of Tripoli. It is a limestone escarpment facing east and NE. over a flat Triassic dome and is ringed round by an outer escarpment of the Cretaceous. The main structure (which appears to be largely consumed by the Mediterranean) is fringed by smaller secondary domes or ruckles which deform the outcrops slightly.

Tectonically this structure belongs to the African shield, not to Barbary (Pfalz, 1935, p. 205). The gentle doming occurred in the late Miocene or early Pliocene ('post-Pontian, pre-Pliocene' teste Solignac, 1947, p. 64). Thanks to it is brought to the surface a sample of deposits left by Triassic and Jurassic seas that spilled southward for a hundred miles over the edge of the Sahara platform. Farther west for hundreds of miles through Algeria, any such deposits that may exist are hidden beneath the thick Cretaceous, Tertiary and Quaternary blanket of the Great Ergs and Hamadas.

The Jurassic rocks of this isolated outcrop in southern Tunisia and Tripolitania display several peculiar features. In the first place the facies has struck all observers as different from that in Barbary: the rocks consist mainly of limestones with pelecypods, gastropods, corals, etc., http://jurassic.ru/
but without cephalopods except at one horizon—the Middle Callovian Coronatum Zone (H. Douville, 1908; Jourdy, 1908; Mathieu, 1949, p. 35). Douville compared the fossils and facies to those of Syria and Abyssinia, though explicitly denying any implication that there was a Jurassic sea connexion across the eastern Sahara and Sudan. Secondly, the truly marine series over a large area begins with small pelecypod beds with *Trigonia pullus* Sow., of Middle or Upper Bathonian date, like those of Egypt, and these beds are transgressive, at least in the north between Medenine and Toujane, on to Permo-Trias (Mathieu, 1949). Thirdly,

**Fig. 38.—** Geographical sketch-map of the northern borderlands of Tunisia and Libya.

the pre-Bathonian beds consist of up to 600 m. of gypsum, in the higher layers of which locally are some thin beds crowded with small indeterminate pelecypod casts faintly resembling *Astarte* and a Gervilliid (Mathieu, 1949, pl. iii). Fourthly, the Triassic († Muschelkalk, with *Myophoria goldfussi*) and Lower Jurassic deposits thin out and either (in the lower part) wedge out, or (in the upper parts, Callovian-Kimeridgian †) are overlapped by the Cretaceous—not towards the south as might be expected, but towards the north. This suggests that the Triassic and Jurassic were deposited on the south side of folded Paleozoic resting on the uptilted northern edge of the Saharan shield recognized farther west by Laffitte (1947). At times this edge probably formed a barrier to long-shore migrations into Barbary; at other times, perhaps first in the Bajocian, it was submerged, allowing the *Ermoceras* fauna of Sinai and Arabia to spread.

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to western Algeria (Arkell & Lucas, 1953). After temporary emergence in the late Bajocian to Lower Bathonian, the barrier disappeared finally with the Middle Callovian transgression which caused the widespread 'equalization' noted in Barbary by Lucas (1942) and brought the influx of northern ammonites such as Erynnoceras into Algeria and Arabia. Any barrier must have been narrow, for on the latitude of Gabes, close to the southern edge of the Atlas trough, over 2000 m. of Jurassic has been proved in borings (Domergue & others, 1952, p. 19).

Geological dating of the Jurassic rocks is difficult owing to scarcity of ammonites. The 600 m. of gypsum and anhydrite is followed by thin limestones and marls in which a meagre fauna of small pelecypods and gastropods occurs, which Dubar (in Domergue & others, 1952, p. 15) considers Toarcian or Lower Bajocian. A small Gervilliid from these beds or a little below (Mathieu, 1949, pl. iii, figs. 11, 12) is totally different from a French Bajocian Oxytoma figured with it for comparison, and Dr L. R. Cox (in lit.) considers it probably of Lower Jurassic or even Upper Triassic age.

The Bathonian beds, probably Upper or Middle Bathonian as suggested by H. Douvillé (1908), consist of a semi-continental or 'estuarine' facies with plants and vertebrates, with marine intercalations containing oyster beds and such shells as Astarte angulata and Trigonia pullus abundantly (Domergue & others, 1952, pp. 15-16; some figures in Mathieu, 1949, pi. iii). As in Egypt, Himalaya, Cutch and Burma, these beds are transgressive, and towards the north they overstep the gypsum and over an area of nearly 40 sq. km. rest on folded Lower Trias. Mathieu (1949, pp. 31-2) infers that the date of folding was late Triassic or early Jurassic, and he names the phase 'Matmatien' after a local district. But from the evidence presented there could be more than one phase superimposed, and the last folding could be as late as Lower (or even Middle) Bathonian. If

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**Fig. 39.**—Horizontal section through the marginal Jurassic of southern Tunisia. After Mathieu, 1949.
such a date should eventually be confirmed here or in other parts of the world, the name Matmatian might be adopted by those who consider a separate nomenclature for tectonic events necessary. In the Ghar Rouban, movements preceded the Lower Bathonian (Lucas, 1952, pp. 72-3).

The Upper Jurassic limestones, which thicken from 80 m. to 320 m. southwards, are monotonous and not susceptible of accurate dating. H. Douville's assignment to Callovian, Oxfordian and Lower Kimeridgian is probably correct. The presence of Middle Callovian has been proved by the finding of *Erymnoceras* cf. *coronatum* in several places. Other invertebrate fossils make the presence of Upper Oxfordian and Lower Kimeridgian probable (Mathieu, 1949, pp. 35-7). Some higher beds with pelecypods and echinoids may be later (Domergue & others, 1952, p. 16).

The alleged occurrence of Purbeckian limestone far south in the Sahara (the Murzuch Limestone in Fezzan), recurrent in the literature, can be discounted. The limestone gives no palaeontological evidence of being Jurassic and is probably Tertiary, perhaps Pliocene (Arkell, 1951; Desio, 1951).
CHAPTER II

THE MIDDLE EAST

THE FRINGE OF THE ARABO-NUBIAN LANDMASS: EGYPT, PALESTINE, JORDAN, SYRIA AND ARABIA

Nubia and a further vast region of the southern Libyan Desert, with the Red Sea Hills of Egypt, the southern tip of Sinai, and a large part of western Arabia in the Hejaz and Nejd, form part of an ancient pre-Cambrian crystalline massif projecting from the continental shield of Africa. Around the fringe of the landmass, on all sides but the south-west, successive Mesozoic formations dip away radially and are arranged in roughly concentric rings, those nearest the landmass forming a tabular belt, those farther out a belt of simple folds, while farther still there is an abrupt contact with a belt of complex folds and overthrust sheets. The tabular belt occupies most of Egypt. The belt of simple folds coincides with deeper parts of the surrounding trough: starting in the Egyptian oases and passing close to Cairo at Abu Roash, it runs through northern Sinai, Palestine and Syria, and then curves round through western Iraq and the Syrian Desert, under the Tigris-Euphrates valley and the Persian Gulf. South of this it is lost beneath the Rub-al-Khali. It is in this zone that the Arabian, Persian, Iraqi, Syrian and Palestinian oilfields lie, and it formed the fore-deep of the southward and south-westward thrusting mountain chains of Asia Minor, Persia and Oman. It stands in the same relation to the thrust mountains and their crystalline foreland as the Indo-Gangetic plain to the Himalayas and their foreland, peninsular India. (See Picard, 1939; Lees, 1948.) (Fig. 40.)

THE NUBIAN SANDSTONE

Palaeozoic sandstones, with local fossiliferous intercalations ranging in date from Cambrian to Carboniferous, are known in the south-western Libyan Desert, Wadi Araba near the north end of the Red Sea Hills, Western Sinai, the Jordan valley and Central Arabia. The true Nubian Sandstone, however, is now known to be Cretaceous over by far the greater area of its outcrop, and especially in upper Egypt and Nubia. In the critical Wadi Qena area, east of Assiut, it alternates with interbedded marine limestones containing ammonites and other fossils of Albian, Cenomanian and Turonian ages, the lowest layers, resting on pre-Cambrian granite, being Albian or possibly Aptian (Hume, 1911, pp. 120-3; Attia & Murray, 1952).

On historical grounds the term Nubian Sandstone should be retained as a formational name, but it should be restricted to rocks of similar age.
FIG. 40.—Structural sketch-map of the Middle East, after Dr L. Picard. (Redrawn from Bull. Geol. Dept. Hebrew Univ., Jerusalem, vol. ii, p. 54.)

Direct palaeontological evidence south of Wadi Qena is scanty. At Jowikol, between Korosko and Aswan, a band of oolitic ironstone yielded four species of freshwater mussels (*Unio* and *Mutela*). From the western end of the Aswan Dam excavations were obtained a single marine *Inoceramus* and a freshwater *Unio* with adherent marine worm-casts. From this a Senonian date and estuarine origin were inferred (Newton, 1909). At Wadi Zeraib in the Red Sea Hills, south of Qosseir, were found dicotyledenous leaves 'of forest trees closely allied to tropical Asiatic species' living at the present day, but not inconsistent with a Cretaceous
date (Seward, 1935). In many places the sandstone contains abundant silicified wood and tree trunks, which may have been drifted long distances, but leaves as perfect as those from the Red Sea Hills figured by Seward can hardly have been drifted out of one climatic zone into another; and their growth must have taken place in a humid tropical climate (Seward, 1935, p. 5). On the other hand, near El Fasher, in eastern Darfur, other plants were found which turned out to be xerophytic, probably strand dune dwellers. They are of world-wide distribution and of either Lower Cretaceous or early Upper Cretaceous date (Edwards, 1926).

The bedding is agreed by all recent observers to indicate deposition in water, and the beds might best be described as fluvio-marine, though perhaps in large part lacustrine in the south. The grains are usually subangular, but Sandford (1935) points out that the shales, mudstones and clays sometimes contain rounded and polished sand grains, or lenticles of white sandstone composed of such grains, indicating wind transport and drift sand not far away. He also figures (1935, pp. 345-6) from SW. of Kharga lenticles up to 16 ft. thick of ‘clayey sandstone and white and purple sandstone’ breccia, which he interprets as ‘scree from a buried rock-face’, but which it might be suggested could be desiccation breccias due to temporary drying and flooding of braided distributaries on deltas or sandflats.

A remarkable feature is the absence of polygenetic basal conglomerate except in a very few places, although the sandstones everywhere rest on an almost level surface of granite and other crystalline rocks (Andrew, 1937). Shukri and Said have shown that the mineral composition of the sandstone is equally unexpected: it consists overwhelmingly of quartz, but the other minerals present are not such as could have been derived direct from the underlying basement complex. Rather it appears that the crystalline complex was peneplaned before deposition of the Nubian Sandstone, perhaps in Palaeozoic times, and that the materials of the Cretaceous sandstones were derived from the destruction of their Palaeozoic predecessors. This idea receives support from the intimate mixture of fresh and decayed grains. Locally, however, quantities of pebbles of assorted igneous and metamorphic rocks are found in isolated pebble beds (Arkell, 1951).

Shukri & Said, like Hume, infer deposition in a shallow sea on the fringe of a sinking peneplain. That the sea at least occasionally invaded the area is shown by the single Inoceramus far in the interior of the massif, at Aswan, and by the ironshot oolite bands there and round Wadi Halfa. But as Beadnell and others have pointed out, a marine origin for the whole series is unconvincing. At the present time, as through all previous geological periods down to the Cambrian, marine life teems in any sea in these latitudes, however shallow, and there seems no reason why it should not have left its remains in the Nubian Sandstone.

Andrew (1937) has rightly concluded that all Nubian Sandstone south of 28° 40' N., i.e. south of St Paul Monastery, is Upper (and Middle)
PLATE 13a.—The Bathonian section, Khashm el Galala, Egypt.

PLATE 13b.—Ras el Abd on the Gulf of Suez.
PLATE 14.—Dark Bathonian beds cropping out at foot of the Cretaceous and Tertiary cliffs, Ras el Abd, Gulf of Suez.

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Cretaceous. Andrew restricted his remarks to the area east of the Nile, but there is no reason to doubt that they hold also for the much greater area of Libyan Desert to the west and south.

Accordingly, over this north-east corner also of the vast African shield, it can be concluded that either Jurassic seas never extended, or all their sediments were denuded before the Upper Cretaceous. The most probable conclusion is that the area was for the most part dry land undergoing peneplanation in the Jurassic; that the various Jurassic transgressions temporarily carried shallow seas over the fringes of the landmass, but that these thin marginal deposits were destroyed or trimmed back by Lower Cretaceous denudation before deposition of the Nubian Sandstone.

COASTS OF THE GULF OF SUEZ, CENTRAL SINAI AND NILE DELTA

On the west side of the Gulf of Suez the Eocene limestone tableland, where it reaches its highest elevations of 1000 to 1500 metres in the North and South Galala Plateaux, is cut through almost to sea-level by the great erosion hollow of Wadi Araba, 50 miles long and 20 miles wide. The floor of the hollow consists of Carboniferous sandstones with thin sandy and sometimes crinoidal limestones crowded with the brachiopods Spirifer and Dielasma. Along both the north and south sides of the wadi, unfossiliferous Nubian Sandstone of Cretaceous type has been observed at a number of places to rest directly on the Carboniferous, with only slight unconformity (Arkell, 1951). After the scarp turns NE., along the faulted coast of the Gulf of Suez, however, a wedge of Jurassic rocks comes in and thickens rapidly. The first known good exposures are close to the coast road on the south side of Ras el Abd (29°33'30"N., 32°21'30"E.) (pl. 13). The rocks consist of over 100 m. of marine marls, limestones and sandstones with Bathonian pelecypods and brachiopods (Farag, 1948). A few kilometres farther north, at the NE. corner of the North Galala Plateau, in a fault block under Khashm el Galala, the Bathonian strata are about 170 m. thick (pls. 13, 14).

At the base of the section at Khashm el Galala are about 50 m. of unfossiliferous sandstones of presumed Triassic age. Resting upon an irregular surface of the sandstones are some thin bands of pink sandy and shaly marls which have yielded a flora of Rhaetic-Infra Liassic age, including Equisetites, Phlebopteris, Zamites and ? Cladophlebis, identical with remains found in the Kohlan Sandstones of the Yemen (Carpentier & Farag, 1948). Immediately above the plant beds follow the marine Bathonian beds, a long series of marls and thin limestones, sandy limestones and sandstones, with at least 20 species of pelecypods, brachiopods and (more rarely) gastropods (Sadek, 1926, p. 35). Shells such as Trigonia cf. pullus Sowerby, Gervillia waltoni, Astarte, Nucula, etc. occur in profusion in certain thin ferruginous bands, the tests preserved intact. Other slabby limestones are crowded with crushed Rhynchonellids and resemble
English Forest Marble. Unfortunately no ammonites have been obtained, but the assemblage is essentially Upper Bathonian. (At Ras el Abd, Farag attributed some of the pelecypods to the Bajocian, but although some of them may occur in the Bajocian of Gebel Maghara, they belong to such long-ranging genera that they provide insufficient evidence for the presence of Bajocian under the Galala Plateau.) Above the Bathonian, without perceptible discordance, follow about 150 m. of Nubian Sandstone,

on which in turn rest Cenomanian marls and chalky Upper Cretaceous limestones.

Borings for oil have shown that in the Canal Zone and around the head of the Gulf of Suez Jurassic rocks occur, even within the rift valley, only north of latitude 20° N., and that they thicken northwards underground just as at the surface. At Ayun Musa, about 8 miles SE. of Suez, two wells proved Jurassic directly underlying Miocene. At Ataqa, on the opposite shore of the Gulf, SW. of Suez, Jurassic was struck at a depth of 156 m., below Nubian Sandstone. Borings also proved Jurassic at depth near

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the NW. corner of the Great Bitter Lake (Abu Sultan) and under the Cretaceous dome of Abu Roash, on the west edge of the Nile valley north of Giza pyramids (Chata, 1951, p. 91).

At Abu Roash a well drilled in 1946 (of which the log and reports have been kindly made available to me by the Standard Oil Company of Egypt) proved pink granite basement at 1898 m., overlain by 336 m. of Carboniferous, 806 m. of Jurassic, and 152 m. of Nubian Sandstone. The Jurassic rocks consisted mainly of shales, with subordinate sandstones, and were identified by lithology and micro-fauna, but the only macro-fossil recognized was a *Nuculana*. The micro-fossils do not admit of reliable subdivision. So great a thickness of Jurassic shows that stratigraphically as well as structurally the Abu Roash dome is comparable with Gebel Maghara in northern Sinai.

At Abu Sultan, near the NW. corner of the Great Bitter Lake, under the Tertiary (Oligocene?) were penetrated 275 m. of beds presumed to be pre-Nubian Sandstone and probably all Jurassic, unbottomed at a depth of 757 m. The lower part yielded species of *Nucula, Nuculana, Astarte, Gervillia, Eligmus*, etc., and were compared to the Bathonian; at two levels were beds crowded with *Posidonia*. Higher up were pelecypods and some brachiopods thought to be Oxfordian to Callovian (Report kindly made available by the Anglo-Saxon Petroleum Company).

Across the peninsula of Sinai all rocks below the Cretaceous Nubian Sandstone crop out south of the line where the Jurassic thins away. Between the Eocene and Upper Cretaceous limestone plateau of central Sinai (Gebel Egma and Gebel Tih) and the pre-Cambrian crystalline rocks of southern Sinai, the Nubian Sandstone outcrop runs in a continuous strip from a point midway down the Gulf of Suez to the head of the Gulf of Akaba. In this outcrop no sign of Jurassic rocks has been reported, although on the west side there is a continuation of the marine Carboniferous of Wadi Araba (Ball, 1916). Upon the Nubian Sandstone follows marine Cenomanian.

**GEBEL MAGHARA, NORTHERN SINAI**

Fifty miles east of Ismailia, which stands at about the centre-point of the Suez Canal, the low-lying and largely sand-encumbered plains of north Sinai are broken by the massif of Gebel Maghara (Djebel Moghara in the French literature). The group of mountains forms an ellipse about 25 miles long by 15 miles wide, the long axis running SW.-NE. On the average they reach 1500-2000 ft., and the highest point, Shusht el Maghara, attains 2412 ft. The structure is a pericline, in the centre of which Jurassic rocks occupy an ellipse measuring 23 miles by 9 miles. Not far away two other small inliers of Jurassic rocks (limestone believed to be Lower Kimeridgian or Upper Oxfordian in age) occur in the isolated dome of Gebel Um Mafruth (852 ft.) and a hill called Jeham, in the Risan Aneiza group (Farag, 1947).
The structure of the main Maghara inlier is in reality two parallel anticlines separated by a narrow, sharp syncline: the greater is centred at Shusht el Maghara, the lesser, to the NW., runs through Gebels Hamaiyir and Um Mafruth (Moon & Sadek, 1921).

The total thickness of Jurassic rocks exposed amounts to about 1905 m., as measured by geologists of the Standard Oil Company of Egypt in 1942 (see Arkell, 1952, p. 307). The stages identified by fossils range from Lower Bajocian or earlier (252-261 m. from the base of the exposure) to Lower Kimeridgian; the latter is developed as dolomites which represent the Glandarienkalk of Palestine and the Lebanon. Upon this rests unfossiliferous sandstone of Nubian facies and presumed Lower Cretaceous age. The lowest Cretaceous fauna, found in marls and limestones resting on the sandstone, contains Costidiscus recticostatus, index fossil of the lowest zone of the Aptian. The Jurassic ammonites and other fossils have been figured by H. Douville (1916) and Arkell (1952, pl. 30).

**LOWER KIMERIDGIAN**

Dolomitic limestones with echinoids, which show that at least the upper part corresponds to the Glandarienkalk.

**OXFORDIAN**

Yellow marls and limestones, resting on siliceous limestones. Upper Oxfordian (Plicatilis Zone) ammonites figured by H. Douvillé are Perissphinctes s.s. indet. (1916, pl. viii, fig. 1), Arisphinctes sp. indet. (pl. viii, fig. 2). Lower Oxfordian is indicated by Euaspidoceras cf. babeanum (d'Orb.) (pl. viii, fig. 6), fragments of Pachyceras sp. indet. (pl. viii, figs. 4, 5), and abundant Hibolites hastatus.

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CALLOVIAN

A great thickness (perhaps 500 m.) of shales, marls and limestones is grouped together in the descriptions as Bathonian - Callovian, not separated. The only Callovian ammonites, however, are a Reineckea aniceps, a 'Stephloceras' [Erymnoceras] and an impression of Quenstedtoceras recorded by Couyat-Barthoux & H. Douville in their preliminary paper (1913, p. 267) and repeated by Hume & others (1921, p. 341), but not mentioned in H. Douville's monograph. Probably these records were based on species of Bajocian Ermoceras and silently corrected by Douville in his monograph. Hoppe's (1922) unfigured Reineckia are equally suspect, in view of the strong resemblance to Reineckiae shown by various Bajocian Ermoceras since found in Arabia.

BATHONIAN

The bulk if not all of the 500 m. of so-called Bathonian-Callovian beds are probably Upper and Middle Bathonian. They contain large numbers of Eligmus rollandi, Gryphaea costellata and Eudesia cardium. The only two ammonites figured by Douville from these beds are Bathonian, namely Micromphalites pustuliferus (Douville, 1916, pi. vi, figs. 2, 3) (Middle Bathonian) and Clydoniceras orientale (Douville, pi. vi, fig. 1) (Upper Bathonian). The association of Eligmus and Eudesia is reminiscent of the Upper Bathonian ('Bradfordian') of Normandy.

UPPER BAJOCIAN

Underlying a 3 m. Bathonian bed with Clydoniceras and Oecotraustes, the Standard Oil Company geologists measured 275 m. of beds without ammonites, and then 148 m. with an Upper Bajocian assemblage containing the celebrated Ermoceras and Thamboceras fauna, known nowhere else in the world until discovered in 1948-51 in central Arabia. The associated ammonites, which at Maghara include Oppelia cf. subradiata (Sow.), Lissoceras oolithicum (d'Orb.), Spiroceras bifurcati (Quenst.), and Leptosphinctes cf. tenuiplicatus (Brauns) with Phylloceratids and Lytoceratids, proclaim an early-Upper Bajocian date, not later than Garantiana Zone.

MIDDLE BAJOCIAN AND EARLIER

From between 95 m. and 115 m. below the lowest Ermoceras bed was collected a good specimen of Normannites cf. braikenridgei (Sow.), which indicates the Sauzei Zone. Below this were measured no less than 558 m. of beds (mostly sandstones) without ammonites, then a 9 m. bed from which was obtained a crushed fragment which could belong to a flat Somminia of the style of S. dominans Buckman or to a Grammoceras cf. muelleri (Denckmann) (topmost Jurense Zone). At base were 252 m. without ammonites to the bottom of the section. (See Arkell, 1952, p. 307.)
PALESTINE AND TRANSJORDAN

The zone of simple autochthonous folds (Picard, 1939 map) (fig. 40) encircling the plateau edge of the Arabo-Nubian massif, of which Gebel Maghara is one of the most important anticlines, continues north-eastwards through Palestine and Syria and then bends round eastwards into Iraq. The surface-forming rocks of Palestine are mainly Cretaceous and Eocene, among which the Jurassic and Triassic systems are brought up as inliers in the major anticlines, or where deep valleys have been eroded through the Cretaceous cover to reach the depression of the Dead Sea.

That there were also post-Jurassic, probably Lower Cretaceous, movements, is proved by the next anticline to Gebel Maghara, the dome of Araif-al-Naga, just on the Sinai side of the Sinai-Palestine frontier, midway between the Mediterranean and the head of the Gulf of Akaba. Here the Jurassic system is missing entirely, cut out by Lower Cretaceous erosion. The core of the dome consists of marine Middle Trias, overlain directly by Nubian Sandstone. The Trias is in Muschelkalk facies with Ceratites, Beneckeia cf. buchi (Dunker) and conodonts. The lowest beds exposed are violet and white sandstones of presumed Lower Triassic or Permian age (Awad, 1945; Eicher, 1946).

Only 18 miles to the NW., slightly en échelon, the anticline of Wadi Raman shows the Trias overlain by an outcrop of marine Jurassic 17 miles long. A thickness of 458 metres is exposed. The succession consists largely of sandstones, alternating with marls, and has yielded only a few pelecypods, gastropods and brachiopods, including Terebratula subsella and Somalirhynchia (Rhynchonella moravica) in a 1-3 m. limestone band 33 m. from the top. The bulk of the series is regarded as Upper Jurassic (Shaw, 1947, p. 20). A system of dykes and sills cuts all the Jurassic rocks but not the Nubian Sandstone (Bentor, 1952). They are probably contemporaneous with the Kimeridgian-Tithonian volcanic episode in the Lebanon.\(^1\)

A further 16 miles to the north, en échelon, begins a similar anticline at Wadi Hathira (Kurnub), in which are exposed 227 m. of Jurassics, base not seen. The facies is different, limestones being much more in evidence and sandstones wanting. The fauna is more numerous but similar to that in Wadi Raman, and seems to be all Upper Jurassic, probably Callovian to Lower Kimeridgian. No ammonites have been found. Lower Cretaceous sandstones follow unconformably, with angular blocks of Jurassic limestone in the base, and Aptian fossils higher up (Blake, 1935, pp. 71-2; Shaw, 1947, pp. 18-20; Blake & Goldschmidt, 1947, pp. 316-7).

The only other exposures of Jurassic rocks known south of the Syrian border are found just beyond the frontier of Palestine, in (Trans)Jordan, on the east side of the Jordan valley about 48 km. N. of the north end of

\(^1\) Note in proof. I was informed in December 1954 by Mr A. Parnes, Jerusalem, that a Bajocian fauna with Stephanoceras has been discovered in the Wadi Raman.

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the Dead Sea. Here the Nahr es Zerka (Wadi Zerka, Jabbok, or Yabbok) has cut through the northern edge of a dome and down to the Lower Trias (Cox, 1932). Above the Lower Trias follow 540 m. of sandstones before the Cenomanian limestone is reached. Presumed equivalents of some part of these sandstones yielded a Middle Trias (Muschelkalk) fauna with Beneckeia cf. bachi (Dunker) not far away to the south, at Wadi Hesban and Wadi Ayun Musa. In the Zerka area (Wadi Huni) there are hard grey Triassic limestones with Myophoria, followed by about 200 m. of limestones, sandstones and shales assigned to the Jurassic, and then by another 200 m. of purple, red and white sandstones without fossils. The Jurassic beds have yielded many pelecypods and brachiopods of Bathonian age, including Eudesia cardium (Lamarck), Eligmus rollandi Douvillé and Gryphaea costellata Douvillé, which proclaim them to be a continuation of the Eligmus-Eudesia beds of Gebel Maghara. Additional Bathonian forms are Burmirhynchia tumida Buckman (= Rhynchonella concinna Davidson non Sowerby), Avnonothyris jordanensis Muir-Wood and Heimia furcillens (Haas). Three other species of brachiopods (a Heimia, Lobothyris and ? Cymatorhynchia) were taken by Muir-Wood to indicate the presence of Bajocian strata also, but subsequent collecting has revealed these species in close association with the Bathonian forms (Cox, 1925; Muir-Wood, 1925; Blake, 1935, pp. 69-71). In default of Bajocian ammonites these Eligmus-Eudesia beds should be regarded as Bathonian. The best correlatives are the ‘Bradfordian’ beds with Eudesia cardium and Eligmus polytypus in Normandy.

The outcrops of the Eligmus-Eudesia beds occur near the mouth of the Yabbok or Zerka valley, and they can be traced for some distance to the south, along the eastern side of the Jordan valley, in which direction they are overstepped by Cenomanian limestone (Avnimelech, 1945; Lees, 1945). This provides further evidence of the Lower Cretaceous folding and erosion already noticed above.

**Syria and the Lebanon**

Offset again to the north, the north-easterly anticlines with Jurassic cores continue along most of the coastal region of Syria. Between Damascus and Beirut lie the famous twin anticlines of the Anti-Lebanon and Lebanon, forming parallel ranges separated by an alluvial valley. The southern end of the Anti-Lebanon anticline, to the west of Damascus, forms Mount Hermon, where Lower Oxfordian marls with pyritized small ammonites of west-European type have long been known through the monograph of Noetling (1887). The anticline of the Lebanon begins south of Beirut and runs parallel to the coast past Tripoli, then, after temporary eclipse beneath basalt, reappears with strike deflected due north as the range of Jebel Ansariya, in which Jurassic is exposed as far as the port of Ladikiya. From the western Lebanon came the material studied by Krumbeck in his monograph on the molluscs and brachiopods of the ‘Glandarienkalk’

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2Q4 THE MIDDLE EAST

(1905), which he showed to be of Lower Kimeridgian age. The total length of almost continuous Jurassic outcrops in the Lebanon and Jebel Ansariya is over 130 miles.

The following is a summary of the succession in the Anti-Lebanon according to Dubertret (1933, p. 289; 1942-5, 1949) and Vautrin (1934, p. 1439) with the present author's classification (plates 15, 16).

LOWER KIMERIDGIAN

6b. Yellow and brown marly, sometimes oolitic, limestones with interbedded marl bands, with some of the same fossils as the Glandarienkalk, including Terebratula subsella Leym., Mytilus subpectinatus, etc. 40 m.

6a. Hard compact crystalline limestone or Glandarienkalk, with

FIG. 43.—Jurassic outcrops and important faults in Syria and the Lebanon.
PLATE 15.—Two views in Upper Jurassic limestone country in the Anti-Lebanon, Syria.
Photo C. L. Dubertret

PLATE 16.—Middle and Upper Jurassic limestones, Couloir de Serrhaya, Anti-Lebanon mountains, Syria.

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abundant radioles of *Balanocidaris glandifera* Münster (‘Cidaris glandarius’ Goldfuss) and the shallow-water fauna described by Krumbeck (1905). *Phylloceras salima* Krumbeck, *Aspidoceras* sp. indet., *Nautilus turcicus* Krumbeck. Relations of the fauna purely central European. 15 m.

**Upper Oxfordian**

5b. Regularly-bedded limestones with abundant *Somalirhynchia africana* Weir (‘*Rhynchonella moravia*’). 25 m. [Bimammatum Zone ?]

5a. Marls with haematite concretions, *Perisphinctes orientalis* Siemiradzki, passing into marls with interbedded buff limestones with corals; *Perisphinctes* sp., *Pholadomya protei* (Brongniart), etc. 30 m. [Transversarium Zone.]

**Lower Oxfordian**


4a. Grey-blue marls with the abundant fauna of small ammonites described by Noetling (1887) and revised by Frebold (1928) and obviously belonging to the Mariae Zone. Noteworthy species figured by Noetling are *Phylloceras plicatum* Neumayr, *Calliphylloceras schemas* (Noetling), *Sowerbyceras helios* (Noetling), numerous *Hecticoceras* spp., including the subgenera *Putealiceras* (schumacheri) and *Brightia* (socini), numerous *Campylites* (rauracum, delmontanum, etc.), *Creniceras renggeri* (Oppel), *Tarameliceras* (Proscaphites) *hermonis* (Noetling), *Properisphinctes latilinguatus* (Noetling), *Grossouvria* spp., *Mirospin* *tces syriacum* (Noetling) and *M. dubium* (Noetling), *Euaspidoceras* aff. *babeanum* (d’Orb.) (cf. loryi Jeannet), and *Hibolites hastatus* (Blainv.). This fauna is being re-studied, on the basis of thousands of new specimens, by Dr O. Haas (‘? 1955). [Mariae Zone.] 20 m.

**Middle-Upper Callovian**


2c. Limestones, grey-blue, fine-grained, with fragments of brachiopods and corals: ‘Rh. moravia’. 350 m.

**Upper Bathonian**

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**Undated**

2a. Dark limestones, locally dolomitic, unfossiliferous. 250 m.

1. Sandstone with lignite, and limestones with small gastropods, interpreted by Vautrin (1934) as lacustrine. (Thickness unknown; base not exposed).

This full succession (1350 metres) is developed only at the south end of the Anti-Lebanon. Towards the north a gap appears above bed 2, and continues to enlarge, so that in turn the Middle-Upper Callovian and Lower and Upper Oxfordian are cut out. Finally, at the north end of the range the Glandarienkalk (No. 6a) rests with a basal breccia directly on the ? Lower Callovian or Upper Bathonian (No. 2) (Vautrin, 1934). If this is not due to later tectonic causes as yet undetected, and is the result of penecontemporaneous erosion as inferred by Vautrin, it indicates probably in part a northward thinning of the Callovian and Oxfordian, and in part marginal transgression and overlap by the Lower Kimeridge; an overlap conspicuous in the Yemen and Hadramaut in southern Arabia. It would seem incorrect to infer from these gaps in the Upper Jurassic sequence in Syria that Callovian folding formed the Yabbok dome in Palestine (Avnimelech, 1945, p. 83).

Special interest attaches to possible future dating of formations 1 and 2, in view of the necessity for supposing that the Bajocian *Ermoceras* fauna of north Sinai and central Arabia communicated freely across southern Syria and perhaps northern Palestine. If these stages are not represented in formations 1 and 2 it is necessary to suppose that their representatives lie buried beneath the surface.

In the Lebanon, near the coast, the Kimeridgian becomes much thicker and is represented by up to 500 m. of limestones. They are monotonous and poorly fossiliferous except at the top, where there is a reef facies with corals, stromatoporoids, Nerineidae, etc. Immediately after this neritic phase there followed in the Lebanon a volcanic episode, with emission of thin basalt flows and deposition of bedded ashes with bituminous shales and lignite. This episode seems to have occurred during the late Jurassic, for the volcanic rocks are overlain by up to 250 m. of limestones dated as at least in part Tithonian by the occurrence of *Berriasella richteri* (Oppel) (Dubertret, 1942-5).

In the gorges of the Nahr Ibrahim, cut through the Lebanon plateau, the whole Jurassic succession is up to 1700 m. thick according to Renouard (1951), who has recorded a number of pelecypods, brachiopods and echinoids from various levels. In the absence of ammonites, however, the detailed classification attempted is unreliable. According to Renouard the volcanic series is up to 180 m. thick, the (Tithonian) limestones above it are 210 m. thick, and those below 1365 m. (maximum thicknesses).

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In eastern Syria, beyond the Euphrates, the belt of autochthonous folds widens and merges into the great Mesozoic and Cainozoic geosyncline of Iraq and the Persian Gulf region, where the Jurassic rocks are buried (as proved by oil borings on the anticlines) under immense thicknesses of Cretaceous and Tertiary sediments. For instance, at Kirkuk, beyond the Tigris, in the foothills of Kurdistan, the Tertiary rocks alone are about 2400 m. thick, and in the Persian foothills they expand to 6000 m. Even at Kuwait, on top of the productive anticline they are over 800 m. thick.

In the Saudi Arabian oilfield near the west coast of the Persian Gulf, opposite Bahrain Island, the Jurassic rocks are 4500 to 6000 ft. underground. Here the upper Jurassic beds, consisting of alternating limestones and anhydrite, form the reservoir rock. They are called the Arab Zone and appear to be Tithonian (Barber, 1948). In Kuwait there is a thick development of salt in this zone.

Under the southern part of the Syrian Desert and the Great Nefud of northern Arabia, the Jurassic system seems to be overlapped southwards by the Nubian Sandstone, which feathers out on a 700-mile front, running east-west, against the crystalline basement complex, as in central Sinai, or against Triassic or earlier sandstones.

About 200 miles NW. of Riyadh, capital of Saudi Arabia, marine Jurassic rocks emerge out of the sands and run at first SE. then due south for about 570 miles as a great limestone cuesta, the Jebel Tuwaiq. The strata are almost horizontal, except for minor normal faulting, but eastwards dip gradually under the Cretaceous and Tertiary formations of the coastal plain and the Rub al Khali. Tectonically we have here moved out of the belt of folds into the tabular region, where the epicontinental sediments repose on the almost undisturbed but uplifted crystalline massif. The limestone and shale members wedge out both north and south, indicating that the outcrop crosses a Jurassic bay. West of the escarpment marine Middle Trias occurs, with some ill-preserved ammonites.

First described from end to end by Philby (1922), the Jebel Tuwaiq has yielded its chief stratigraphical secrets only in the decade 1940-50 to geologists of the Arabian-American Oil Company, and in particular Max Steineke and R. A. Bramkamp, successively Chief Geologist (Steineke 1947; Barber, 1948; Arkell, Bramkamp & Steineke, 1952) (plates 17, 18).

The principal escarpment-former is the Tuwaiq Mountain Limestone, 215 m. thick, of Middle Callovian date, which produces the bare limestone plateau travelled by Philby, and in which he found the first ammonites (Erymnoceras) and other fossils. Subsidiary escarpments are formed by other limestones lower down in the succession of shales and sandstones. The total thickness of Jurassic rocks proved is over 1000 m. although the range is only from Lower Toarcian to Lower Kimeridgian. Features of special
interest in the faunas so far discovered are: (1) The Lower Toarcian assemblage of *Spiriferina* with *Bouleiceras* and other peculiar ammonites; (2) The Bajocian *Ernoceras-Thambites* ammonite fauna, previously known only at Gebel Maghara in Sinai; (3) The NW. European Middle Bathonian ammonite genera *Tulites*, *Micromphalites* and *Clydoniceras*, associated with entirely new genera; (4) The presence of the Upper

**FIG. 44.**—Sketch-map to show the Trans-Erythraean trough and southern Mediterranean, and occurrences of the peculiar genera *Bouleiceras* (Lower Toarcian) and *Ernoceras* (Upper Bajocian).

Bathonian *Eligmus* beds with *Gryphaea costellata* Douvillé, as in Sinai, Palestine, Syria and Somaliland; (5) The presence of the Coronatum Zone of the Middle Callovian, with *Erymnoceras* and *Pachyceras*, but no sign of the more ubiquitous Lower Callovian ammonite faunas.

**TITHONIAN**?

Riyadh Group. The group contains thick beds of anhydrite (Hith Anhydrite), the collapse of which has greatly disturbed the strata. At

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PLATE 17.—Callovian limestones and Bathonian shales, Wadi Birk, Central Arabia.

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PLATE 18a.—Haisiya Pass through the Jebel Tuwaiq (Geology as for Plate 17).

PLATE 18b.—Outcrop of the Toarcian Bouleiceras beds, Jafair Trail, outer Jebel Tuwaiq, Central Arabi
outcrop no ammonites have yet been found. For particulars of the Arab Zone underground in the oilfields near the Gulf coast see Barber, 1948.

**LOWER KIMERIDGIAN**

Jubaila Limestone (110 m.). Compact limestones, shelly limestones and oolites with *Ceromyopsis somaliensis* Weir, *Pholadomya protei* (Brong.) and other pelecypods. A few poorly-preserved Perisphinctids of the group of *Progeronia progeron* (von Ammon), found in the Tenuilobatus Zone of Central Europe.

**OXFORDIAN?**

Hanifa Formation (100 m.). Limestones and oolites with subordinate marl and shale; colonial corals common at several levels, but no reefs. *Somalirhynchia africana* Weir, *Gryphaea balli* (Stefanini) and many other pelecypods, largely European. A single poorly-preserved Perisphinctid is comparable to *P. africanus* Dacqué, a species of the Plicatilis Zone of Mombasa.

**MIDDLE CALLOVIAN**

Tuwaiq Mountain Limestone (215 m.). Limestones, mainly hard, compact, lithographic, with a few oolitic and detrital layers; basal 35-40 m. soft and chalky. Colonial corals common in the middle and upper parts, but reefs only observed at one locality NW. of Riyadh. Abundant pelecypods, mainly of common European species. *Erymnoceras* spp. and *Pachyceras* sp. in the lower chalky beds, which therefore alone are dated.

**UPPER BATHONIAN?**

Upper Dhruma Formation (86 m.). No ammonites. The upper 65 m. consist mainly of shale with *Gryphaea costellata* (Douvillé), the lower 21 m. of limestone, which is full of *G. costellata*, also many *Eligmus rollandi* and other pelecypods, especially *Pholadomya lirata* (Sow.) and other Myacea.

**MIDDLE (AND LOWER?) BATHONIAN**

Middle Dhruma Formation (170 m.). Limestones with some subordinate shales, containing four successive ammonite zones:—

4. *Dhrumaites*
2. *Tulites* spp.
1. *Thambites* spp. and *Clydoniceras* sp.

Zones 2 and 3 are Middle Bathonian. Many pelecypods occur throughout, including *Eligmus rollandi* which, with *Eudesia cardium*, is found already in zone 1.
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UPPER BAJOCIAN

Lower Dhruma Formation (upper part, 60 m.). The Dhibi Limestone at the top (38 m.) passes northward into shales with rich fossil-bands. In this occurs the *Ermoceras* and *Thamboceras* fauna of Sinai, together with a few poorly-preserved ammonites that can only be likened to NW. European *Teloceras*, *Stephanoceras* and *Normannites* of late-Middle Bajocian affinities. Also *Eligmus rollandi*, *E. polytypus*, *Eudesia cardium* and many other fossils, including echinoids and horn corals.

MIDDLE BAJOCIAN

Lower Dhruma Formation (lower part, 67 m.). Limestones and shales, in the lower part of which are fairly abundant *Dorsetensia*.

TOARCIAN

Marrat Formation (111 m.). Dolomite, limestone and subordinate sandstone. The lower 34 m. yields *Bouleiceras* spp., *Protogrammoceras madagascariense* (Thevenin), *Spiriferina* spp., *Pecten ambongoensis* (Thevenin), *Stomechinus* sp. and horn corals, and is Lower Toarcian in date, correlating with Madagascar, Kenya, Baluchistan and Portugal (p. 241). The middle 56 m. is without ammonites. The upper 21 m. yields a probably Middle Toarcian assemblage comprising *Nejdia bramkampi*, *N. furnishi* and *Hildaites sanderi* Arkell.

UNDATED

Minjur Sandstone (315 m.). No marine fossils. Some layers with moulds of fossil wood, others with abundant quartz pebbles. Cross-bedding frequent.

MIDDLE TRIAS

Jilh Formation (326 m.). Sandstones, limestones and shales. In the upper part of the Upper Jilh (the highest 67 m.) occur occasional poor casts of marine fossils including Middle Triassic ammonites (*Protrachyceras*), *Myophoria*, etc.

SOUTHERN ARABIA: YEMEN, ADEN HINTERLAND, MAKALLA, DHOFAR

Towards the southern end of Jebel Tuwaiq the Middle Jurassic and Callovian limestones wedge out. The escarpment proportionately dwindles until eventually the cuesta disappears in the low desert sands. According to Lamare's map (1936, pl. ii) a tongue of the pre-Cambrian Arabo-Nubian massif runs SE. almost to the coast east of Aden. Beyond it, however, Upper Jurassic limestones come in again in the Yemen, resting on undated sandstones and overlain by Nubian Sandstone and the Aden lavas. (Fig. 45, p. 305.)
Yemen

The succession in the Yemen plateau is as follows (Lamare, 1930, p. 52; Basse, 1930):

Lavas, 240 m.
Nubian Sandstone, 200 m., with a thin sandy, unfossiliferous limestone band near base; at bottom is a thin band of sandy marl.
Amran Series, 310 m. Limestones with subordinate marls, from the highest 220 m. of which (from beds 6, 8, 10) Mme Basse (1930, pp. 135-45) has described *Balanocidaris glandifera, Rhynchochondra moravica* Uhlig, *Terebratula* cf. *subsellata* Leymerie, *Arcothelius subpectinatus* (d'Orb.) and a number of other pelecypods and gastropods: an unquestionably Lower Kimeridgian assemblage.

Kholan Series, 230 m. Sandstones and sandy shales, pebble beds, pebbles of the basement complex in pockets and disseminated; found only in northern Yemen. The only fossils are vegetable imprints in the upper part. Lamare (p. 52) inclined to regard the plants as Middle Jurassic, but the nearest comparison in the Jebel Tuwaiq is with the Minjur Sandstone, which is at latest pre-Toarcian, and Carpentier & Farag (1948), who found identical plants in Egypt (see p. 287), consider the flora Rhaetic-Infra-Liassic. Basement complex below.

The principal fossil locality, near Amran, lies about 30 miles NW. of Sanaa, capital of the Yemen. About 130 miles east of Amran, at a ridge called 'Alam Aswad, Philby collected a similar assemblage of mollusca (including *Arcothelius subpectinatus*), assigned to the Lower Kimeridgian by Cox (1938). The rock is a limestone, containing numerous branching Hydrozoa and a few corals, and is exposed to a thickness of about 125 m.

Aden Hinterland and Shugra

Limestone outcrops 50 miles and 100 miles north of Aden have yielded fragmentary Perisphinctids which were figured by Newton & Crick (1908) and Tipper (1910) and were correctly dated by Crick to Lower and Middle Kimeridgian. From the the hinterland of Shugra, on the coast about 60 miles ENE. of Aden, in a brown shelly limestone, Wyman Bury brought badly preserved internal whorls which E. Dacque identified as *Parkinsonia* or perhaps *Perisphinctes* of the group of *P. funatus*, and shells of *Posidonia* closely allied to *P. alpina* and thought were of Callovian age (in Stefanini, 1925, p. 194). Stefanini, however, pointed out that *Posidonia* occurred inside a specimen of an undoubtedly Kimeridgian Perisphinctid from near Makalla (figured by Stefanini, 1925, pl. xxvii, fig. 1); and a record of *Parkinsonia* could be accounted for by an *Idoceras* like *I. farquharsoni* Spath (1935, p. 213, pl. xxiv, fig. 1), since figured from Somaliland. *Posidonia somaliensis* Cox (1935, p. 166) has since been described as abundant in the Middle Kimeridgian Daghani Shales near Berbera, just across the Gulf of Aden.

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Makalla

Near Makalla, on the coast about 300 miles ENE. of Aden, Little (1925) described and mapped about 150 m. of Upper Jurassic limestones and shales, and an oil-shale with *Posidonia*, *Aptychus latus* and other fossils, including fragmentary *Perisphinctids*. Little found that these beds rest upon an eroded surface of the crystalline basement complex and are overlain unconformably by a band of Lower Cretaceous limestone, on which follows up to 500 m. of Nubian Sandstone. Three fragments of *Perisphinctids* from the oil-shale and just above at Neifa, Makalla, collected by Little, were figured by Stefanini (1925, pl. xxvii, figs. 1-3); one was compared to a Spiti Shales species, the other two to Portuguese 'Lusitanian' species. All three fragments are too small for reliable specific identification, but there can be no doubt of their representing a late-Lower Kimeridgian fauna of the Pseudomutabilis Zone. Fig. 3 matches closely a *Lithacoceras* figured by Schneid (1914, pl. i, fig. 2) from the Pseudomutabilis Zone of Franconia as *Perisphinctes* aff. *stenocyclus* Fontannes; fig. 1 seems to be a *Torquatisphinctes* of the group of the East African *T. beyrichi* Futterer (1894, pl. ii); fig. 2 is presumably part of a *Katroliceras*. Fig. 1 was said to be crowded with small valves of *Posidonia* sp. (presumably *P. somaliensis* Cox, 1935, p. 166, abundant in the Kimeridgian of Daghani, British Somaliland).

Dhofar, etc.

Still farther along the coast, near Dhofar, Nubian Sandstone has overstepped the Jurassicics and rests directly upon the crystalline complex (Lees, 1928), and the same arrangement holds in the islands of Abd el Kuri and Socotra (Kossmat, 1907). These occurrences indicate a second landmass or large island in the Jurassic, named the Arabo-Somali massif by Picard (1939). It was separated from the Arabo-Nubian massif by the Jurassic tract just described, which runs north-south from central Arabia into Somaliland and Ethiopia and has been aptly named the Trans-Erythraean trough by Lamare (1936, p. 51). The trough first came into existence with the Toarcian or Bathonian transgression, and on both sides of it, in the Yemen and at Makalla, there is evidence of its being widened by transgression in the Lower Kimeridgian (Arkell, 1952, p. 301). (Fig. 44.)

The Arabo-Somali island was shown on a palaeogeographic map by Stefanini (1928, p. 17) as extending all over eastern Arabia including Oman, where Lees in 1928 showed thick marine Jurassic to exist, and as embracing the whole Persian Gulf and the Fars area of Persia, which are now also known to have been submerged in the Jurassic. Stefanini’s name of ‘Farsia’ therefore is too misleading to be adopted for the Arabo-Somali island.

The Jurassic rocks of Oman are described with those of the Persian mountains in Chapter 13.
CHAPTER 12

EAST AFRICA

ETHIOPIA (ABYSSINIA), ERITREA AND SOMALILAND

Our knowledge of this vast area is still patchy, but the extensive British, Italian, German and French literature enables a general picture to be obtained and fills in the detail at a number of scattered points. Jurassic rocks 300-900 m. thick appear at intervals along the coastlands of the southern end of the Red Sea and the Gulf of Aden almost from Massawa in Eritrea to Cape Guardafui. Inland they extend under the lavas of the high plateau of Abyssinia (Tigrai and Shoa) and crop out in a broad belt stretching from north to south down the centre of the country, from the Harrar province to the Juba River, there to narrow and disappear just before reaching the coast. (Fig. 45.)

This general north-south arrangement is original, reflecting the Trans-Erythraean trough of Jurassic times. As its appropriate name implies, the Jurassic trough bears no directional relation to the great mid-Tertiary rift faults of the Red Sea, the Gulf of Aden and East Africa. The faults and rift valleys cut across the earlier seaway as if it had not existed, and it is they and the Tertiary or late Cretaceous lavas that determine the present major features of the topography. As shown by Gregory (1921), the fault bounding the west side of the Red Sea branches near Massawa, the main fork turning south along Annesley Bay and bounding the high plateau of Abyssinia, the other, subsidiary, fork forming the Danakil horst and continuing along the coast. Similarly the fault bounding the south coast of the Gulf of Aden runs obliquely inland in a WSW. direction south of Berbera, forming the northern boundary of the plateau of Harrar. About 100 miles east of Addis Ababa the two great faults approach within 40 miles of one another, then turn off SW. to Lake Rudolf, the two fault scarps standing face to face across the intervening rift valley. The funnel-shaped lowland between the sea and the mouth of the rift valley, forming an equilateral triangle with sides about 500 miles long, is a sunk-land. The western part is largely plain, the Afar of Suess. Most of the floor of the sunk-land, like that of the rift valley, is covered by lavas, but the underlying Mesozoic sediments are seen here and there in domes, anticlines and subsidiary fault-blocks. In the plateaux on either side they are cut into by erosion and appear along the river valleys.

For convenience in treating the Jurassic rocks, the high plateau of Abyssinia north and west of the rift faults (Tigrai and Shoa) will be described first; then the Danakil horst in Eritrea and the minor structures in French and British Somaliland, along a course crossing the Trans-Erythraean trough from NW. to SE. parallel to the present coast; then the

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main central outcrops on the south and east of the rift faults, from the Harrar plateau southwards through Jubaland to the Indian Ocean.

The North Abyssinian Plateau (Tigrai and Shoa)

The foundations of our knowledge of the geology of this region were laid by W. T. Blanford (1870), of the Geological Survey of India, who was deputed by the Government of India to accompany as naturalist the British Army on its march from Annesley Bay in Eritrea to Magdala and back in 1868. His clear and fascinating account is well worth reading still. The expedition marched due south along the western edge of the plateau by way of Adigrat and Antalo to Magdala.

Resting upon the metamorphic basement complex is up to 300 m. or more of unfossiliferous sandstone, which Blanford named the Adigrat Sandstone. ‘It is usually white or brown in colour, the former much predominating. Occasionally it is pale brown and lilac, or, as about Takonda, brick red; these colours being chiefly restricted, however, to bands interstratified with the mass of the rock. It is usually very quartzose, frequently felspathic, less commonly argillaceous. Shales of a blue or lilac colour are frequently met with towards the base of the group, but the principal characteristic of the great bulk of the sandstone is its massive character and the absence of marked bedding, so that the high cliffs of it which form the head of the Haddas and Komayli ravines, and which surround the valleys south of Senafe, appear as if cut out of a huge unstratified block’. (Blanford, 1870, pp. 170-1).

Above the sandstone, with a conformable junction, follows the Antalo Limestone. ‘It is usually in thin beds of grey colour, less commonly ochreous, and it much resembles some of the beds of Lias limestone in the south-west of England. The rock when broken is compact and earthy, or but slightly crystalline.’ (Blanford, p. 176.) Generally the traps of the plateau summit overspread the Antalo Limestone directly, but at intervals a higher sandstone is intercalated, representing outliers that existed before the lavas were erupted. This sandstone is also unfossiliferous, but it now seems likely that it is Lower Cretaceous and approximately to be equated with the Nubian Sandstone.

Blanford recorded a list of mollusca and two echinoids from the Antalo Limestone, but unfortunately no ammonites were found. His records, and some figures, suggest at least two horizons: Bathonian (Trigonia pullus Sow., Modiolus imbricatus Sow.), and Upper Jurassic, probably Lower Kimeridgian.

Further progress has been made to the south, in Shoa (Choia), north and NW. of Addis Abbaba. Here tributaries run down to the Blue Nile (Abai) in tremendous gorges, the sides of which lay bare all the strata of the plateau. The Jurassics reach a height of 8500 ft. above sea-level. The succession worked out by Aubry (1886), H. Douvillé (1886) and Futterer (1897) is as follows (the classification in stages being as usual the
present author's). For general accounts see also Krenkel (1926) and Stefanini (1933).

[Abyssinian lavas, forming top of plateau; up to 500 m. LOWER CRETACEOUS? 200 m. Sandstones, conglomerates, marls, variegated clays, and gypsum, unfossiliferous. (= Nubian Sandstone?)

FIG. 45.—Sketch-map showing the distribution of Jurassic limestones (black) in NE. Africa. Inliers of the Lugh Series marked LS. Based mainly on Stefanini, 1933. (For revision of the north-west edge of the Abyssinian lava plateau on the Sudan border, see Andrew, 1948.)

LOWER KIMERIDGIAN, 100-170 m. Upper Antalo or Lagagima Limestone. Limestone, marls and marly limestones with molluscan fauna like that of the Swiss Jura. Terebratula subsella, Acrocidaris nobilis Ag., etc.

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BATHONIAN AND CALLOVIAN, 400 m.


UNDATED

*Abai Beds*, 200 m. Crystalline yellow limestone with layers of granular gypsum and dolomitic limestone, and casts of small indeterminable lamellibranchs referred to by H. Douvillé (1886, p. 239) as ‘Corbules’, by Furon (1950, p. 293) as ‘Cyrènes’.

*Adigrat Sandstone*, 500 m. White and blue sandstones, often micaceous, with layers of green and vari-coloured clay.

While the absence of Oxfordian may be due to collection-failure, it is nevertheless remarkable that the apparent superposition of Lower Kimeridgian on Callovian repeats the arrangement in the northern Lebanon range in Syria, attributed above to wedging out of the intervening formations against the margin of the trough of deposition. The two stages, Bathonian and Kimeridgian, moreover, are those already noted as transgressive in Egypt, Syria and southern Arabia. Which extended farthest to the west or north-west in Abyssinia remains to be determined. The answer awaits discovery along the Blue Nile and its tributaries. The mapping of these valleys and of the western edge of the volcanic plateau is still in a rudimentary state. The latest synthesis is that of part of the country falling within the Sudan map compiled by Andrew (1948). Future research will no doubt prove whether the sandstone shown on this and preceding maps as cropping out between the Tertiary lavas and the pre-Cambrian is wholly a continuation of the Adigrat Sandstone as indicated on Stefanini’s splendid map (1933) or in part Cretaceous and the continuation of the true Nubian Sandstone. If the latter, then the Jurassic's have wedged out between the sandstones under the plateau. The most westerly exposures of Antalo Limestone at present known are in the Abai valley 37° 57' E., and a limestone (in both places associated with chert) has been found south of Suakin in Khor Langeb 36° 35' E., 17° 16' N. (Andrew, 1948, p. 98.)

ERITREA (DANCALIA)

South of Annesley Bay, south of Massawa, the Red Sea rift valley forks, one branch continuing to the Straits of Bab el Mandeb and Aden, the other following the foot of the Abyssinian plateau edge southwards, to become later the Great African Rift Valley. Between the two forks in Eritrea alongside the coast lies Dancalia, or the Danakil Horst of Gregory (Alpi Dancale of the Italians), consisting of pre-Cambrian basement

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complex overlain by Adigrat Sandstone (missing in places) and Antalo Limestone, which in turn are largely covered by Tertiary lavas. The outcrops have been worked in considerable detail, but the result suffers from scarcity of ammonites and of overall measurements. (Vinassa de Regny, 1924, 1931; Díaz-Romero, 1931.)

As in Shoa and at the eastern extremity of British Somaliland (see p. 312), the lowest post-Archaean strata consist of unfossiliferous sandstone followed by thick beds of unfossiliferous dark limestone. The earliest fossiliferous limestone is again Bathonian, yielding among other fossils Burmirhynchia and Gryphaea costellata. The next recognizable horizon is one with Somalirhynchia africana, which in British Somaliland is Upper and perhaps also Lower Oxfordian (Muir-Wood, 1935, facing p. 81; and see p. 309), and in Syria is high Upper Oxfordian (bed 5b, p. 295). The only identifiable ammonite recorded, from the topmost division of the limestone, is referred to Idoceras rufanum Dacqué (1914, p. 4; figd. 1905, p. 147, pl. xiv, fig. 15), a species from the Lower Kimeridgian of Harro Rufa in the Harrar Province. A second doubtful ammonite from the same level is compared to Anavirgatites subambiguus Spath, which would correlate with the Gawan Limestone of British Somaliland (see p. 308).

**FRENCH SOMALILAND**

The only Jurassic outcrop in French Somaliland is in the centre of a dome at Ali Sabieh, 45 miles SW. of Jibouti, where the upper part only of the limestones rises through the surrounding lavas. The lowest formation exposed is 15 m. of thin-bedded limestones with crushed ammonites; next come 200 m. or more of hard, compact, poorly-fossiliferous limestones; then a varied shelly series (thickness not stated) with many pelecypods and gastropods. The limestones finally pass up gradually and with perfect conformity into sandstones, at least 300 m. thick and unfossiliferous. (Dreyfuss, 1931.)

Owing to poor preservation, the three figured fragments of Perisphinctids from the bottom of the series are inadequate for dating, and judgment must be reserved. Plate xiii, figs. 1 and 2 of Dreyfuss' memoir are indeterminable and could be many other forms besides those to which he assigns them, while fig. 3 is certainly not Katrolceras pottingeri (Sowerby), though it may be of much the same date. A more suitable identification for both figs. 2 and 3 might be Aulacosphinctoides cf. kachhensis Spath (1931, Cutch, p. 528, pl. lxxxiii, fig. 2), a species of the Middle and Upper Katrol Beds (Middle or Upper Kimeridgian) of Cutch. This would make the base of the Ali Sabieh section equivalent to some part of the Daghani Shales of British Somaliland (see p. 308).

From the gradual upward passage of the top of the limestone, the very highest layers containing Exogyra bruntrutana, into sandstones, Dreyfuss insists that at least the lower part of the sandstones must be Jurassic (he suggests Portlandian); but the Jurassic Purbeck Beds pass up by

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imperceptible gradations into the Cretaceous Wealden Beds in the English type areas, and this does not make the Wealden Beds necessarily Jurassic. The age of the sandstones is unknown and will remain so until fossils are found.

**BRITISH SOMALILAND**

Jurassic outcrops in British Somaliland are restricted to small faulted tracts separated by long distances. The largest is near the western boundary with French Somaliland, the Meragalleh area, south of Jibouti. Here there occur up to about 800 m. of Jurassic limestones, sandwiched between gritty and pebbly Adigrat Sandstone below and Nubian Sandstone above. By far the most important tract, however, is the narrow faulted outcrop, 18 miles long, at Bihendula and Daghani, about 12 miles south of the capital and port of Berbera on the Gulf of Aden. Owing to relatively easy access, this outcrop has been investigated by a long series of geologists at intervals over a century. Jurassic fossils were first brought back from here by Burton in 1855 and recognized as Jurassic by Carter in 1857. J. W. Gregory first wrote on the subject in 1897, and through his energy and enthusiasm a symposium on the Jurassic palaeontology by himself and other specialists was published in 1925 as the first volume of the Monographs of the Hunterian Museum of the University of Glasgow, based on collections made by Wyllie & Smellie of the Anglo-Persian Oil Company. One of the specialists, Dr J. Weir, published an important revision in 1929 in a later volume (3) of the same series. Finally, in 1933 came a much more detailed examination in the official descriptive memoir by Macfadyen, followed by a second symposium by specialists on the palaeontology (Macfadyen, Spath, Cox & others, 1935), as Part 2 of the official memoir.

The Jurassic limestones of the Bihendula-Daghani ridge reach the great thickness of 1006 m. and range from Bathonian at the base to Tithonian at the top. Hence Gregory’s twofold division into Bihen and Meragalleh Limestones has had to be abandoned in favour of a more detailed sequence of formations proposed by Macfadyen, who retains a restricted Bihen Limestone at the base.

The following summary is based on Macfadyen (1933, pp. 27-9, 80-1) and Spath (1933) and relates to the Daghani section. For complete bibliography see Macfadyen, pp. 39-41. Some important fossils other than ammonites have been added from Macfadyen & others, 1935.

**[CRETACEOUS]**

**Nubian Sandstone, 600-1700 m.** Usual characters, with fossil wood and at one locality a lenticle of lignite. Passing into Cretaceous limestones in the more easterly outcrops (see p. 313).]

**TITHONIAN**

**Gawan Limestone, 244 m.** Fine-grained grey to brown limestone, in parts cherty, the highest 15 m. sandy, and locally a little conglomerate

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at the top. Between 88 m. and 100 m. from base: *Anavirgatites* aff. *ambiguus* (Schneid), *A. cf. subambiguus* Spath, 'Pseudovirgatites' cf. *silvescens* (Schneid), *Sublithacoceras* cf. *senex* (Oppel), *Simoceras* sp. nov.? [Presumably from this limestone came the *Anavirgatites* sp. nov. figured by Stefanini, 1925, pl. xxviii, fig. 2, and *Pseudinvoluticeras somalicum* Spath, 1925, p. 141, pl. xv, fig. 7.]

**MIDDLE AND LOWER KIMERICIDIAN**


*Wanderer Limestone*, 103 m. Grey thinly-bedded lithographic limestone. The Lower Kimeridgean age of this formation is proved by the occurrence of *Glochiceras nimbatum* (Oppel) and *Sutneria* sp. There also occur a number of *Perisphinctids* which Dr Spath determined before recent nomenclatural and systematic revision of this difficult group. From his names it appears to be an assemblage of Lower Kimeridgian *Discosphinctes*, *Virgataxioceras* and other early Ataxioceratids, though some of the names (perhaps requiring revision) suggest the Bimammatum Zone. *Zeilleria latifrons* (Krumbeck), a brachiopod of the Syrian Glandenkalk (Kimeridgian) also occurs.

**UPPER OXFORDIAN ?**

*Gahodleh Shales*, 113 m. Olive to grey gypseous shales with *Belemnopsis* *tanganensis* (Futterer) and *B. aff. orientalis* (Waagen), no ammonites. *Somalirhynchia africana* Weir.

**LOWER OXFORDIAN ? CALLOVIAN (pars)?**

*Bihen Limestone* (upper part), 30 m. (or more). Dark grey massive coral limestone. No cephalopods. *Somalirhynchia africana* Weir, *Terebratula* cf. *subella* Leymerie. A specimen of *Pachyceras indicum* Spath, not in situ, possibly from this formation. The corals are all Upper Jurassic kinds.

**BATHONIAN**

*Bihen Limestone, lower part*, 50 m. (or less). Thin-bedded grey and brown rather shaly echinoid limestones, with thin bands of coral limestone composed of similar corals, down to 17 m. from the base. *Paracenoceras*
### Table 16.—East Africa:

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## Correlation Table

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prohexagonum Spath not in situ but probably from here and comparable with a Bathonian (Stonesfield Slate) species. *Eligmus rollandi* Douvillé and *E. weiri* Cox abundant, *Gryphaea costellata* Douvillé abundant, also the brachiopod genera *Burmirhynchia*, *Cererithyris*, *Charltonithyris*, etc. (Muir-Wood, 1935, facing p. 79.)

**UNDATED**

*Adigrat Sandstone*, 152 m. at Bihendula. Yellow and grey gritty current-bedded sandstones. No fossils.

The brachiopods of the Lower Bihen Limestone are said to be of Callovian appearance. Unless the *Eligmus rollandi-Gryphaea costellata* fauna passes up from the Upper Bathonian to the Callovian southwards, however, the age of these beds is Upper Bathonian by analogy with Sinai, Palestine, Syria and Arabia. The evidence from Jebel Tuwaiq strongly suggests that they are not Callovian. There is no reliable evidence for the presence of anything earlier than Upper Bathonian.

It is possible that the boundary between the Bathonian and Middle Callovian or Oxfordian does not coincide with the line of division between Lower and Upper Bihen Limestone drawn by Macfadyen, but falls lower than 50 m. above the base.

Correlation of the ammonite fauna of the Gawan Limestone with the standard Jurassic sequence still remains an open problem. The *Anavirgatites* and *Sublithacoceras* spp. identified by Spath with species of the Neuburg beds figured by Schneid were first referred by Spath (1925) to the Upper Kimeridgian. Later, however, (1935, p. 208) he regarded this fauna as post-Portlandian. The evidence for this is questionable, and since in the Daghani section the *Anavirgatites* and *Sublithacoceras* are only 80-100 m. above the Middle Kimeridgian and 144 metres below the top of the Jurassic limestones, there is more room for Portlandian and later faunas above than below them. Moreover, *Sublithacoceras* bears an extremely close resemblance to *Pectinatites*. We do not, however, commit ourselves either way by classing the Gawan Limestone as Tithonian, using that term in the historically correct sense, to mean the southern European equivalents of Upper Kimeridgian, Portlandian and Purbeckian, or any additional stages there may be between or above those and below the Cretaceous. (See Arkell, 1946, p. 21.)

Various other isolated outcrops occur farther east (Macfadyen, 1933, pp. 30-31) but have not been studied in detail, though they contributed material used in the palaeontological symposium of 1935. The most easterly is at the extremity of British Somaliland, near the boundary with Italian Somaliland, in the precipitous scarp of the Al Hills, south of Alayu and Bunda Ziada (Barrington Brown, 1931, p. 263 and pl. xxiii). Resting on the crystalline complex at the base are 90 m. of sandstones and grits with a shale band, followed by 180 m. of unfossiliferous limestone stringed with quartz grains and including two thick bands of sandstone; these

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together presumably represent the Adigrat Sandstone and Abai Beds of Shoa (p. 306). At Haurartiro a little to the west (longitude 48° 43' E.) geologists of the Shell Company collected *Bouleiceras arabicum* Arkell and fragments of other species from near the base of the Jurassic; these were sent me in 1953 through the kindness of Dr P. E. Kent and the late Mr E. J. White.

The base of the Bihen Limestone in the Al Hills is marked by the *Eligmus rollandi*-Gryphaea costellata fauna, including these and many other pelecypods and brachiopods, in a 7 m. band of grey limestone. The total thickness of Jurassic limestones from the base of the *Eligmus* bed upwards is 290 m.—not much more than a quarter of the thickness at Bihendula. At the top, with perfect conformity, follows a thin grey marl with Barremian ammonites. The Nubian Sandstone of more westerly outcrops has here passed into limestones, and from the basal marl band have been identified the Barremian ammonites *Holcodiscus cf. gastaldianus* (d'Orb.), *H. cf. caillaudianus* (d'Orb.), *Pseudothurmannia? sp., Procheloni­ceras* sp. (Spath, 1935, p. 214). In view of this some of the underlying limestones classed as Jurassic may belong to the earlier stages of the Neocomian.

Farther east along the south coast of the Gulf of Aden, Stefanini's map (1933) shows five more inliers of Jurassic limestone and Adigrat Sandstone extending almost to Cape Guardafui. One of the last, at Ras Hantara, shows 300 m. of Jurassic limestones, with *Somalirhynchia africana* near the base, resting on sandstones and they in turn on granite (Stefanini, 1932, p. 48). On the islands of Abd el Kuri and Socotra, on the other hand, the Cretaceous rests directly on the crystalline basement complex (Kossmat, 1907), as at Dhofar on the opposite coast of Arabia (Lees, 1928, pl. li). The thinning of the Jurassic from Bihendula to the Al Hills, the overlap of the Lower Kimeridgian on to the pre-Cambrian near Makalla, and this final overlap by the Cretaceous, indicates that we have crossed the eastern margin of the Trans-Erythraean trough on to a separate massif (Arabo-Somali massif of Picard). Similar overlap of Nubian Sandstones on to pre-Cambrian takes place southward throughout British Somaliland, where no Jurassic has been found between these formations on the southern plateau east of longitude 43° E. (Macfadyen, 1933, p. 29).

**The South Abyssinian Plateau (Harrar)**

About latitude 43° E., in western British Somaliland, the buried coast of the massif turns south and then SE., and a broad sheet of Jurassic limestones spreads over the plateau south of the funnel of the Rift valley, across central Ethiopia to the valley of the Juba River. In the central region, around and south of Harrar, outcrops cover an extensive area in the basin of the upper Webi (or Ouabi) Shebeli River, of which numerous tributaries have cleared away the Cretaceous rocks and the overspreading lavas. Travellers of several nations have brought collections from different
parts of this area. In it are the localities, become well-known to Jurassic palaeontologists, of Harrar, Direadau, Harro Rua, Atshabo (Asciabo), Cabenaua, Abu el-Kassim, Tug Terfa, and Tug Fidaedi or Tagfidaedi.

There is no single measured type section comparable with Bihendula for British Somaliland, though from measurements by Vageler at Abu el-Kassim, Reck & Dietrich (1923) estimated there are at least 300 m. of Upper Jurassic limestones followed by Neocomian and Aptian, while a measured section of the lower beds, about 150 m. thick (overlapping considerably with the other section) at a locality about 20 miles ENE. of Harrar, is figured by Lamare (1930, pp. 58-9).

For the most part, however, the succession is known from a number of isolated collections from different localities. Notwithstanding this disadvantage, the ammonite faunas are so strikingly similar to European Upper Jurassic assemblages that there is no difficulty in placing them in stratigraphical order.

As in other regions, earlier authors claimed to recognize Bajocian and Liassic fossils from some of the localities, but these claims have proved to be unfounded, as was pointed out by Dacqué (in Dacqué & Krenkel, 1909, p. 160). The main marine transgression, as in the rest of Ethiopia and Somaliland, was Bathonian, as recognized by Cottreau (1924). There is also a well-developed uppermost Oxfordian ammonite assemblage directly comparable with that of the Bimammatum Zone of western Europe. This was clear from Perispinctids (*Perispinctes* sensu stricto, *Discosphinctes*, etc.) figured from Atshabo and Harrar by Dacqué (1905, 1914), and was recognized by him. More recently confirmation has come in the shape of *Ringsteadiae* from Dogou in Harrar Province, figured by Scott (1943). Hitherto this genus was known only from England, France and Germany; it gives an exceptionally precise correlation with the topmost zone of the Oxfordian of NW. Europe.

The following is a composite succession, built up from the faunas figured in a scattered literature. Further Upper Oxfordian and Kimeridgian ammonites, chiefly from Ogaden, have been figured by Valduga (1954) in a paper which reached me too late for consideration here. See also Venzo (1942).

**Cretaceous**

Lower Cretaceous is present in both marine and Nubian facies.

**Tithonian**

*Tug Terfa*: thirteen ammonites collected here (the Terfa is a tributary of the Webi, south of Cabanaua) by Donaldson Smith and identified by Crick (1897) are revised by Spath (1925, p. 158) as six species of *Virgatosphinctes* and two species of *Aulacosphinctes* and compared to forms figured by Uhlig & Oppel from the Spiti Shales. Spath considered that they constitute one fauna and may be tentatively referred to the Transitorius Zone; i.e. the highest zone of the Tithonian, to which belongs the
Stramberg Limestone (= Ardesian Stage of Toucas), but later (1933, p. 818) he seemed to suggest an Upper Katrol (Upper Kimeridgian) date. The Middle Spiti Shales afford the only close comparison.

**MIDDLE KIMERIDGIAN**

*Tagfidaedi*: from this locality, a village on the River Dakhatto, about 112 miles SSE. of Harrar, Mme Basse (1930, p. 113, pl. iv, fig. 15) has figured two well-preserved specimens of a *Subplanites* strongly reminiscent of some high in the Middle Kimeridgian of Kimeridge. The larger specimen shows a type of ribbing found, in a less exaggerated form, in *Virgatosphinctoides* grandis and *nodiferus* Neaverson (1925, pl. iv) from England, and again in *P. abbachensis* Schneid (1914, pl. iii, fig. 4) from the Lithographica Zone near Kelheim. *Hybonoticeras* and *Subplanites* have also been recorded from the district by Gortani (1951).

**LOWER KIMERIDGIAN**

*Cabenaua* (south of Harrar): from here Mme Basse (1930, pp. 123-4) has *Aptychus latus* and *Idoceras aff. balderum* (Oppel) (Basse, pl. v, fig. 12).

*Dogo and Ganame* (SSW. and SW. of Harrar): among the fine Barnum Brown collection monographed by Scott (1943; and see Brown, 1943) from these localities are *Idoceras rufanum* Dacqué, *Torquatisphinctes beyrichi* (Futterer), two species of *Aspidoceras* s.s. (one a Cutch species of the Middle Katrol Beds), four species of *Physodoceras*, three of *Simaspido­ceras* (including the peculiar *Aspidoceras argobbae* Dacqué) and two of *Glabrophysodoceras*. These are stated to be 'closely associated' with Upper Oxfordian forms, and in similar matrix, whence Scott makes the suggestion that in this district they 'extend downward from the Kimeridgian into the topmost Oxfordian.' Rather than accept a hypothesis of this kind, however, after so many such have been proved wrong in the past, pending further stratigraphical collecting it is preferable to assume the genera to be coeval with their European relatives of the Acanthicus Beds and Lower Kimeridgian.


*Harro Rufa* (between Atshabo and Harrar): *Idoceras rufanum* Dacqué.

*Diredaua*: *Aspidoceras evolutum* Scott, *Glabrophysodoceras abyssinianum* Scott.

**UPPER OXFORDIAN** (Bimammatum Zone)

*Atshabo* (SW. of Harrar): from this locality Dacqué (1905, 1914) figured the remarkable series of Perisphinctids which in the 1905 memoir he mistook for Kimeridgian but in the 1914 memoir correctly recognized as Upper Oxfordian, and probably Bimammatum Zone, with strong European affinity. Among them may be recognized typical NW. European Upper Oxfordian subgenera such as *Perisphinctes* sensu stricto (*P. anabreviceps* Dacqué and *P. dacquéi* Spath 1925) non Steiger 1914, Dacqué,
Dichotomosphinctes (P. gallarum Dacqué) and Disco­sphinctes (P. arussiorum Dacqué). Revisionary remarks on these forms will be found in Arkell, 1937-39, Monograph of the Ammonites of the English Corallian Beds, pp. xlvii, liv, lx, lxii, lxiii.

Dogou and Ganame: Three Perisphinctids figured by Scott as Lithaco­ceras are of doubtful age and generic position, though probably Upper Oxfordian, but his Perisphinctes vokesi and P. spathi are unquestionably Upper Oxfordian, as are also Ringsteadia africana Scott and R. dava Scott.

Diredaua (NW. of Harrar): Ringsteadia dava Scott occurs at this locality only, also a ? Dichotomoceras and Dichotomosphinctes (Scott, 1943, pp. 68, 69).

UPPER OXFORDIAN (Transversarium Zone)

Diredaua: Dacqué (1914, p. 12) records but does not figure badly preserved Perisphinctids which he compares to P. rota Waagen and P. subrota Choffat, forms suggesting that he had them from an exposure of the Plicatilus Zone, which is developed in Kenya (with Krana­sphinctes). With them occurs Somalirhynchia.

BATHONIAN

Cottreau (1924) recognized Isastraea cf. limitata McCoy, Rhynchonella morierei Dav., Modiolus plicatus Sow., M. cf. imbricatus Sow. and Cero­myopsis tenera (Sow.) among fossils collected from three localities south and SE. of Harrar, and inferred the presence of the Bathonian as in Shoa. Since then some of the echinoids found in the Lower Bihen Limestone at Bihendula have been recorded from localities in the Harrar Province (Currie in Barnum Brown, 1943).

UNDATED

Adigrat Sandstone with basal conglomerate rests as usual on the crystalline basement. It appears to thicken northwards and towards the base passes into arkose and sandy limestones (Lamare, 1930, pp. 5, 58-9).

JUBALAND

This term is used in its geographical rather than political sense for the whole basin of the Juba River south of about latitude 6° N., and of its principal western tributary, the Daua. The Daua joins the Juba at Dolo, near the present meeting-place of the frontiers of Kenya, Ethiopia and Italian Somaliland. Into and through this huge basin the Jurassic limestones spread southward continuously from the Harrar region, on a front nearly six degrees wide (between longitude 39° and 45°E.), overlapped irregularly both east and west by Cretaceous sediments and on the west in part by Tertiary lavas. Before reaching the coast the Jurassic outcrop narrows to a tongue along the Juba River and finally disappears about 1° north of the equator and the sea, beneath Pleistocene and Holocene
deposits of the coastal plain. These deposits unfortunately deprive us of cliff sections.

Knowledge of this region is largely due to Professor G. Stefanini, who made expeditions and collections, compiled a splendid geological map, monographed many of the fossils himself, and organized a team of specialists for a symposium (Stefanini, 1925, 1929, 1932, 1933, 1939). The Kenya part of the region has been revised by Dixey (1948) and Ayers (1952), and later by P. V. Caswell and P. Joubert, whose unpublished report has been kindly made available to me.

As in the more northerly parts of the trans-Erythraean trough, the Jurassic and supposedly Jurassic deposits are divisible into a poorly fossiliferous sandstone and shale group below, the Lugh Series, and a thick limestone group above, the Bardera Series (including the synonymous Juba and Duaa Limestones). Both localities are on the Juba River. The Bardera Limestone, where complete, exceeds 1000 m. in thickness in NE. Kenya and seems to represent most of the Jurassic, from Lower Toarcian at least to Kimeridgian. In NE. Kenya it passes up into the Mandera Beds (about 300 m. thick), which are possibly in part Lower Toarcian and in part Tithonian. In Italian Somaliland, however, the Cretaceous begins with marine Aptian limestones with *Cheloniceras*. The Mandera Beds are unconformably overlain and overlapped by the Marehan Sandstone Series (c. 200 m.), which is presumed to be Cretaceous.

**Kimeridgian**

The highest fossiliferous Jurassic in the region may be a 1 ft. band of limestone crowded with *Trigonia* and other pelecypods, monographed by Venzo (1949). According to unpublished work by the Geological Survey of Kenya this is in the Upper Mandera Beds and so cannot be Bathonian as Venzo supposed.

From Ted, ENE. of Lugh, and from Mansur, *Idoceras rufanum* Dacqué and *Lithacoceras gananense* Stefanini are recorded (Stefanini, 1933a, pp. 44-5). The supporting faunas of Kimeridgian and Oxfordian ages have been monographed by Weir (1929) and Stefanini (1939). Westwards the upper parts of the limestone overlap the lower and in places completely overlap the Lugh Series. Along the western edge of the outcrop the upper part of the limestone ends in an escarpment about 500 ft. high. The base of the limestone is in some places separated from the basement complex by nothing but a pebble bed, but in other places grits, sandstones and conglomerates intervene (Dixey, 1948).

**Oxfordian**

Although other mollusca, and also brachiopods, echinoids and corals, abound in the Bardera Limestone, ammonites are scarce. From Kukatta on the Juba River, Spath (1930, p. 43, fig. 1) and from Ted, ENE. of Lugh, Stefanini (1933a, p. 40) have recorded the Plicatilis Zone form *Perispinctes (Kranaospinctes) africanus* Dacqué (see Arkell, 1939, Mon. [http://jurassic.ru/](http://jurassic.ru/))
Am. Engl. Corallian Beds, pp. lx, lxii). The presence of this zone was confirmed by a small collection of fragmentary Upper Oxfordian Perisphinctids from the 'Lower Shales' in the Limestone, sent me in 1951 from the Daua valley (Kenya), collected by Dr P. E. Kent for the Anglo-Iranian Oil Company. With them is a fragment of *Dhosaites* sp. indet. From a lower horizon at the same place were sent a fragment of *Pelto­ceratoïdes cf. constantii* (d'Orb.) and a large *Euaspidoceras* sp., the former at least denoting the Cordatum Zone. (Recorded in Ayers, 1952, p. 29.)

In 1954 I received another collection from the 'Lower Shales' of the Rahmu area; it consists of fragmentary but unmistakable Perisphinctids and Mayaitids of the Plicatilis Zone.

**CALLOVIAN**

Lower down the Juba the limestones overlap south-eastward against the granite of Matagoi. Not far from where this happens, at Anole Issa, has been found the only known occurrence of a Lower Callovian ammonite fauna in East Africa and Arabia, between the equator and the 'fertile crescent.' The assemblage comprises *Kamptokephalites* (close to the English *herveyi*) and *Indocephalites?, Hecticoceras issa* Stefanini (of the group of *H. hecticum*), *Sivajiceras, Choffatia, Grossouvria* and *Subgроссouvria* (Stefanini, 1933a). This is the Macrocephalus Zone as developed in Cutch and Madagascar.

**BATHONIAN**?

Near Bardera, on the Juba, the basal bed of the Bardera Limestone is a lumachelle composed of thick-shelled bivalves such as *Megalodon, Isog­nomon* and *Gervillia*, with a coral, *Montlivaltia*. Towards the SE., near Matagoi, this bed overlaps the Lugh Series on to granite. At Muddo Erri are highly fossiliferous limestones with *Eligmus* and many other fossils, comparable with the basal limestone of Bihendula in British Somaliland (Weir, 1929, p. 14).

**LOWER TOARCIAN**

An important new fossiliferous horizon was found by F. M. Ayers and P. E. Kent in 1951 on the far western escarpment of NE. Kenya, where the Jurassic sediments feather out against the basement complex of the African shield. The ammonites and other fossils (sent me for determination in 1952) comprise the *Bouleiceras* assemblage of Madagascar and central Arabia, including *Bouleiceras arabicum* Arkell and *B. nitescens* Thevenin, *B. sp. nov.?, Pecten ambongoensis* Thev., *Spiriferina rostrata* var. *madagascariensis* Thev., with other pelecypods, gastropods and corals. The fossils were collected at Didimtu Hill, 5 miles south, slightly west, from Bur Maya and 80 miles north, slightly east, of Wajir. The bed directly overlies the basal conglomerate, grits and sandstone (known as the Mansa Guda formation), and the metamorphic basement complex crops out not more than 2½ miles to the west. It appears, therefore, that there was a Lower Toarcian transgression over the shield, coinciding
with the advent of the first marine Jurassic fauna in Madagascar, British Somaliland and central Arabia. This horizon is included in the base of the local Bardera (= Daua) Limestone by the Geological Survey of Kenya (Ayers, 1952, p. 9).

**LOWER LIAS AND UNDATED**

The Lugh Series of the type area, on the Daua and Juba Rivers, reaches a thickness of about 130 m. Fossils found so far are inconclusive but point to a Lower Lias or Rhaetic age (Stefanini, 1929, 1932). From rather above the middle there is a fish tooth identified as *Eugnathus* sp., a genus occurring in the Lower Lias of Lyme Regis, and, from near the base, teeth of *Colobodus* cf. *maximus* (Quenst.) and *Hybodus minor* Ag., which are probably Hettangian or Rhaetic. Not far above the base occurs a small pelecypod, about 11 mm. long, comparable with *Mytilus psilonoti* Quenst. of the Hettangian of Württemberg. This shell also occurs in Algeria, where it is supposed to be Hettangian, and in the Isalo Group of Madagascar associated with *Myophoria vulgaris*, which indicates Upper Trias.

**Relation of the Jurassic Rocks to Rift Faulting**

It has sometimes been supposed that in this region block-faulting occurred between deposition of the basal Lugh Series and Bardera Limestone, so that the Bardera Limestone was deposited in rift valleys between upstanding sandstone blocks (Busk, 1939, 1945). It has been confirmed, however (Dixey, 1945, 1948), that the upstanding blocks are outliers of Marehan (Cretaceous) Sandstone resting on Bardera Limestone, so that the relationships are as had previously been understood by Weir and Parkinson. There is no evidence that any of the rift faulting is earlier than in the Red Sea and Gulf of Suez, where it is clearly later than the Lower Eocene. (See also Pulfrey, 1947, p. 284.) The lavas, tuffs and ashes of the Jubaland area are interbedded with the Tertiary sediments or overlie them and the Jurassic limestones indiscriminately.

**KENYA (MOMBASA AREA)**

For about 300 miles south-westwards along the coast from the mouth of the Juba River almost to Mombasa no Jurassic rocks are known. Wide low coastal plains covered with dunes and Pleistocene raised reefs lead back indefinitely to scrub-covered inland plains with thick quartzose superficial covering, which feathers out upon the pre-Cambrian crystalline rocks of the shield.

About fifty miles north of Mombasa there begins a narrow outcrop of Jurassic rocks, chiefly shales with nodules, but including limestones, running parallel to the coast between a fringe of late Tertiary and Pleistocene sands and reefs and a hilly hinterland of Duruma Sandstone. The Duruma Sandstone contains a Permian *Palaoanodontia* in the lower part, Triassic *Estheriae* and plants (*Carpolithecus, Thuyites* and *Equisetites*) in the
middle part, and remains of monkey-puzzle trees (*Dadoxylon*) of indefinite date in the upper part. The Duruma Sandstone is of great but undetermined thickness. The Jurassic appears to rest against it with marked unconformity, but there may be extensive faulting at the junction. (Gregory, 1921, chapter iv; McKinnon Wood, 1930, pp. 219-21.)

The coastal strip of Jurassic rocks, overlain by Cretaceous farther south, but interrupted at intervals by a blanket of Tertiary and Quaternary deposits, stretches southwards through Tanganyika almost to Portuguese East Africa. Whether it continues beyond the border underground is not known, but the Cretaceous coastal strip stretches for 750 miles to Mozambique, where it is cut off by the south-westward turn of the coast.

Despite the present discontinuity of the outcrops there is no doubt that the Upper Jurassic deposits, from the Callovian upward, were formed in direct marine communication with those of Jubaland and the Trans-Erythraean trough. In the neighbourhood of Mombasa reappears the Macrocephalus Zone first met at Anole Issa in southern Jubaland and the same strongly-developed Upper Oxfordian and Lower to Middle

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Kimeridgian already familiar in Abyssinia and Somaliland. In addition there are some ammonites of the Lower Oxfordian and a strong fauna of Middle-Upper Callovian date, but no Jurassic assemblage later than Middle Kimeridgian.

The greatest interest of the Mombasa Jurassics attaches, however, to earlier Bathonian and Bajocian assemblages, here met with for the first time in going southwards. These faunas consist largely of Phylloceratidae and Lytoceratidae, families of the open ocean. We have evidently here passed out of the Trans-Erythraean trough and into a broader sea which extended to Cutch and connected round the east side of the Arabo-Somaliland with the Tethys of Persia and the Caucasus. The Bathonian ammonites, being largely Phylloceratidae, fail to give an exact indication of age relative to the neritic standard succession in NW. Europe, but it is probable that they are older than the Upper Bathonian shallow-water deposits of the Trans-Erythraean trough, Maghara and Palestine. The Eligmus-Gryphaea costellata fauna of pelecypods is not found in Kenya, but this could be due to facies difference. Nor can the Mombasa Bathonian be compared to the ammonite-bearing Bathonian of central Arabia, for Phylloceratidae and Lytoceratidae, so far as known, did not penetrate into the Tuwaqiq bay.

From the Callovian to the Middle Kimeridgian, as elsewhere, there is much less local differentiation of facies, and both the Mombasa coast and the Trans-Erythraean trough were in free communication with both Cutch and Europe.

The following synopsis of the Jurassic column is based mainly on the works of Dacqué (1910, 1914) and Spath (1920, 1930, 1933—Cutch pt. 6). Now that many ammonites have been figured and their chronological significance has been pointed out, a great deal remains to be done by zonal collecting to establish the detailed succession and to relate the individual assemblages more closely to the local stratigraphy. At present the records are to some extent conflicting: for instance, although the Changamwe Shale contains both Kimeridgian and Upper Oxfordian faunas, it is said to overlie Coroa Mombasa and other limestones which in part also contain Kimeridgian forms. These anomalies will no doubt be resolved by local workers in the future. Meanwhile the stratigraphical succession given by McKinnon Wood (1930, p. 221), with revised stage-dating in the light of Spath's 1933 work and the present author's comments which follow, is best placed here separate from the synopsis of the ammonite succession. It is as follows:

<table>
<thead>
<tr>
<th>Formation</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changamwe Shale</td>
<td>Middle and Lower Kimeridgian and Upper Oxfordian</td>
</tr>
<tr>
<td>Coroa Mombasa and other limestones and shales</td>
<td>Upper and Lower Oxfordian</td>
</tr>
<tr>
<td>Rabai Shale</td>
<td>Callovian</td>
</tr>
<tr>
<td>Miritini Shale</td>
<td>? Bathonian (and Upper Bajocian ?)</td>
</tr>
<tr>
<td>Kibiongoni Beds</td>
<td>Middle (and Upper ?) Bajocian</td>
</tr>
<tr>
<td>Kambe Limestone</td>
<td></td>
</tr>
<tr>
<td>Posidonia Shale</td>
<td></td>
</tr>
</tbody>
</table>

http://jurassic.ru/
Posidonia alpina (= ornati) occurs in some localities with Callovian (loc. 18) and even higher ammonites (loc. 25), as well as in the Middle Bajocian.

Large collections have been received while this book was in the press, and only brief mention of some of them can be inserted in proof. For correlation see Table 16, pp. 310-11.

**MIDDLE KIMERIDGIAN (Beckeri Zone)**

From the eastern slopes of Coroa Mombasa, Spath (1930, p. 63, 1933, p. 818) records Phylloceras aff. saxonicum Neumayr, Taramelliceras cf. kachhense (Waagen), Lithacoceras sp., Katroliceras sp., Subdichotomoceras sp., Pachysphinctes major Spath, P. habynsis Spath, Aspidoceras wynn ei (Waagen), Hybonoticeras aff. hybonotum (Oppel) and H. sp. nov. ‘This is clearly a Middle Kimeridgian assemblage, referable to the Beckeri Zone’, and it is the highest Jurassic assemblage yet obtained from Kenya.

To the list should be added Katroliceras pottingeri (Sow.), figured by Futterer (1894, pl. i) and Spath (1931, Cutch, pl. cii, figs. 5 a-d) as identical with the Cutch species, and Hybonoticeras hildebrandti (Beyrich) figured by Futterer (1894, pl. iii).

**LOWER KIMERIDGIAN**

To the Lower Kimeridgian belong many Changamwe Shale ammonites, especially the common Perisphinctes (Torquatisphinctes) beyrichi Futterer (1894, pl. ii) and many Aspidoceratids such as A. iphicerum (Oppel), A. iphiceroides Waagen, A. aff. longispinum (Sow.), A. kilindianum Dacqué and Physodoceras liparum (Oppel), also Holcophylloceras polyolcum (Benecke) and abundant Belemnopsis tanganensis (Futterer). The D’Arcy Exploration Company collected most of these at Mtwapa Creek, north of Mombasa, and with them were Taramelliceras cf. kachhense (Waagen) and Perisphinctes cf. mombassanum Dacqué.

**UPPER OXFORDIAN**

Bimammatum Zone. To this zone probably belong most of the Perisphinctids figured from the Mombasa area by Dacqué (1910) and placed by him in the Upper Oxfordian but subsequently stated by Spath to be Kimeridgian: namely, P. (Discosphinctes) fraasi Dacqué, P. (D.) mombassanum Dacqué at least in part, P. (Dichotomosphinctes) krapfi Dacqué, and P. (D.) inconstans Spath, 1925 (= P. virguloides Dacqué, 1910, pl. iii, fig. 1, non Waagen); also P. (Dichotomoceras) anomalum Spath (1930, p. 45, pl. vi, fig. 1), which is close to P. (D.) dichotomoides Arkell of the English Pseudocordata Zone and doubtless contemporary with the Ringsteadiae figured by Scott from Abyssinia (see p. 316). To this zone belong several Taramelliceras recorded by Spath and a Perisphinctes (Orthosphinctes) aff. tiziani (Oppel) collected by Mr Caswell at Tangila.

Transversarium Zone. An interesting assemblage of this zone, well
preserved in clay-ironstone, has been collected by Mr P. V. Caswell of the Geological Survey of Kenya from surface outcrops of the Coroa Mombasa limestone and shales at Tangila, SW. of Mombasa, and at the brickyard and pier east of Port Reitz Hotel. My determinations of some 60 specimens include

*Perisphinctes (Perisphinctes) anabrevicaps* Dacqué
*Perisphinctes (Perisphinctes) virguloides* Dacqué 1914
*Perisphinctes (Perisphinctes) orientalis* Siemiradzki (common)
*Perisphinctes (Kranasphinctes) africanus* Dacqué
*Perisphinctes (Dichotomosphinctes) cf. dobrogesis* Simionescu
*Perisphinctes (Dichotomosphinctes) spp. indet.
*Prograyiceras bassei* Basse & Perrodon
*Prograyiceras aff. alfuricum* (Boehm)
*Epimayaites cf. sublemoini* Spath
*Epimayaites cf. axonoides* Spath

It is remarkable that the Mayaitids (which are nearly as abundant as the Perisphinctids in individuals) resemble Madagascan, Cutch and Indonesian species but not those figured from Mtaru in Tanganyika by Tornquist (see p. 328). Another collection sent later by the D’Arcy Exploration Co. from a different part of the shore of Port Reitz, however, contains *Mayaites stuhlmanni* (Torn.), *Epimayaites cf. lemoini* Spath and numerous *Dhosaites rabai* (Dacqué), associated with *Perisphinctes maximus* (Y. & B.) and *Belemnopsis tanganensis* (Futterer).

**LOWER OXFORDIAN**

From Tangila Mr Caswell also sent me fragments of a giant *Euaspidoceras cf. acuticostatum* (Young & Bird), in a calcareous sandstone matrix from a shale. This suggests the Cordatum Zone. *Peltoceras aff. arduennense* Dacqué (1910, pl. i, fig. 7) seems to be a *Parawedekindia of* about the same date.

**UPPER COLLOVIAN**

The Mirritini Shale of Mombasa has yielded several species indicative of Upper Callovian: especially some of the *Grossouvriace* and *Binatispinctes* recorded by Spath (1930), which compare best with forms from the Hackness Rock of Yorkshire (condensed Athleta and Lamberti Zones). *Sindeites sindensis* Spath (1933, p. 816) is a Cutch Middle Callovian species, but no Reineckeidae and no *Erymnoceras* are so far known, which suggests that the Middle Callovian is missing or not yet discovered.

**LOWER CALLOVIAN**

Macrocephalitids of the subgenera *Kamptokephalites*, *Dolikephalites* and *Pleurocephalites* are recorded by Spath (1930, p. 65; 1933, p. 816)
and prove the presence of the Macrocephalus Zone: all three are characteristic of the English Upper Cornbrash. With them are *Sivajiceras* of the Lower Callovian of Cutch, and various *Indosphinctes* and *Choffatia* of both Indian and European Lower Callovian species. Nuclei of *Macrocephalites* and *Dolikephalites* also occur in the undoubtedly Bathonian
fauna of locality 19' on the Kenya-Uganda railway (Spath, 1930, p. 66; 1933, p. 815), which proves that the age of the fauna is Lower Callovian, Macrocephalus Zone.

**Bathonian**

It is probable that the Kambe coral limestone is Bathonian and correlates with the coral limestones of Harrar and Matumbi, and with the Tanga Limestone, but palaeontological proof is still lacking.

An assemblage of small limonitic ammonite casts collected from an outcrop of presumed Kambe Limestone by J. W. Gregory (Spath, 1920) consists mainly of Phylloceratids, which indicates a direct Tethyan connexion, not by way of the Trans-Erythraean trough. The list (Spath, 1920; 1930, p. 66) is:

- *Phylloceras aff. kudernatschi* (Hauer)
- *Phylloceras cf. kunthi* Neumayr
- *Calliphylloceras cf. disputabile* (Zittel)
- *Holocophylloceras zignodianum* (d'Orb.)
- *Sowerbyceras aff. tortisulcatum* (d'Orb.)
- *Nannolytoceras cf. tripartitum* (Raspail)
- *Oppelia* sp. indet.
- ? *Oecotraustes* sp. indet.
- *Cadomites cf. tenuicostatum* (Hochstetter)

The age of this assemblage may be Upper Bajocian (see Spath, 1933, p. 815, footnote), but Bathonian is more likely.

**Bajocian**

From *Posidonia* shales, the lowest Jurassic rocks known to be exposed in the Mombasa district, Spath (1933, p. 815) identified an assemblage like that described by Gemmellaro from *Posidonia* shales in Sicily. "The most obvious feature of the fauna is the predominance of *Phylloceras*; out of 343 specimens from three localities no fewer than 240 are Phylloceratids. *Lytoceras (Polystomiceras* and *Nannolytoceras*) comes next, with 76 specimens, and the remaining forms belong to *Oppelia* (7), *Oecotraustes* (2), *Dorsetensia* (1), *Stephanoceras* (15), *Morphoceras*? (1) and *Spiroceras* (1). A fragment of a small *Dorsetensia* was figured (Spath, 1930, p. 32, pl. i, fig. 5). The *Spiroceras* is Upper Bajocian, but the *Dorsetensia* is Middle Bajocian in all parts of the world. Presumably both Middle and Upper Bajocian are represented.

**Tanganyika**

A strip of Jurassic rocks, separated from the sea by narrow bands of Cretaceous and Tertiary, runs almost the whole length of the Tanganyika coast, from Tanga in latitude 5° S. to Lindi in latitude 10° S. It is

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interrupted in at least two places by faulting or overstep by the later systems; especially in the central region where the Tertiary outcrop is exceptionally wide and where the Ruvu and Rufiji Rivers have masked much country with alluvium. The Jurassic outcrops fall naturally into three groups: (1) Tanga in the north; (2) the hinterland of Dar-es-Salaam in the centre, known chiefly along the railway that crosses the outcrops on its way inland to Morogoro; (3) the hinterland of Kilwa, Kiswere, and Lindi in the south. The southern area includes the famous locality, Tendaguru, one of the most celebrated dinosaur sites in the world.

In the north and central districts the Jurassic begins with undated or poorly dated shales and sandstones, of which the oldest fossils found at outcrop are pelecypods and gastropods of the Lower Oolites; and these rest upon thick continental sandstones correlated with the Karroo (Permian in age?). In part at least the latter are a continuation of the Duruma Sandstone of Kenya. They contain coal-seams with many kinds of plants, a marine Upper Permian intercalation in the upper part, and freshwater pelecypods, reptiles and plants elsewhere. The fossils suggest that the highest beds are equivalent to the Stormberg (highest) division of the Karroo and probably Rhaetic in age; they are transgressive over the earlier divisions.

In the southern district the Jurassic rests in places directly on the crystalline basement complex and the Upper Jurassic overlaps the Lower.

_Tanga and the Hinterland of Dar-es-Salaam_

All the Jurassic formations of this area have been grouped together as the Ruvu Beds by Hennig (1924, p. 114). Although the term seems to have been adopted by the Geological Survey (Wade, 1937, p. 48) it is redundant, since it includes stages of very different ages and lithologies, from Bajocian to Oxfordian or even Kimeridgian inclusive. The underlying ‘Ngerengere Beds’, in which Hennig implied there are representatives of every stage of the European Lias, are unfossiliferous and lithologically form part of the Karroo (Wade, 1937, p. 44).

The following is a synopsis of the ammonite faunas (or, failing ammonites, other fossils), with their dates according to the classification here adopted, known from outcrops and borings and from sections along the railway between Dar-es-Salaam and Morogoro (Table 16, pp. 310-11).

? LOWER KIMERIDGIAN

The highest fossiliferous Jurassic rocks so far known occur near Tanga at Usumbara and the Mkulumusi estuary, where they have yielded *Balanocidaris glandifera* and brachiopods (etc.) of the Lower Kimeridgian and possibly uppermost Oxfordian of Syria and the Lebanon (Jaekel, 1893). Koert (1904) confirmed that these beds overlie the Oxfordian
Fig. 48.—Geological sketch-map of Tanganyika, based on the Geological Survey map.
shales with septaria. (Dacqué (1910, pp. 48, 49) appears to have overlooked Koert's confirmation of Jaekel's dating, and tried to make this fauna Callovian—an impossibility.)

**Oxfordian**

Two Oxfordian faunas have been figured from the neighbourhood of Tanga: a series of Mayaitids from Mtaru Hill on the right bank of the Pangani River opposite Chogwe, collected from septarian nodules in a blue-grey marl (Tornquist, 1893); and some of the same Mayaitids with Aspidoceratids and Perisphinctids from lithologically similar beds (pyritic concretions in a clay-shale) near Mkusi, SW. of Tanga (Futterer, 1894, p. 15 ff.).

The Mtaru assemblage consists of four peculiar species of *Mayaites*, *M. olocostephanoides*, *M. panganensis* (a *Pachyceras* ?), *M. stuhlmanni*, *M. horologicum*, all of Tornquist, and some Perisphinctids. The only identifiable Perisphinctid is *P. mtaruensis* Tornquist, which appears to be a *Kranaosphinctes* so far as form, coiling and ribbing show, but the suture has a much smaller, simpler and less retracted suspensive lobe. Tornquist correctly recognized the Mayaitids as Oxfordian and correlated the bed with the Dhosa Oolite of Cutch. Spath (1933, p. 819) accepted the correlation. The date of the Dhosa Oolite is basal Upper Oxfordian (Plicatilis Zone) and highest Lower Oxfordian (Cordatum Zone); but this is not the same as the Upper Oxfordian fauna of Tangila in Kenya (see p. 323).

The Mkusi assemblage is smaller but gives the same date. It comprises *Mayaites aff. stuhlmanni* Tornquist and *M. olocostephanoides* Tornquist, *Kranaosphinctes africanus* (Dacqué) (Futterer, 1894, pl. v, fig. 1), *Euaspidoceras africanum* (Futterer) and *E. depressum* (Futterer). The two species of *Euaspidoceras* can be dated with confidence to the lower part of the Plicatilis Zone (*perarmatum* and *catena* beds of England). The Mtaru Mayaitids are therefore older than those of Kenya.

The same type of *Euaspidoceras* occurs also in the so-called 'Oxford-Bank' near the top of the section by km. 119 on the Dar-es-Salaam railway (Hennig, 1924, p. 93); and what appears to be another *Mayaites* has been figured from behind Saadani (Futterer, 1894, p. 40, pl. vi, fig. 1).

The most extensive fauna of lowest Upper Oxfordian age so far known was collected by Mr W. G. Aitken of the Geological Survey of Tanganyika and sent me for study in 1951. It comes from a band of sandy limestone possibly 2 ft. thick, in a sandstone series which forms two ridges cut through by the Wami River about 3 miles from the 'Fall Line' scarp. The spot from which the collection came is on the south bank of the river east of Kwa Dikwaso (Bagamoyo Hinterland). Among 48 specimens, mainly fragments, are the following 16 species:

*Phylloceras* aff. *subobtusum* (Kudernatsch)

*Calliphylloceras* cf. *disputabile* (Zittel)
**TANGANYIKA**

*Tanganyika*

**Ptychophylloceras ptychoicum** (Quenst.) (= *subptychoicum* Dacqué)

*Sowerbyceras* sp.

*Tarameliceras* cf. *flexuosum* (Munster)

*Mayaites* cf. *subtumidus* (Waagen)

*Euaspidoceras depressum* (Futterer)

*Euaspidoceras* cf. *riazi* (Collot)

*Euaspidoceras* cf. *douvillei* (Collot)

*Mirospinhinctes* aff. *frickensis* (Moesch)

*Perispinhinctes rotoides* Ronchadzé

*Perispinhinctes* cf. *antecedens* Salfeld

*Perispinhinctes* cf. *greslyi* de Loriol

*Perispinhinctes* cf. *pickeringius* (Young & Bird)

*Perispinhinctes africanus* Dacqué (or *burui* Boehm)

The Perispinhinctids indicate lowest Plicatilis Zone (Highworth Limestones), but there are also some elements suggestive of the highest Cordatum Zone. This also must be earlier than the Tangila fauna of Kenya (p. 323).

**Upper Callovian**

A quarry in siliceous limestone near Pendambili station, worked during construction of the railway from Dar-es-Salaam to Morogoro, yielded a splendid collection to an engineer named Kinkelin. After him was named *Proplanulites kinkelini* Dacqué, which later became type species of the genus *Kinkeliniceras* Buckman (Fraas, 1908; Dacqué, 1910; Hennig, 1924, p. 60 ff.). The ammonites from here comprise *Phylloceras* aff. *haloricum* Hauer (Hennig, 1924, p. 76, pl. iii, fig. 12), *Calliphylloceras* disputabile (Zittel), *Lytoceras* cf. *adeloides* Kudernatsch, *Kinkeliniceras kinkelini* (Dacqué), *K. pendambilianum* (Dacqué), *Hubertoceras* cf. *omphaloides* (Waagen), *Peltoceratoides ngerengereanum* (Dacqué). This is an Upper Callovian assemblage (Athleta-Lamberti Zones). Against it Hennig’s addition (1924, p. 82) of a *Cadoceras* (which would indicate Lower Callovian) cannot be trusted. Probably also Upper Callovian is *Euaspidoceras horridum* Müller sp. (1900, p. 528 and pls.), from Mameka.

Another Upper Callovian fauna was collected by Dr P. E. Kent in 1951 a quarter-mile from Mkulumuzi Bridge, near Tanga, in a soft buff sandy limestone with ochreous fossils. The ammonites here comprise an assemblage of *Binatisphinctes* spp. of the style of *B. fluctuosus* (Pratt) and *B. welschi* and *B. robauxi* Gérard & Contaut, with *Grossouvria* and *Subgrossouvria*. It is comparable with the fauna of the Miritini Shale of Mombasa (see p. 323).

**Lower Callovian**

Near the 5·5 km. milestone from Tanga on the Usambara railway a path formerly led off NNW., and about 2·1 km. along it an ironshot
oolite crops out. The oolite contains many cephalopods and brachiopods, fewer gastropods. It is interbedded in and near the base of a series of shales with septarian nodules, and was proved in borings to overlie the (Bathonian?) limestones mentioned below, though in some borings it was absent, which shows that it is impersistent. G. Müller identified the following ammonites (Koert, 1904): *Holcophylloceras mediterraneum* (Neumayr), *Ptychophylloceras feddeni* (Waagen), *Macrocephalites macrocephalus* (Schlotheim), 'Sphaeroceras' bullatum' (d'Orb.), *Perisphinctes funatus* (Oppel). These have never been figured, and apparently never seen by an ammonite specialist. Pending that, judgment must be reserved, but if the 'Sphaeroceras bullatum' is a *Kheraiceras* (as it might well be), the horizon may be the Macrocephalus Zone.

**Bathonian and Bajocian**

From superposition proved in the borings, the limestone that forms the hills at Sigi and Mkulumusi, near Tanga, is presumably Bathonian (Koert, 1904). The beds are hard and contain poorly preserved fossils of little value for dating. The facies is called pelagic and compared by Dacqué (1909, p. 162) to the Antalo Limestone of Abyssinia. Behind Saadani it has yielded *Eopecten abjectus*, *Camptonectes lens*, *Trigonia 'costata*', *Rhynchonella*, etc.

On the Dar-es-Salaam to Morogoro railway there is no satisfactory evidence for dating anything below the Upper Callovian limestone of the 'Kinkelin quarry'. The profile given by Fraas (1908, p. 645) at Pendambili is said by Hennig (1924, p. 59) to be 'strongly composite' and to some extent muddled. Hennig made out a detailed succession of unimportant beds, without thicknesses, which have not been accepted by the Geological Survey (Wade, 1937, p. 48). At the base, however, in a band called 'Reck's fossil-bed' and an overlying limestone, the Kidugallo Oolite, there occurs a faunule of pelecypods and gastropods which suggest early Bajocian: they include *Eopecten abjectus* and *Variamussium pumilum*. The Bajocian grades down into Ngerengere Sandstones along the railway, and at Matuli in shaly sandstone has been recorded a *Leioceras* sp. (Hennig, 1924, pp. 10-12).

In 1951, borings in search of material for cement, 5 miles north of Kidugallo on the Central Railway (75 miles from Dar-es-Salaam), passed through 90 m. of uniform carbonaceous shales with some bedding-planes covered with small crushed *Posidonia ornata* Quenst. From the cores were sent me crushed specimens of *Planammatoceras* sp., with *?Leioceras* and *?Ludwigia*, indicative of the Lower Bajocian (Opalinum or Murchisonae Zones).

**Undated**

Along the Dar-es-Salaam railway the Middle Jurassic marine beds pass down into Ngerengere Sandstones, with thin bands of oolitic
limestone in the upper part, but no fossils. They are arkosic and pass down into arkoses, probably Triassic in age, which rest on the basement complex.

The Kilwa-Kiswere-Lindi Hinterland

In general the structure is similar to that of northern Tanganyika, except that the Tertiary coastal belt is narrower and the Cretaceous plateau is wider. The Cretaceous overlaps the Jurassic, which is gently folded along north to south axes and crops out in a network of valleys cut into the plateau. The capping of the plateau consists of Neocomian and Aptian beds (variously called the Makonde and Lindi formations) and rises to heights of about 400 to 600 m. above the sea. The whole country is thickly covered with bush.

The fullest and most complete Jurassic outcrops occur in the hinterland of Kiswere, along the Mandawa River and its tributaries. Part of the area was described by Hennig (1937). During 1951 Mr W. G. Aitken of the Geological Survey made a reconnaissance of much of the area and for the first time measured the formations, and Dr P. E. Kent for the D'Arcy Exploration Company also visited, with him, some of the sections and made collections and valuable observations. They proved an unexpectedly great development of Upper Jurassic marine strata to a total thickness of about 735 m., lying in a trough of deposition parallel to the present coast and thinning rapidly inland against the crystalline shield. It has been my privilege to study the remarkable collections of ammonites made by the Geological Survey and Dr Kent and to have the use of their unpublished field data and diagrams. The ammonites prove the presence of marine faunas ranging from Middle Callovian to Tithonian, the highlight being a splendid assemblage of the Anceps Zone in pure Cutch development, hitherto unknown in Africa.

The general succession is as follows (Aitken, 1954, 1955):—

<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trigonia smeii Sandstones</td>
<td>up to 165 m.</td>
<td>Tithonian and Upper Kimeridgian</td>
</tr>
<tr>
<td>Septarian Marls</td>
<td>up to 390 m.</td>
<td>Kimeridgian</td>
</tr>
<tr>
<td>Unnamed beds (Nerinella Sandstones pro parte)</td>
<td>up to 180 m.</td>
<td>Oxfordian and Callovian</td>
</tr>
<tr>
<td>Pindiro Beds (unknown thickness) and coral limestone of Matumbi plateau</td>
<td></td>
<td>Supposed Middle Jurassic (no ammonites)</td>
</tr>
<tr>
<td>? Basal sandstones (in north only)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tithonian

The presence of at least a Lower Tithonian fauna comparable with that of the Lower Umia formation of Cutch is attested by some ammonites in a coarse pebbly grit. One, from a locality on the Kikundi stream, is a large *Micracanthoceras* sp. The remainder, from farther south, are poorly-preserved *Perisphinctids* so finely ribbed as to be comparable only to *Virgatosphinctes communis* Spath of the Lower Umia.

http://jurassic.ru/
KIMERIDGIAN

The upper part of the thick mass of yellowish marls with septaria yields in abundance, preserved in the septaria, an assemblage of \textit{Pachysphinctes} and \textit{Aspidoceras} monographed by Dietrich (1925) from an outcrop on the Mahokondo stream, 25 km. NW. of Kiswere harbour. Collections of these ammonites, in the same preservation, were sent me by Mr Aitken and by Dr Kent from the vicinity of Nchia village and river (a tributary of the Mandawa). Dietrich handled over 200 Perisphinctids and over 100 Aspidoceratids from Mahokondo and remarked that these two genera greatly predominate over all other forms, but that besides some other ammonites there were pelecypods, brachiopods, crustacea and drift wood, indicating a neritic environment. The full list of ammonites, incorporating some nomenclatural revisions, is as follows:

\begin{itemize}
  \item \textit{Lytoceras} aff. \textit{fraasi} Dacqué
  \item \textit{Phylloceras} cf. \textit{subplicatius} Burckhardt
  \item \textit{Ptychophylloceras ptychoicum} (Quenst.)
  \item \textit{Holcophylloceras mesolcum} (Dietrich)
  \item \textit{Glochiceras} aff. \textit{fialar} (Oppel)
  \item \textit{Taramelliceras} cf. \textit{compsum} (Oppel)
  \item \textit{Taramelliceras} cf. \textit{harpoceroides} Burckhardt
  \item \textit{Streblites futtereri} (Müller)
  \item \textit{Streblites} cf. \textit{planopicta} Dietrich (non Uhlig?)
  \item \textit{Pachysphinctes africogermanus} Dietrich
  \item \textit{Pachysphinctes mahokondobeyrichi} (Dietrich)
  \item \textit{Pachysphinctes recki} Dietrich
  \item \textit{Pachysphinctes mulleri} Burckhardt (= \textit{P. elizabethae} Müller non de Riaz)
  \item \textit{'Idoceras'} mahokondobalderus Dietrich (gen. indet.)
  \item \textit{Nebrodites aethiopicoherbichi} Dietrich
  \item \textit{Aspidoceras richthofeni} Müller (= \textit{A. kilindinianum} Dacqué)
\end{itemize}

As Dietrich rightly perceived, this is a fauna of the Mutabilis and/or Pseudomutabilis Zones (Lower Kimeridgian).

UPPER OXFORDIAN

From the top of the underlying beds, a varied sequence of sandstones, marls and sandy limestones, 180 m. thick, Mr Aitken has collected a large, well-preserved \textit{Perisphinctes} (\textit{Arispinctes}) \textit{maximus} (Young & Bird), tending towards \textit{P.} (\textit{A.}) \textit{cotovui} Simionescu, and \textit{Perisphinctes orientalis} Siem, \textit{P.} cf. \textit{ingens} (Y. & B.), \textit{P.} \textit{antecedens} Salf., \textit{P.} \textit{wartae} Buk., \textit{P.} \textit{cf.} \textit{dibrogensis} Sim., \textit{Euaspidoceras} \textit{depressum} (Fut.) and a Mayaitid; an assemblage which gives a firm dating to the Plicatilis Zone.

MIDDLE CALLOVIAN

At various localities on the several rivers that unite to form the Mandawa River, and at a lower level in the series, Aitken collected well-preserved

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Middle Callovian ammonites belonging mainly to species figured from the Anceps and Rehmanni Zones of Cutch. Species sent me up to 1954 include the following:

- *Calliphylloceras disputabile* (Zittel) (= *demidoffi* Rousseau?)
- *Holocosphylloceras* and *Ptychophylloceras*
- *Lytoceras adeloides* (Kudernatsch)
- *Indosphinctes cf. indicus* (Siemiradzki)
- *Indosphinctes pseudopatina* (Parona & Bonarelli)
- *Choffatia aff. difficilis* (Buckman)
- *Grossouvria* spp.
- *Obtusicostites cf. ushas* Spath or *buckmani* Spath
- *Kinkeliniceras discoideum* Spath
- *Kinkeliniceras subwaageni* Spath
- *Sivajiceras aureum* Spath
- *Sivajiceras aff. kleidos* Spath
- *Sivajiceras cf. fissum* (Sow.)
- *Hubertoceras arsicosta* (Waagen)
- *Hubertoceras dhosaense* (Waagen)
- *Hubertoceras omphalodes* (Waagen)
- *Sindeites* sp. (fragment collected by P. E. Kent)

Dacqué (1910, pp. 53, 56) had reported Upper Callovian in a hard siliceous limestone 24.5 km. NW. of Kiswere, by the Mahokondo stream, but if it was this fauna that he encountered, he certainly dated it too late.

**Bathonian and Bajocian**

Older Jurassic rocks are exposed north of the Marandu River, in the Matumbi (Mtumbei) plateau, but they have so far yielded no ammonites. In about 120 m. of sandstones and sandy oolites (Kent MS.) there is a limestone with corals, calcareous algae and pelecypods, from which such Bathonian forms as *Trigonia pullus* and *Eopecten abjectus*, with *Rhychnonella lotharingica*, are recorded (Müller, 1900; Dacqué & Krenkel, 1999, p. 163).

Not far north of the Mbemkuru River, at a point about equidistant from Kilwa and Lindi, Hennig (1937) has described folded beds (Pindiro Shales) which he claims are Bajocian or Bathonian and overlain unconformably by unfolded Oxfordian and Kimeridgian. But the palaeontological evidence for the age of the Pindiro Shales is slender and the tectonic interpretation requires confirmation.

**Tendaguru**

Thirty-eight miles NW. of the port of Lindi is the famous locality of Tendaguru, where great quantities of dinosaur bones were excavated from the uppermost Jurassic by a German expedition in 1909-12 and by a British Museum expedition from 1925 onwards. The dinosaurs comprise chiefly Sauropoda, including *Brachiosaurus*, or *Gigantosaurus*, the largest land animal known to have lived on earth, with some Ornithopoda. (See

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Janensch, 1914; Parkinson, 1930a.) Some, including *Brachiosaurus*, occur also in the Morrison formation of Colorado, Wyoming and Utah. The geological age of these beds has given rise to much discussion and many conflicting opinions, unfortunately not untouched by nationalistic feeling. It is now, however, settled beyond reasonable doubt on the basis of ammonites by the work of Dietrich (1927, 1933, 1933a) and Spath (1933).

The chief cause of difficulty is the fact that Tendaguru lies near the Mesozoic shoreline, with the result that the 735 m. of marine Upper Jurassic formations just described (unbottomed) in the Kiswere hinterland have partly thinned and partly wedged out until at Tendaguru they are represented by only 120 m. of beds, resting directly on gneiss of the basement complex. In addition, a large part of the strata have become fluvio-marine or 'estuarine', with disappearance of the marine fossils.

Above the Jurassic dinosaur beds there is an inferred (but seldom perceptible) disconformity, on which follow Lower Cretaceous *Trigonia schwarzi* beds (Hauterivian-Barremian), which pass up into Aptian (Urgonian).

The Jurassic beds, to which the name Tendaguru Beds is best restricted, form a mainly sandy series of alternating or cyclic coarse to pebbly sandstones, fine sandstones, silts, and sandy clays, often well laminated and occasionally greyish-green or reddish in colour. There is much variation also along the strike. The bedding-planes change direction frequently, as if material had been deposited from a slowly-moving quicksand, and there are clay pellets of 'desiccation breccia' type. Elsewhere the silts are well laminated, as if deposited in still water. The Tendaguru Beds, in fact, are products of a large river subject to tropical floods and desiccation. The sea was never far off, perhaps kept out by a lagoon bar; occasionally it broke through and drifted in ammonites and other marine shells, which thus alternate in succession with products of the river and land, including the dinosaur bones (Parkinson, 1930).

The German expeditions established the following detailed sequence, which, owing to facies changes and local variations, is admittedly schematic (Dietrich, 1933, 1933a):

[Gap above: then *Trigonia schwarzi* Sandstone]

Upper Saurian bed
    Smeei bed: sandstone packed with *Trigonia smeei*
    Littoral bed with *Cyrena* and *Mytilus*
Middle Saurian bed
    Littoral bed with *Cyrena* and *Mytilus*
Lower Saurian bed
    Nerinella bed: sandstone with *Trigonia dietrichii*

[Gneiss below]

There is no significant difference between the vertebrate faunas of the three saurian beds: which suggests that the whole series did not take a geologically long time to form.

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Unfortunately *Trigonia smeei* was recorded in the earlier reports as from both the Smeei bed and the overlying Cretaceous, and since Kitchin (1929) believed it to be Cretaceous, and thought some of the other mollusca were of the same age, he supposed that the Jurassic ammonites in the Tendagura Beds must have been derived and that the whole series was Cretaceous. It is now known that *Trigonia smeei* is in fact Jurassic and does not occur in the *T. schwartzi* beds, and that no ammonite showing signs of derivation has been found (Dietrich, 1933, 1933a; Spath, 1935).

Nor is there any satisfactory evidence that the Tendaguru *Nerinella* (or ‘Nerinea’) Bed, only a few feet thick, is on the same horizon as any part of the 180 m. of ‘Nerinella Beds’ in the Kiswere hinterland, and some confusion may have arisen through correlation of the two. On the contrary, neither Callovian nor Oxfordian ammonites have been found at Tendaguru, where the few ammonites known from the *Nerinella* Bed are late Kimeridgian and not much older than those in the *Smeei* Bed.

The published forms from the two beds are as follows (Zwierzycki, 1914; Dietrich, 1925, 1933; Spath, 1933 (Cutch) p. 820):—

**Smeei Bed**

*Holcophylloceras mesolcum* (Dietrich)  
*Haploceras elimatum* (Oppel)  
*Hildoglochiceras kobelli* (Oppel)  
*Hildoglochiceras dieneri* (Uhlig)  
*Hildoglochiceras spira* (Zw.)  
*Subdichotomoceras sparsiplicatum* (Waagen)  
*Subdichotomoceras latissimus* (Zw.)  
*Subdichotomoceras denseplicatum* Dietrich, 1933, *non* Waagen  
*Craspedites* africanus Zw. (*genus indet.*)  
Perisphinctid, involute, *indet.* (*bleicheri* Zw. *non* de Lor.)

**Nerinella Bed**

*Haploceras priscum* Zw.  
?*Pachysphinctes staffi* (Zw.) (*Aulacosphinctoides?*)  
*Subdichotomoceras sparsiplicatum* (Waagen)  
Perisphinctid, giant, *indet.* (*achilles* Zw. *non* d’Orb.)

Dietrich (1933) and Hennig (1937) averred that the Middle Saurian bed passes laterally into the upper part of the Septarian Marls of Mahokondo, but palaeontological evidence for this seems to be lacking.

The list for the Smeei Bed is obviously Upper Kimeridgian (or Lower Tithonian as the term is understood in this book): *Subdichotomoceras sparsiplicatum* is a species of the uppermost Katrol Beds of Cutch, and *Hildoglochiceras kobelli* (Oppel) occurs on this horizon in Cutch and Madagascar and in the Middle Spiti Shales. Spath’s conclusion (1933, Cutch, p. 820) seems unanswerable, that the whole of the Tendaguru Beds (including the Nerinella Bed) are much younger than the Septarian Marls of Mahokondo.
Although Cretaceous transgressions encroached on the east coast of Africa in places almost as far south as the Cape, no marine Jurassic is known on the mainland south of Tanganyika. In the Island of Madagascar, however, Jurassic sediments reappear in force, all stages being represented from Lower Toarcian to Tithonian. The island is equal in area to France and the Netherlands combined, and the Jurassic outcrop stretches for about 900 miles, almost the whole length of the island. It is confined to the west side (fig. 49) and consists of a simple monocline dipping gently westward, with underlying Triassic sandstones and shales of Karroo facies resting on the crystalline basement complex which builds the central and eastern parts of the island. The arrangement is a mirror image of that in Kenya and Tanganyika and strongly suggests that the Straits of Mozambique were in existence in Jurassic times. They are in fact believed to have been initiated at least as a gulf in the Permian.

The simple disposition of the Madagascar Jurassics is broken in the centre by a broad anticlinal uplift which reaches the sea at Cap St André and divides the lengthy outcrop into two. The interruption has a width varying from about 50 to 100 miles. To some extent this anticline represents a projection from the east coast of the Jurassic strait, but it is probably due more to early Cretaceous uplift, for Cretaceous rocks overstep across it on to Trias and in one place even touch the basement complex. (Int. Geol. Map Africa, sheet 9, 1950; Besairie, 1946; Basse, 1949.)

In fauna, and often also in facies, the Jurassic rocks bear a strong resemblance to those of India, especially Cutch. This was first pointed out by H. Douville (1904, pp. 216-7) and all subsequent researches have tended to strengthen the comparison. The sequence of correspondences begins as early as the Permo-Carboniferous, where the sedimentary record in Madagascar opens with tillites resting upon the basement complex and followed by continental deposits with the Glossopteris flora of the Lower Gondwanas (see p. 383). For the Trias comparisons are closer with the adjoining continent of Africa, and the first marine Jurassic horizon, the Lower Toarcian with Bouleiceras, which occurs only in the north, corresponds with that in NE. Kenya and the Tuwaq Bay of central Arabia (pp. 300, 318). In the north there is also marine Bajocian, but with only rare ammonites. Thick and transgressive Bathonian of coralline and pelecypod faciesushers in the main marine sequence in all parts of the island, and the assemblage of Corbula, Protocardia, etc., is identical with that found at the base of the Cutch sequence as well as in the Attock district and in Burma; while the occurrence of Eligmus rollandi provides a link also with the Trans-Erythraean trough, Arabia and Sinai.

From the Lower Callovian upward, the ammonite sequence is almost identical with that of Cutch, with which it also agrees in the mixture of Phylloceratids with other ammonites. Direct connexion with the fringing sea of Tanganyika and Kenya is also evident at several horizons, and it is

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interesting to find all three areas linked by even such a negative peculiarity as the absence of the normally almost ubiquitous ammonite fauna of the basal Kimeridgian Tenuilobatus Zone. Particularly striking similarities are the wealth of Lower Callovian Macrocephalitids, preserved in a 'golden oolite' as in Cutch, the abundance of 'late Macrocephalitids' (Mayaitids) in the Oxfordian, and the abundance of Virgatosphinctes and Hildoglochiceras kobelli in the Lower Tithonian.

Fig. 49.—Geological sketch-map of Madagascar.

Considering the enormous size of the outcrop, the difficulties of travel and collecting, and the frequent occurrence of laterite or dense forest over much of the surface, the labours of French geologists during the last 50 years have produced a marvellously detailed picture. Measurements of thicknesses, however, are for the most part still lacking. For the northern part of the outcrop we have splendid monographs by Besairie (1936) and Barrabé (1929) as well as the earlier works by Lemoine (1906, 1910-11) and Thevenin (1906, 1908), while for the south the picture has been extended by a magnificent monograph by Mme Basse de Ménorval...
and subsequent work, especially on the Oxfordian, by Nicolai (1950) and Collignon (1949). Excellent general syntheses have been provided by Besairie (1932, 1946) and Basse (1949).

Correlation along the whole 900 miles of outcrop has been so far established as to enable our present purpose to be served by the following single palaeontological synthesis. (See also Table 16, pp. 310-11.)

[LOWER CRETACEOUS]

In the north there is a passage from the Tithonian into the Cretaceous with well-developed Berriasian and Valanginian Belemnite Marls, but in the south the Neocomian is missing and Aptian with Cheloniceras and Tropaeum rests directly on Tithonian and Kimeridgian (Basse, 1934). The following horizons are developed in the north (Besairie, 1932, 1936):

Valanginian: Beds with numerous Rogersites spp., also Hoplitoides, Neocomites, Uhligites, Bochianites, Neolissoceras grazianum (d’Orb.), Phylloceras spp. and Hemilytoceras liebigi (Oppel).

Berriasian: Beds with Kitianella pexiptycha Uhlig and Berriasella spp.

TITHONIAN

In the north are chiefly clays and marls with belemnites, resembling the Neocomian into which they pass up without a break, but containing occasional limestone bands. In the south, and locally in the north, the facies is a glauconitic sandy limestone. The following two faunas have been distinguished (Besairie, 1932, 1936; Basse, 1934):

Upper Tithonian: Beds from 0-5 m. to c. 12 m. thick, with numerous Aulacosphinctes spp., including A. hollandi Uhlig and A. aff. spitiensis Uhlig, with Blanfordiceras acuticosta Uhlig, B. hourcqii Besairie, Himalayites spp. and Acanthodiscus sp. In the south Micrancanthoceras cf. brightoni Spath (Basse, 1934, pp. 73-4).

Lower Tithonian: Beds with numerous Virgatosphinctes spp., for the most part not yet worked out, but characterized especially by V. andranosamontae (Lemoine; 1911, pl. vi; Besairie, 1936, pl. x, figs. 14-17). In these beds occur also Uhligites sp., Holocophylloceras silesiacum (Oppel), Haploceras elimatum (Oppel) and the interesting Hildoglochiceras kobelli (Oppel) and its allies (Lemoine, 1910, pl. iv; Besairie, 1930, pl. xii, fig. 2; 1936, pl. x, fig. 12; Barrabé, 1929, pl. viii, fig. 1), found also in Tanganyika, Cutch and the Middle Spiti Shales. They were recorded in Madagascar as early as 1904 (H. Douville, 1904, p. 213). For a fuller list of the Tithonian faunas (not, however, at that date yet separated) see Spath, 1933 (Cutch), pp. 822-3. Spath concluded that this assemblage is intermediate in age between the ‘Upper Katrol’ fauna of Gudjinsir in Cutch and the Umia Ammonite Beds. It combines some features of both. On the other hand, Micrancanthoceras is already represented. A further link with the Smeei bed of Tendaguru is Subdichotomoceras sparsiplicatum (Waagen) (Lemoine, 1911, pl. viii, fig. 4), exactly as figured by Zwierzycki (see p. 335).
No definitely Upper Kimeridgian fauna is known in Madagascar, but at one locality, the rich Antsalova district, there is between the *Virgatosphinctes* beds above and the *Hybonoticeras* beds below a horizon with *Uhligitès* spp., *Haploceras elimatum* and *Hildoglochiceras kobelli* (Besairie, 1936, p. 65).

**Middle Kimeridgian**

In the north at Antsalova and some other localities from 1 m. to 10 m. of limestones have yielded numerous *Hybonoticeras* spp. and *Aspidoceratids*, especially *Physodoceras avellanoides* (Uhlig), *P. cf. cyclotum* (Oppel) and *Metahaploceras* (Besairie, 1936, pp. 64-5, pls. ix, x). This is presumably also the level of *Hemisimoceras* spp. from Antsalova figured by Spath (1925a, pp. 25-6 and plate).

**Lower Kimeridgian**

Only the upper part (Pseudomutabilis Zone) seems to be represented. In the north there are limestones and marls with *Aspidoceras* of the *longispinum* group and *Pachysphinctes*, typical *Lithacoceras*, *Torquatosphinctes* and *Taramelliceras*, etc., underlain by marls with *Nebrodites* (Besairie, 1936, pp. 64, 130-3, pls. ix, x). In the south the same zone is widely represented by glauconitic and often oolitic limestone, but the lowest Kimeridgian (Tenuilobatus Zone) is wanting there also (Basse, 1934, p. 71).

**Upper Oxfordian**

*Bimammatum Zone*. There is as yet no evidence for the existence of this zone in Madagascar.

*Transversarium Zone (Plicatilis Zone)*. In the south-west the lower part of this zone (at least) is represented at Ankazoabo (Nicolai, 1950, p. 149; Collignon, 1949) by various *Perisphinctes* (*Dichotomosphinctes*) including *rotiformis* Spath and *jacobi* Collignon, with *P. aff. bocconii* Gemmalario, *Mayaites maya* (Sow.) ('enormous specimens'), *Euaspidoceras* spp. (unfigured) and various *Phylloceratids*. From the same beds, however, are recorded other *Euaspidoceras* and *Peltomorphites* which indicate the Cordatum Zone. These zones therefore seem to be here combined as at Kwa Dikwaso, Tanganyika (see p. 328), whether by condensation or mixing remains to be investigated. An Upper Oxfordian *Dichotomosphinctes* is figured from the north-west by Besairie (1936, pl. viii, fig. 15). *Taramelliceras anar* (Oppel) is also recorded (Basse, 1934, p. 67) and a whole series of Mayaitids (Basse & Perrodon, 1952).

**Lower Oxfordian**

*Cordatum Zone*. As just mentioned, elements of this zone such as *Peltoceras eugenii* (Raspail), *P. cf. bidens* (Waagen), *Euaspidoceras babeanum* (d'Orb.), *E. aff. obesum* (Spath), *E. cf. nikitini* Borissjak, are recorded from

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Ankazoabo in the south-west, associated with forms of the early Plicatilis Zone (Collignon, 1949), as in Tanganyika.

**Mariae Zone.** At Kilambia in the south-west an iron-shot oolite has yielded an assemblage of European Peltoceratids which might be early Cordatum Zone and seem as a whole more likely of about Mariae Zone age: *P. annulare* (Quenst.), *P. praespissum* Spath, *P. cf. semirugosum* Waagen, *P. interscissus* Uhlig, *P. torosum* (Oppel), *P. arduennense* (d'Orb.). With these is *Paryphoceras* cf. *rugosum* Spath, a species of the Dhosa Oolite of Cutch. Another Cutch species common to Europe is found near by, *Campylites secula* Spath (Collignon, 1949; Nicolai, 1950). In most places the oolite and its ammonites do not occur; instead large areas are covered by sandstones with *Gryphaea dilatata* (Basse, 1934, p. 71).

**Upper Callovian**

A zone of *Peltoceras athleta* has been distinguished by a number of authors (see Besairie, 1932, p. 180) but it is not clear that the Peltoceratids are *athleta* or even necessarily Callovian species. The most unequivocal Upper Callovian fauna is recorded by Basse (1934, p. 69) from 8 km SSE of Ankazoabo in the south-west: she recognized *Putealiceras* (3 spp.), *Sublunuloceras* and *Distichoceras* (*Sindeites*) associated with *Peltoceras athleta*, in oolitic argillaceous sandstone overlying the yellow Callovian oolite.

**Middle Callovian**

If not Upper Callovian, the pyritic ammonites with Hecticoceratids found in grey marls in the Pays Sakalave belong here as believed by Barrabé (1929, p. 119; 1928, p. 1222); also beds on the banks of the Betsiboka with 'numerous *Hecticoceras* and *Pleurocephalites* and *Belemmites tanganensis* Futterer' (Besairie, 1932, p. 180). Spath (1925a, p. 25) also saw a small assemblage with *Pleurocephalites* and *Hecticoceras* which he tentatively assigned to the Anceps Zone. *Reineckeia* cf. *anceps* was recorded by Lemoine (1907, p. 33 and 1910, pl. v, fig. 4) and also by Basse, (1934, p. 63), associated with *Sublunuloceras*, *Choffatia* and *Holcophylloceras mediterraneum*. Middle Callovian ammonites have also been obtained east of Andranomantsy in the north (Collignon, 1953), and in the Mangoky area in the south the earliest marine assemblage comprises Cutch forms of *Obtusicostites*, *Hubertoceras* and *Kinkeliniceras*, with Phylloceratids, as in the Mandawa area of Tanganyika (Hirtz, 1949, p. 6).

**Lower Callovian**

In both the north and the south the Lower Callovian is conspicuously represented by yellow or golden oolite with numerous fossils (H. Douville, 1904, p. 213). It is perfectly conformable with the Bathonian pelecypod limestones and the passage is often gradual. Besairie (1932, p. 179) recognizes two ammonite zones, a lower with *Macrocephalites* (*Kamptokephalites* aff. *dimerus* Waagen, an upper with *M. madagascariensis*.
Lemoine and many other forms. The conspicuous Macrocephalitids have long been known, especially through the photographs of Lemoine (1910, pls. i-iv; since largely renamed). A list, together with identifications of the associated ammonites of the genera *Ptychophylloceras, Calliphylloceras, Holcophylloceras, Lytoceras*, some Hecticoceratids, *Hubertoceras, Choffatia* and *Indosphinctes*, is given by Spath (1933, p. 821). The large supporting fauna includes *Elignus rollandi* Douvillé (Barrabé, 1929, pp. 111-19; Basse, 1934, pp. 59-67). Besairie (1936, p. 62) attempted to separate a third zone which he correlated with the Koenigi and Callovienne Zones, but the assemblages he placed on this horizon belong in part to the Macrocephalus Zone (the Maintirano faunule, which contains *M. aff. typicus* Blake and *Kheraiceras cosmopolita* P. & B. sp.) and in part seem to be the same as the Hecticoceratidae beds assigned to the Anceps Zone. His plates vii and viii illustrate more of the Macrocephalitids and other fossils from the Lower Callovian, including forms of *Choffatia* as well as of Macrocephalitids that could hardly be distinguished from those of the English Upper Cornbrash. (See also Besairie, 1930, pl. x.) The Macrocephalitidae of SW. Madagascar have since been monographed by Basse & Perrodon (1952), and Collignon (1953) has listed a number of forms from the north of the island. A good representative collection of 15 species from near Sakahara was sent me in 1954, collected by Dr P. E. Kent.

Bathonian

At least in some places in the north the Lower Callovian ammonite limestones pass down by intercalation into shallow-water Bathonian pelecypod beds with *Corbula lyrata* Sow., *Protocardia grandidiieri* (Newton), *Pseudotrapezium depressum* Newton, and *Astarte baroni* Newton and, locally, corals and at the base reefs of *Girvanella*. The Bathonian limestones are very thick and form dry karst country like the 'causses' in France. At the base in places are marls with dinosaur bones. The upper beds, with *Corbula*, are transgressive in the south, overlapping on to Trias (Barrabé, 1929, p. 107; Basse, 1934, p. 45 ff.). These Upper Bathonian pelecypod beds (locally with *Elignus*; see Besairie, 1930, pl. x, fig. 4) were described and correctly dated to the Bathonian by H. Douvillé (1904, p. 212); they are, however, Upper not Middle Bathonian as Besairie states (1936, p. 120, with good figures of the pelecypods, pl. vii). By their fossils, facies and transgressive quality they correspond to Upper Bathonian beds in southern Tunisia, Egypt, Somaliland, ? Jubaland, Cutch (Kuar Bet Beds, see p. 391) and Burma. Until recently the only Bathonian ammonite known with certainty from Madagascar was a single small *Cadomites cf. rectelobatus* (Hauer), found above the coral limestones in the north (Besairie, 1930, p. 534, pl. vii, fig. 6). If a fragmentary 'Cardioceras' figured by Barrabé (1929, p. vii, fig. 30) is a Clydoniceratid as Mme Basse (1952, p. 86) surmises, this too probably came from the Bathonian beds. East of Andranomantsy, in the north of the island, Collignon
(1953) has found interesting Bathonian ammonites including Clydoniceras, Micromphalites, Oppelia aspidoides, Gracilisphinctes and Epistrenoceras histricoides (Rollier), some of which he sent me for determination.

**Middle Bajocian**

In the north, the basal part of the limestones forming the 'causses' contains a silicified fauna pronounced 'clearly Bajocian' already by H. Douvillé (1904, p. 212), who recorded among the fossils a single ammonite, Sonninia decora Buckman. Some brachiopods and echinoids have been figured from this level by Besairie, and also half a small ammonite which he assigns to the genus Witchellia, but which from its evolute coiling and abrupt umbilical wall appears to be a Dorsetensia of the edouardiana group, close to those found in Arabia and the single fragment from Kenya (Besairie, 1936, p. 116, pl. vi, figs. 22, 23). It is only in the north that Bajocian appears to be developed. It is transgressive (Basse, 1949, p. 60). Both the ammonites hitherto recorded are Middle Bajocian.

**Upper Toarcian**

North of the Betsiboka, in the province of Nosy Be, are sandstones, black shales and black limestones with carbonaceous layers, from which H. Douvillé (1904) recorded 'Harpoceras cf. serpentinum, H. cf. metallarium, H. cf. dumortieri', with Spiriferina rostrata, Posidonia alpina and plant remains (see Lemoine, 1907, p. 31). If the second and third ammonites are really a Haugia and a Dumortieria as stated by Lemoine, this fauna is certainly later than the Bouleiceras beds and is Upper Toarcian. The succession in the Ampasindava district (Besairie, 1946, p. 15) is:

3. Beds with Dumortieria and Harpoceras
2. Shales with plants: Equisetum, Pecopteris
1. Limestone with Spiriferina rostrata [= the Bouleiceras beds]

**Lower Toarcian**

The earliest marine Jurassic fauna in Madagascar is the celebrated Bouleiceras assemblage. It occurs only in the north, in the basin of the Sitandiky, north of Cap St André, where it rests on Triassic sandstones and clays with Myophoria. The beds consist of marly limestone and marls, crowded with fossils, as described by Thevenin (1906, 1908). The most characteristic are the strange genus Bouleiceras, with ceratitic sutures, with which are associated Protogrammoceras madagascariense (Thevenin), Nejdia pseudo-grunerii (Thevenin), Spiriferina rostrata Schloth. var. madagascariensis Thevenin, the strange Pecten ambongoensis Thevenin, and many other fossils (list in Barrabé, 1929, p. 88). Thevenin considered the age to be between Domerian and Toarcian, but the Lower Toarcian age inferred by me when considering the Arabian occurrence in 1951 has been confirmed by a new discovery in Portugal (see p. 241). South of Cap St André the marine beds are represented by thick fluvio-marine or

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deltaic sandstones and clays which persist up to the Bajocian inclusive and appear to form a continuation of the Triassic Isalo Sandstones (Besairie, 1946, p. 17; Basse, 1949, p. 60).

**TRIAS**

The Isalo Sandstones begin with an unconformity and basal conglomerate. The thickness is up to at least 500 m. The lowest beds are Eo-Trias; the highest probably Upper Trias, consisting of sandstones and shales with *Myophoria vulgaris* and *Mytilus psilonoti*, which correlate with the Lugh Series and Adigrat Sandstone of Abyssinia (Barrabé, 1929, p. 77; Basse, 1949, p. 58). The correspondence with Jubaland is unmistakable (see p. 319).]

**THE AFRICAN SHIELD**

A considerable excursion into the stratigraphy of the northern part of the African shield was made in the chapter on North Africa (pp. 256, 286), because various rocks there had been loosely referred to the Jurassic. It was seen that all these alleged Jurassic sediments turned out to be Cretaceous where not Triassic. The Jurassic appeared to be represented by a lacuna, from which it is to be inferred that it was a period of erosion on the northern part of the shield. The same applies to the southern part also.

In South Africa the whole of the uppermost (Stormberg) division of the Karroo is customarily referred to the Trias, excepting the Drakensberg Volcanics (= Stormberg lavas) at the top, which are thought to be Rhaetic-Lias (Du Toit, 1926, p. 277). These immense lava sheets are presumed to have resulted from fissure eruptions on a land surface. The next sediments laid down in South Africa are Neocomian, and by the time they were formed the Karroo surface had been profoundly eroded.

In East Africa and Madagascar there is a much less definite top to the Karroo, and from what has been mentioned in earlier parts of this chapter it will be apparent that in those regions the sequence of events in the Rhaetic and Lower Lias periods is by no means yet fully elucidated. The earliest marine horizon in both Madagascar and East Africa is the *Bouleiceras* zone, basal Toarcian, which represents a transgression across Karroo-type sandstones. It is quite possible that along the eastern margin of the continent Karroo-type sedimentation continued throughout the Lower and Middle Lias, and in Tanganyika even up to the base of the Bajocian. (For the latest information on the Karroo, see the symposium on the Gondwana Series issued by the XIXth International Geological Congress, Algiers, 1952, pp. 181-256.)

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PART IV

SOUTHERN ASIA
CHAPTER 13

THE RANGES OF SOUTH-WEST ASIA

ASIA MINOR (ANATOLIA)

Throughout the mountainous peninsula, 900 miles long by 400 miles wide, that comprises Asia Minor, the sedimentary records of the Jurassic transgression are unusually imperfect and scattered. So great has been the erosion that, as in the Highlands of Scotland, it is no longer possible to determine whether the absence of Jurassic rocks over hundreds of square miles is due to non-deposition or to wholesale removal by denudation. The sediments covered the eroded remnants of a late-Palaeozoic orogeny and then were caught up in the mid-Tertiary orogeny with intense folding and overthrusting, more than usually complicated by posthumous reactivation of the older structures. There is evidence that at least in the SW. of the peninsula Upper Jurassic and Cretaceous limestones of two different facies, deposited a considerable distance apart, have been brought together by thrusting.

After Permian erosion of the late-Palaeozoic mountains, the Mesozoic transgression began in the north-west, in some places with the Lower Trias and in others with the Middle or Upper Trias, while in the central regions it began with the Lower Lias. In the SE. of the peninsula the earliest sediments seem to be Cretaceous, consisting of a featureless and poorly fossiliferous mass of limestones. It is likely that the main chains of the Taurus, like the High Atlas and Anti-Atlas, were never submerged during the Jurassic. The Lias to the north of this barrier is typical of the Tethys, showing many palaeontological links with the Mediterranean and Alpine regions and Carpathians, but the Lias and Bajocian to the south, in Syria and Arabia, belong to a different province. In the Callovian and Oxfordian the barrier began to break down in the east, letting typical European ammonite faunas spread over Arabia, Syria, Sinai and East Africa. These faunas did not come direct from the Balkans but rather from the north-east, across the Caucasus and northern Persia from South Russia.

The survival of mountains undergoing rapid erosion in south-central Anatolia during the Jurassic is to be inferred from the presence of Jurassic flysch adjoining the SW. coast round the head of the Bay of Antalya (Adalia). Both west and east of this is a great development of almost unfossiliferous limestones, a ‘comprehensive series’, 2500 m. thick, in which Toarcian ammonites are reported, but which ranges up from the Jurassic to the Eocene inclusive, without a break (Blumenthal, 1945, p. 110; Tromp, 1941, 1947). Farther east, in SE. Anatolia, the Hercynian ranges were not submerged until the Upper Cretaceous; the first Mesozoic marine beds to overstep the folded Carboniferous are radiolarites of
Senonian age, though locally the Trias may be represented by dolomites (Blumenthal, 1941, p. 324). On the NW. coast also, south of the Sea of Marmara, similar radiolarites are Upper Cretaceous (Erk, 1942), or Lower Cretaceous (Altinli, 1943), though in the central regions, around Ankara, there are red limestones and jaspers with Radiolaria interbedded in the Upper Jurassic (Upper Oxfordian) and also underneath fossiliferous Lower Lias, and therefore presumably Triassic (Chaput, 1936, p. 243)—but not necessarily (Bailey & McCallien, 1953, p. 427). There are good reasons for believing that the Turkish radiolarites are of shallow-water origin and connected with the presence of basic igneous rocks (Tromp, 1948). The same goes for supposedly Triassic radiolarites in Cyprus (Henson & others, 1949).

![Fig. 50.—The Jurassic outcrops of Anatolia (Asiatic Turkey), based on the Geological Survey map.](http://jurassic.ru/)

Sedimentation continued quietly in many parts of Anatolia until after the Lower Eocene, when the mid-Tertiary orogeny produced reactivation of the old structures and fresh folds and thrusts. According to Egeran (1947, p. 55) the occurrence of free folding on a large enough scale and with sufficient uniformity of strike for the development of nappes was prevented by the existence of old horsts in the orogenic zone. The role of these horsts was similar to that of the horsts in North Africa (pp. 260, 272) and presumably they had a similar history of intermittent relative upward movement during the Jurassic. The same has been inferred for Cyprus (Henson & others, 1949, p. 33). According to Bailey & McCallien (1953), however, a Palaeozoic nappe was thrust south over Mesozoics for a distance of 350 km. and is left as worn-down klipes near Ankara.

Across the planed-off structures of the mid-Tertiary orogeny and over flysch sandstones of Middle Eocene to Oligocene age the Neogene,
ASIA MINOR

beginning with the Burdigalian, was laid as a continuous blanket over most of Asia Minor and Cyprus. At least in Cyprus, deposition was interrupted by thrusting at the end of the Miocene, followed by renewed subsidence. Finally, in the late Pliocene there was regional doming and extensive block-faulting, accompanied by volcanism in Anatolia, doubtless reverberations of the major orogeny that was taking place at that time in the Zagros ranges of Persia and of the Pliocene folding in the Tellian Atlas.

Lias and Middle Jurassic of Anatolia

Lias occurs in the centre and east of northern Anatolia in three distinct groups of small outcrops, each group separated by about 130 miles from the other. The most westerly group lies to the north and west of Ankara and includes the celebrated localities Yakacik (Jakadzik) and Kesiktash (Kessik-tash) described by Pompeckj (1897) and Vadasz (1913). About 130 miles ENE. of this is another group north of Amasiya, in the Akdag range (Akdag = White Mountain), including the well-known locality Merzifun (Meister, 1913; Pia, 1913; Gugenberger, 1929). About the same distance ESE. is the third and most easterly group, north of Erzincan, in which are the more scattered localities of Reksene, Deredolu and Bayburt (Otkun, 1942, Ketin, 1951, Baykal, 1951) (plate 20).

The survival and exposure of these small fragments of a once continuous marine formation seem to be purely fortuitous and provide an object-lesson in the possibilities of complete removal. The outcrops near Ankara form part of a complicated mosaic of faulted ancient and Neogene volcanic rocks, and Jurassic and Cretaceous and Tertiary sediments. The outcrops in the Akdag range consist of long, narrow wedges ('Schuppen') folded in between ridges of Permo-Carboniferous *Fusulina* limestone; those of the eastern group, near Erzincan, are completely surrounded by metamorphic rocks. The facies of all is similar, consisting largely of hard or marly, reddish, compact limestones reminiscent of the Adneth Limestone of the Alps, but generally more argillaceous. Cephalopods are by far the most abundant fossils, and among them there is a marked preponderance of Phylloceratina and Lytoceratina. Crinoids also abound, often attached to ammonite shells; brachiopods are common, and there are bands of *Gryphaea*. At Merzifun sponges are frequent, indicating an almost clear-water environment. The ammonites represent a mixture of predominantly North-Alpine with Mediterranean (especially Apennine) forms, and others that are local or eastern.

According to the analyses by Pia and Gugenberger, however, the Akdag Lias is all Pliensbachian with Domerian, mainly of the Jamesoni Zone, with Margaritatus Zone also represented, but nothing either older or younger. At Kesiktash, near Ankara, Sinemurian is present, for the ammonites denote Bucklandi Zone and Margaritatus Zone. In the eastern group of occurrences, Otkun (1942) is able to show the presence of Sinemurian (Bucklandi, Raricostatum and 'Armatum' Zones), Pliensbachian
(Jamesoni and Margaritatus Zones), Toarcian (Bifrons and Jurense Zones), and Lower Bajocian (Opalinum Zone).

The Jurassic succession around Bayburt is about 2300 m. thick and is as follows (Ketin, 1951, pp. 118-19):—

[Berriasian]
White limestones with *Berriasella boiseri* (Pictet), *B. pontica* Ret., etc. 1600

Upper Jurassic

<table>
<thead>
<tr>
<th>Sediment Type</th>
<th>Details</th>
<th>Metres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy and conglomeratic beds with Aptychi</td>
<td></td>
<td>300</td>
</tr>
<tr>
<td>White, thin-bedded fossiliferous limestone with <em>Soxverbyceras tortisulcatum</em> (d'Orb.), Perisphinctids and brachiopods</td>
<td></td>
<td>4 to 5</td>
</tr>
</tbody>
</table>

Middle Jurassic missing?

Lower Jurassic

<table>
<thead>
<tr>
<th>Sediment Type</th>
<th>Details</th>
<th>Metres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstones and shales with interbedded volcanic rocks</td>
<td></td>
<td>300 to 350</td>
</tr>
<tr>
<td>Shales with thin volcanics, with <em>Harpoceras</em> and <em>Amaltheus cf. margaritatus</em></td>
<td></td>
<td>8 to 10</td>
</tr>
<tr>
<td>Red fossiliferous limestones and marls with <em>Phylloceras</em> frondosum Reynès, <em>P. alontinum</em> Gem., <em>P. bonarellii</em> Bet., <em>Verniceras</em>, etc.</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Red sandy limestone, marl, and tuff; brachiopods</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Lava and tuffs</td>
<td></td>
<td>300</td>
</tr>
<tr>
<td>Sandstones, conglomerates, and sandy shales with <em>Arietitids</em> and brachiopods</td>
<td></td>
<td>250 to 300</td>
</tr>
</tbody>
</table>

[Metamorphic Series below.]

The Yakacik Lias also contains interbedded polygenetic conglomerates (Bailey & McCallien, 1953, p. 427).

Omitting the great numbers of *Phylloceratina* and *Lytoceratina*, which are useless for accurate dating, the following are some notable ammonite genera and species.

Lower Bajocian, Opalinum Zone (Bayburt, Kayabashi)
- *Leioceras* sp.
- *Walkericeras* sp.
- *Eryctes* sp.

Toarcian, Jurense Zone (Bayburt)
- *Pleydellia aalensis* (Ziet.)
- *Pseudolioceras*
- *Pseudogrammoceras*
- *Dumortieria*, 6 spp.
- *Phymatoceras tirolense* (Hauer)

Toarcian, Bifrons Zone (Bayburt; ? Kesiktash)
- *Hildoceras* spp.
- *Hildaites* sp.
- *Catacoeloceras* spp.

Pliensbachian, Margaritatus Zone (Merzifun, Kesiktash)
- *Arieticeras*
- *Coeloceras limatum* Pompeckj
- *Coeloceras* spp.
Pliensbachian, Jamesoni Zone (Reksene, Merzifun, Deredolu)

*Uptonia* spp.
*Phricodoceras taylori* et spp.
*Polymorphites*
*Tropidoceras*
*Coelodoceras ponticum* (Pia) (Akdagh)

Sinemurian, Raricostatum and 'Armatum' Zone (Reksene, Deredolu)

*Eoderoceras* cf. *armatum* (Sow.)
*Epideroceras* spp.
*Echioceras*, 18 spp.
*Microderoceras* spp. [? Turneri Zone]

Sinemurian, Bucklandi Zone (Kesiktash, Deredolu)

*Arietites rotiformis* (Sow.)
*Arietites* cf. *latesulcatus* (Quenst.)
*Arietites* cf. *rotator* (Reynes)

On the evidence of a *Spiriferina moeschi* Haas and *Terebratula* cf. *punctata* Sow., Arthaber (1915, p. 198) believed that Lower Lias exists at Tsherkessli, near Ismid, on the east coast of the Sea of Marmara, and Altinli (1943, p. 89) describes limestones in the coast range near Bursa (Brusa) which he believes to be Domerian. Doubtful Bajocian also occurs here and at Yakacik, near Ankara (Chaput, 1936, p. 243), but in the east, at Bayburt, Upper Jurassic rests on Upper Toarcian (Ketin, 1951, p. 119).

**Upper Jurassic of Anatolia**

Records of post-Liassic faunas are scarce. After the basal Bajocian (Opalinum Zone) of Bayburt and Kayabashi, mentioned above, the next-youngest unequivocal fauna known is Callovian, probably Middle Callovian. This occurs at Yakacik (Jakadsik) near Ankara, where *Posidonia alpina* is recorded, with *Phylloceras* cf. *kudernatschi* Hauer, *Reineckeia*, *Perisphinctes* and *Oppelia*, the facies recalling that of the Basses-Alpes (Vadasz, 1918). The occurrence of *Posidonia* suggests connexion with the Posidonia shales of the Crimea and the Caucasus. To the same age is to be dated *Indosphinctes abichi* (Neumayr & Uhlig), another Caucasian species, figured by Gugenberger (1929, p. 451, pl. xii, fig. 23) from Merzifun and incorrectly referred to the Kimeridgian. It seems to be identical with *I. choffati* (Par. & Bon.) from the Callovian of Hungary, as figured by Loczy (1915, p. 412, pl. x, fig. 7, pl. xi, fig. 6).

Callovian ammonites (*Kosmoceras, Hecticoceras, ? Quenstedtoceras* and a Perisphinctid) have also been recorded from the coast range on the Sea of Marmara, in sandstones with basal conglomerates, which overstep the supposed Lias and rest with strong angular unconformity on the folded and eroded Palaeozoics (Altinli, 1943, pp. 91-3). Wilser (1928, p. 216) infers an unsubmerged 'Pontic massif' under the Black Sea in Liassic times.

Oxfordian ammonites are recorded 'three hours' walk SW. of Ankara',

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in a compact grey limestone: namely, *Ptychophylloceras tatricum* (Pusch), *Sowerbyceras tortisulcatum* (d'Orb.), *Perisphinctes 'plicatilis'* (Sow.) and *Peltoceras arduennense* (d'Orb.) (d'Archiac in Tchiatcheff, 1853-69, pp. 83-6). Other records of Oxfordian fossils near the north coast, east of Amasra, and elsewhere (Philipson, 1918, pp. 12-13, 61) are more equivocal and require confirmation. *Sowerbyceras tortisulcatum* (d'Orb.) has been figured from Yakacik, and a *Peltoceras* sp. (not *athleta*) and an Upper Oxfordian Perisphinctid (not *plicatilis*) from Etimesgut, near Ankara (Stchepinsky, 1946, pl. xi, figs. 5, 4, 6); also Upper Oxfordian or Lower Kimeridgian Perisphinctids (pl. xi, figs. 8-11; also Stchepinsky, 1942) and Tithonian Berriasellids (pl. xii, figs. 1-3) from Gümüşane.

The Tithonian and perhaps also Berriasian is represented in the coast range south of the Sea of Marmara by compact, sublithographic and locally dolomitic limestones with the Infusorian *Calpionella*, also Radiolaria (*Coenosphaera*, a form identified in the Hawasina Cherts of Oman by Davis, 1950, p. 208), sponge spicules, Foraminifera, etc. These beds pass down without interruption into the sandstones from which Callovian ammonites were recorded (Altinli, 1943, pp. 93-7). A little to the east, between Gemlik and Bursa (Brusa), however, the Tithonian sublithographic limestones with *Calpionella*, Radiolaria and sponge spicules pass laterally into pseudo-oolites and coral limestone of 'calcaire à entroques' type where they cross over a swell in the Palaeozoic floor near Diskaya. The Tithonian limestones transgress unconformably over folded Permocarboniferous shales and Permian *Fusulina* limestones and are in turn overlain disconformably by Upper Cretaceous limestones which contain several layers of radiolarites (Erk, 1942).

The only evidence for contemporary volcanicity in the Jurassic of western Anatolia is the presence of a bed of red volcanic tuff in the supposed Middle Jurassic of the coast range south of the Sea of Marmara (Altinli, 1943, p. 92), but in the NE., near Bayburt, there are andesitic lavas and tuffs in between ammonitiferous Lower and Middle Lias, and also in the Sinemurian and Upper Toarcian sediments (Ketin, 1951) (see p. 350).

**CYPRUS**

The island of Cyprus preserves in its northern Kyrenia range a fragment of the outermost arc of the Taurus thrusts. The thrusting probably occurred at more periods than one but culminated in the late Miocene, when narrow slices were driven on steeply-inclined planes southward against the foreland, represented by the central and southern parts of the island (Henson & others, 1949). On the foreland no Jurassic rocks are known; it is inferred that if any were deposited they were condensed and thin, this having been a swell subject to intermittent uplift. The rocks present in the Kyrenia range, on the contrary, indicate considerable subsidence and deposition, perhaps continuous from Triassic to the end of the Jurassic. The Jurassic is represented by the Hilarion Limestone,
a hard, compact, partly metamorphosed limestone, varying in colour from black to white and sometimes oolitic, which still remains to be studied in detail. The thickness has been variously estimated at 1500 m. and 'not greater than 300 m.'. The only fossils so far obtained are the hydrozoan \textit{Ellipsactinia} and a coral, \textit{Cladocoropsis mirabilis} Felix, described from similar poorly-fossiliferous limestone in Dalmatia, which there lies above the Lias and below the Middle Kimeridgian Lemes Beds (see p. 193).

![Geological sketch-map of the Crimea.](http://jurassic.ru/)

\textbf{The Crimea}

Both structurally and stratigraphically the SE. part of the Crimean peninsula (fig. 51) represents a detached prolongation of the northern slope of the Caucasus. It is an area remarkable for great thicknesses of strata (Oxfordian-Kimeridgian, and Tithonian, each up to 600 m.), leading up to the enormous totals reached in the Caucasus, and for strongly-developed intra-Jurassic folding. It is for these foldings that the Crimea has become famous, for they constitute the type for the Cimmerian movements. The name is taken from the ancient Greek settlement of Cimmerium, at Mount Opuk (570 ft.) on the north coast of the Kertch peninsula, in the eastern Crimea, and from the half-mythical Cimmerian people. Suess ('Face of the Earth', vol. i, p. 474) recognized two periods of folding: one between Trias and Lias, the other between Jurassic and Cretaceous. Stille (1924, 'Grundfragen', p. 132) called these the older
and younger Cimmerian orogenies and showed that there were several other phases, extending from pre-Rhaetian to Valanginian. Subsequent work has shown that there are in fact important unconformities and conglomerates in the Crimea at the base of the Bajocian, the Oxfordian, the Tithonian, and the Hauterivian, but only very doubtfully between the Rhaetian and Lias and not between the Jurassic (Tithonian) and Cretaceous (Berriasian). The term Cimmerian is therefore not used here. (For further discussion of these movements see p. 636.)

The Tithonian and Lower Cretaceous beds are best seen about Theodosia, the lower stages farther SW. The following is a general summary, based, where not stated to the contrary, on Moisseiev (1937).

Valanginian and Hauterivian (50 m.)
Clays and marls. Ammonites monographed by Karakash (1907).

Berriasian (100 m.)
Marls and clays with thin breccia-like limestones rich in ammonites, monographed, with those of the Tithonian, by Retowski (1893).]

Tithonian (up to 600 m.)
Marls with bands of limestone, sometimes conglomeratic; *Aptychus punctatus* Voltz abundant. Ammonites monographed by Retowski (1893).

(Unconformity: Nevadan phase)

Kimeridgian (c. 200 m.)
Compact reddish limestones and argillaceous limestones, with gastropods, *Solenopora, Diceras*, etc., and rare ammonites, including *Aspidoceras acanthicum* (Oppel).

Upper Oxfordian (150-400 m.)
The Kimeridgian passes down into thick coralline and Nerinean limestones with a rich molluscan fauna but without ammonites. These beds closely resemble the Rauracian and Sequanian of the Jura. No Lower Oxfordian is known. At the base of and sometimes replacing these limestones so as directly to pass up into the Kimeridgian are up to 150 m. of coarse conglomerates and sandstones, which in places rest on eroded Lower Jurassic and Trias.

(Unconformity: Agassiz (= Yaila) phase)

Callovian
A rich Middle and Upper Callovian ammonite fauna has been described (de Tsytovitch, 1912) from vertical beds of green calcareous sandstone on the shore at Sudak. It includes numerous Hecticoceratids, also *Erymnoceras coronatum, Kosmoceras, Peltoceras*, Perisphinctids, Phylloceratids

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and Lytoceratids, including most of the forms of the last three families that are also recorded from the Balaclava Shales. At Mount Perchem conglomerates are interbedded. *Macrocephalites* is recorded from the Balaclava Shales, the top of which is therefore Callovian.

**Bathonian**

Balaclava Shales (main part) with *Posidonia buchi*, exposed round Balaclava Bay. *Oxycerites 'fusca' and aspidoides* are recorded (Moisseiev, 1937, pp. 37, 53), with abundant Phylloceratidae, Lytoceratidae (especially *L. adeloides* (Kud.)) and Perisphinctids (Stremoukhoff, 1894, p. 323; 1898).

**Bajocian** (up to 1000 m.)

Inland, *Parkinsonia parkinsoni* is recorded with plant-remains (Moisseiev, 1937, p. 53) in the shale, which must therefore extend from Upper Bajocian to Callovian (as do similar *Posidonia* shales in other places, such as Algeria and Sicily). The outstanding feature of the Bajocian in the Crimea, however, is the Bitak series of conglomerates and sandstones, which locally comprises conglomerates not less than 1000 m. thick. This series rests unconformably on folded Lias and represents the principal Jurassic orogeny of the Crimea. It was followed by eruption of lavas and tuffs. Fossils are scarce but include *Meleagrinella echinata, Posidonia buchi* and plants.

(Unconformity: Donetz phase)

**Lias** (about 150 m.)

As in the Caucasus, the Lias is chiefly represented by shales and sandstones with plant-remains (Gresten facies), but locally these are followed by 1-3 m. of crinoidal limestone with many Pliensbachian brachiopods such as *Spiriferina* spp., or by limestones with Toarcian ammonites, *Lytoceras jurense*, 'Coeloceras', etc. In some places more micaceous shales follow above, to a thickness of a few tens of metres. The beds below the limestones in places contain conglomerates of quartz and sandstone pebbles, and they may pass down into the Rhaetian.

('hypothetical Salghir phase'; Moisseiev, 1937, p. 13)

Submarine eruptions of andesitic lavas, agglomerates and tuffs occurred during the Bajocian-Bathonian, and some activity continued into the early Callovian (Federovitch, 1927).

**The Caucasus**

The Caucasus ranges are one of the largest Jurassic areas, and perhaps the most varied, complete and important in the world. From Black Sea to Caspian stretch 500 miles of continuous Jurassic outcrops, with an average width of 50 miles. In some places there was sedimentation to

http://jurassic.ru/
FIG. 52.—Jurassic outcrops of the Caucasus and Little Caucasus and some neighbouring areas. Based mainly on the Russian Geological Survey map. (Outcrops in the Elburz omitted: see fig. 53.)

http://jurassic.ru/
immense thicknesses, in other places emersion, isoclinal folding, subaerial volcanism and outbreaks of lava from submarine fissures, all during Jurassic times. In attempting to synthesize such a region there is a choice between a catalogue of observations, in which the reader would become lost in a mass of detail and a maze of outlandish names, and a brief summary of the area as a whole. The second choice is rendered inevitable both by reason of space and by the fact that observations backed by modern work on the ammonites are still so scattered, and separated by so many gaps, that nothing like completeness could yet be achieved even were all the known details presented.

In broad outline the structure of the Caucasus is an anticlinorium. In the western half the Jurassic formations are pierced by an elongated central core of crystalline rocks, igneous and metamorphic, partly Palaeozoic but mainly older, rising in the central Caucasus for many miles above 10,000 ft. Upon it stand the late-Pleistocene to Recent volcanoes of Elburs (18,523 ft.) and Kazbek (16,546 ft.). In general the Jurassic sediments dip off the flanks of this watershed in parallel ranges falling northwards in the Kuban and southwards in Georgia. The eastern half consists entirely of Jurassic rocks (perhaps older in the centre) which in Daghestan form a series of parallel ranges in the south limb of the main anticline, and a great plateau, cut by gorges of north-flowing rivers, in the north limb. In general, however, the outcrops trace a series of concentric ellipses, the youngest formations on the outside, the oldest in the centre. The central Main Ridge of Daghestan consists of isoclinally folded metamorphic slates, phyllites, quartzites, etc., of which the age is still questionable: they may be Lower Liassic, Triassic, or even in part Palaeozoic.

The unmetamorphosed sedimentary series of proved Liassic age is immensely thick (8500 m. for the Toarcian and Lower Bajocian alone) and in places rests directly on pre-Cambrian gneisses with a basal conglomerate; and even the Bajocian contains granitic debris. Right up to the Upper Bajocian the rocks are coal-bearing, with in some places only minor marine intercalations. On these grounds it has generally been supposed that the crystalline core was an island in Jurassic times, but long strips of Liassic sediments faulted into the midst of it, shown on the Russian Geological Survey map of 1929, make this interpretation extremely doubtful and suggest that the plant-remains are drifted. The elastics appear to have been derived from the north (Mokrinskij, 1939).

A fully marine regime became established in some places in the Pliensbachian and probably everywhere during the Bajocian. The subsidence was accompanied in the Middle Bajocian by volcanism, which produced great thicknesses of tuff in the sediments of the southern slopes of the western Caucasus and in the outcrops of the Little Caucasus, to the south of the Kura River basin. At the same time there was a massive outflow of submarine lava. This series in Georgia is 2000 or even 3000 m. thick (Mokrinskij, 1939, p. 509). The scene of maximum volcanicity appears to have been the north-eastern Little Caucasus. Here the
1000–3000 m. of Middle Bajocian sediments and volcanics are followed by 650 m. of quartz porphyry assigned to the Upper Bajocian, and continuance of intermittent volcanism is proved by pyroclastics interbedded in all parts of the 2000 m. or so of overlying Bathonian, Callovian, Oxfordian and Kimeridgian. Only the Tithonian limestone is free (Leontyev, 1950).

While these events were in progress in the west and south, uniform sedimentation went on in Daghestan, resulting in an unbroken series of dark shales with nodules, spanning all the stages from Toarcian to Middle Callovian.

In late Kimeridgian times the Nevadan movements convulsed the western region, producing isoclinal folds and profound erosion. Across the eroded structures so formed the Tithonian sea spread unconformably, as in the Crimea. Unfortunately, work on the Tithonian sediments has not progressed to the point where it is possible to date the transgression precisely; but the light-coloured coral and shell limestones, which form so strong a contrast with the dark shales and sandstones of most of the earlier Jurassics, contain some of the fauna both of the Stramberg Tithonian and the Lower Volgian of the Moscow basin, with additional elements of the Spiti Shales. In any case the transgression was progressive, for in the southern Caucasus the Tithonian is completely overlapped by the Valanginian.

The marine period initiated with the Tithonian transgression lasted until the end of the Cretaceous. Then began the emergence of the present Caucasus, which was thrown up by successive orogenies in the early, middle and late Tertiary. The extent of these orogenies may be gauged by the occurrence of Jurassic sediments thrust over Upper Cretaceous, and by the elevation of Middle Tertiary deposits to heights of over 2000 m. above the sea; and even Pliocene deposits have been folded and elevated to over 1000 m. (Stahl, 1923; p. 54).

The Jurassics of the Caucasus and Crimea were deposited in a marginal trough fringing the southern edge of the Russian platform and perhaps separated by land from Anatolia (Wilser, 1928; Egeran, 1947, pl. 2). Deposition and sedimentation were extremely active in the Lower Lias period: a point of correspondence with the Elburz and not with Anatolia. The Anatolian Lias agrees rather with that of the Central Iranian plateau, and both are situated on ground that in the Tertiary orogeny developed as ‘median masses’. For elaborate palaeogeographical maps see Mokrinskij (1939) and for a sketch of the tectonics, with many references, Renngarten (1939).

**Tithonian**

Typical light-coloured Tithonian limestones and dolomites are well developed in many parts of the Caucasus, especially in Daghestan. They have locally a basal conglomerate and in the north Caucasus overstep unconformably on to lower stages down to the crystallines. The facies is often coralline, with *Nerinea*-limestone, especially in the upper part.
It is thus not surprising that ammonites are scarce and exact dating inconclusive. The facies is central European and Mediterranean, but Russian elements are reported: e.g. Dorsoplanites in the Nerinea-limestones in Daghestan (Oswald, 1914, p. 11), Pavlovia in Kuban (R. Douvillé, 1910) and Lomonossoveella lomonossovi (Visch.) in Daghestan (Renz, 1913, p. 663). There are connexions with Stramberg and the Spiti Shales, especially in the Tuapse region, at the extreme western tip of the Jurassic outcrops, from which a number of ammonites of Kimeridgian aspect have been figured (Khudyaev, 1932), some under unnecessary new names. Stratigraphical collecting in future may be expected to throw important light on the Tithonian succession; especially if the stratigraphical relation of the Russian elements to the Stramberg and Spiti elements could be established.

On the north slope and in Daghestan the Tithonian limestones pass up with complete conformity into similar limestones and dolomites dated to the Valanginian, but on the south slope of the central Caucasus the Valanginian rests unconformably on Middle Jurassic and on gneiss (Oswald, 1914, pp. 10-11).

In the Nalchik region of the north Caucasus, compact limestones and limestone breccias up to a thickness exceeding 600 m., with pelecypods, are attributed to the Tithonian (Pchelintzev, 1931).

LOWER KIMERIDGIAN

Various places on the northern slopes have yielded samples of the Lithacoceras and Ataxioceras fauna of the Tenuilobatus Zone of Crussol, which Khudyaev (1932) identifies with a number of species figured by Fontannes. The material is poor and the specific attributions are questionable, but the dating is correct. Assemblages without ammonites, probably Lower Kimeridgian, have been figured from the Kuban by Pchelintzev (1931, 1933). From the neighbourhood of Guli in Daghestan Renz (1913, pp. 652-3, 692) lists numerous species of Idoceras, Simoceras and Nebrodites (with two Phylloceratids) which point to approximately the same horizon and comprise links with the Mediterranean region, especially Sicily.

UPPER OXFORDIAN

The Bimammatum Zone appears to be represented by red and grey limestones (dolomitic on the north slope of the central Caucasus) with marls and volcanic tuffs (on the Dsirula dome), from which are recorded Amoeboceras alternans and a varied non-cephalopod fauna (Oswald, 1914, p. 11). Perisphinctes caucasicus Khudyaev (1932, pl. iii, fig. 3), from the Tuapse region and recorded as Tithonian, looks likely to belong to this horizon or the Transversarium Zone (cf. de Riaz, 1898, pl. vii, fig. 4, pl. ix, fig. 2).

To the Transversarium Zone have been referred reddish limestones with Sowerbyceras tortisulcatum (d’Orb.) in the central Caucasus, and

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the Khaltan series of glauconitic sandstones with 'Perisphinctes plicatilis' in the SE. Caucasus (Oswald, 1914, p. 11), and there are also records of Perisphinctes marnesiae de Loriol and Aspidoceras perarmatum (Sow.) (Khudyaev, 1932); but none of these forms has been figured. Upper Callovian Perisphinctids were figured under Upper Oxfordian names by Neumayr & Uhlig (1891, pl. iv, figs. 2, 3).

LOWER OXFORDIAN

In Daghestan Renz (1913, p. 691) records from near Guli various Perisphinctids, of which the only one figured (pl. xxix, fig. 5) is a Properisphinctes aff. bernensis (de Loriol) (cf. Arkell, Mon. Am. Engl. Corallian Beds, pl. lxi, fig. 5), and he figures from Arakani (pl. xxix, fig. 3) Cardioceras (Scarburgiceras) subexcavatum Maire; while Oswald (1914, p. 11) mentions Peltoceras arduennense from the same region. In the western Caucasus Oswald (1914, p. 12) records grey limestones with Properisphinctes bernensis (de Loriol) and Prososphinctes mazuricus (Bukowski); and from the northern slopes Khudyaev (1932) recorded Proscaphites aff. richei (de Loriol). All these forms indicate the Mariae Zone.

UPPER CALLOVIAN

Ammonites of the Lamberti and Athleta Zones are strongly represented. In Daghestan (Renz, 1904, p. 85) the Upper Callovian consists of grey shaly sandstones with sandy and calcareous intercalations, resting on thick-bedded yellow sandstones. From these beds come Peltoceras athleta. From the north Caucasus Quenstedtoceras brasili, henrici and praelamberti have been figured, as well as numerous Hecticoceras of familiar west European species (Chickhachev, 1933). From Upper Callovian or Lowest Oxfordian beds also come Hecticoceras (Putealiceras) schumacheri (Noetling) and H. socini (Noetling), two species of Mount Hermon in Syria, recorded by Renz (1913, p. 691) from Sumbatul in Daghestan, as also Hecticoceras (Brightia) daghestanicum Neumayr & Uhlig sp. (1892, pl. vi, fig. 1), which appears to be close to H. (B.) subnodosum Tsytovitch (1911, pl. vi, fig. 8). The Upper Callovian with Peltoceras athleta has been separated stratigraphically from the Middle with Erymnoceras and Kosmoceras in the north Caucasus by Nikshick (1915) and in Daghestan by Kazansky (1909). Quenstedtoceras is also recorded from Georgia (Djanelidze, 1932).

MIDDLE CALLOVIAN

In the north Caucasus the Middle Callovian is strongly represented by rich ammonite faunas of the European Coronatum and Jason Zones. Among species figured are Erymnoceras coronatum (Brug.) and others, Kosmoceras jason (Rein.), K. castor (Rein.), K. aff. gulielmi (Sow.) and others, and Hecticoceras pseudopunctatum (Lahusen), with which occur some Phylloceras spp. (Nikshick, 1915; Chickhachev, 1933). Reineckeia anceps (Rein.) is recorded from Chod in the central Caucasus and from Daghestan
(Neumayr & Uhlig, 1892, p. 52). Probably from the same zone comes *Indosphinctes abichi* (Neumayr & Uhlig), a link with Cutch and Anatolia.

In Daghestan (Renz, 1904, p. 85) the Middle Callovian represents the highest part of a thick series of black shales with nodules, which extends down unchanged into the Toarcian and is one of the most characteristic features of a vast area. These beds are locally developed as impure limestones which yield *Erymnoceras, Kosmoceras*, etc. (Kazansky, 1909).

**LOWER CALLOVIAN**

Callovienne and Koenigi Zones. Species of *Kepplerites* and *Proplannulites* were already figured by Neumayr & Uhlig (1892, pl. iii, fig. 4, pl. iv, fig. 1), who also recorded *Cadoceras* spp. and *Chamousetia chamousseti* (d’Orb.). In the north slopes of the Caucasus the beds belonging to these zones have been separated from the Middle Callovian (Nikshick, 1915), but separation from the Macrocephalus Zone has not yet been attempted. Some and perhaps all the Macrocephalitids figured from Georgia (Radcha) by Djanelidze (1932), however, are late forms of the Koenigi Zone. *M. colchicus* Djan. (pl. vi, fig. 3) is a typical *Pleurocephalites* which might easily have come from Cocklebury Hill, Chippenham, from the Kellaways Clay. This and (for some of the beds) an even later dating is borne out by the associated *Cadoceras, Reineckeia* and *Choffatia* spp. figured (pl. iii, figs. 3-5). The *Aspidoceras* (pl. i, fig. 2), however, must be Upper Callovian; and it comes from a different locality.

Macrocephalus Zone. The existence and strong representation of this zone in at least the northern Caucasus is put beyond doubt by two plates of photographs published by Ilyin (1932). These show typical *Dolikephalites typicus* Blake, var. *balkarensis* Ilyin, *Macrocephalites* sensu stricto (pl. ii, fig. 1, 2) and *Kamptokephalites* (pl. ii, fig. 3), all of which might have come from the English Upper Cornbrash.

**BATHONIAN**

The black shales with nodules in Daghestan probably span the whole Bathonian, but so far few ammonites have been collected that can definitely be so dated, and of these none has been figured. From Guli, Renz (1913, p. 690) lists *Parkinsonia ferruginea* (Oppel) and *Lissoceras psilodiscus* (Schloenb.) which indicate Lower Bathonian, *Perisphinctes moorei* Oppel which may be a *Procerites*, also *Cadomites rectelobatus* (Hauer), *Phylloceras kudernatschi* Hauer and *Lytoceras adeloides* (Kud.). Neumayr & Uhlig (1892, p. 88) have a similar list from Gunib, but the *Stephanoceras* they figure (pl. v, fig. 3, pl. vi, fig. 2) is not *C. rectelobatus* (Hauer), from which it differs by its steadily enlarging ribs, which are still becoming blunter and more distant on a septate whorl; this is no doubt a Bajocian form. Neumayr & Uhlig (p. 103) admitted that their material did not warrant any attempt to distinguish Bathonian from Bajocian.
In the basin of the Belaia River, on the north slopes of the Caucasus, clay shales of the Garantiana and Parkinsoni Zones are overlain by *Phylloceras* beds of supposedly Bathonian age, and then an unfossiliferous series, upon which rests the Callovian with a basal conglomerate and signs of discordance (Nikshick, 1915). In the Kuban *Lissoceras psilodiscus* and *Oppelia fusca* are recorded above the Parkinsoni Zone (Zatvornitzky 1914).

In the separate outcrop south of the basin of the Kura River the Bathonian occurs in its typical neritic facies with quantities of brachiopods and pelecypods, referred to common European species. The only ammonites known are *Calliphylloceras achtalense* (Redlich), *Lytoceras polyhelictum* Böckh, and a Perisphinctid (Redlich, 1894). These were collected near the railway at Achtala, 53 km. south of Tiflis. *Lytoceras polyhelictum* Böckh is a species of the Klaus Beds in the Alps, but in Daghestan, Kuban and Georgia it has been found with ammonites of the Parkinsoni Zone (Upper Bajocian) (Kakhadze, 1937, p. 152). Two Perisphinctids, *P. loczyi* Papp and *P. daghestanicus* Papp (1907, pl. vii), if really Bathonian, may be *Gracilisphinctes* or perhaps *Pseudoperisphinctes*; but the drawings are inadequate. In the north-eastern Little Caucasus volcanic rocks and sediments assigned to the Bathonian are said to be up to 2500 m. thick (Leontyev, 1950).

**Bajocian**

The Bajocian is complete and highly fossiliferous, from Daghestan in the east to western Georgia in the SW. and the Kuban in the NW. In the black shales of Daghestan ammonites are incredibly abundant and reproduce in species and preservation the facies of the Swabian Jura, Normandy and Dorset. Renz (1904, p. 84) was able to recognize the Opalinum, Murchisonae, Sowerbyi (or Concava ?), Sauzei, Humphriesianum and Parkinsoni Zones. Most abundant of all are Stephanoceratids, which include *Stephanoceras, Stemmatoceras, Skirroceras, Normannites, Otoites, Emileia, Erycites, Chondroceras*; there are also *Sonninia, Witchellia, Ludwigia, Leioceras*, etc., and many Parkinsonids and Perisphinctids. (Long lists and some figures in Renz, 1904, 1913; Neumayr & Uhlig, 1892). With them are also great numbers of Phylloceratids and Lytoceratids; and although the numbers of species are not great, in numbers of individuals these families equal all the other ammonites. Renz (1913, p. 700) explains this by supposing that they were drifted, with associated fossil wood, from more southerly seas, but no evidence for this having since appeared from adjacent regions of the Middle East, the whole assemblage must be assumed to have lived together.

In western Georgia there is a similar wealth of Middle and Upper Bajocian ammonites, which occur in sandstones and shales interbedded with tuff-breccias and porphyritic volcanic rocks (Kakhadze, 1937, with 8 plates of ammonites). The Bajocian clastics are sometimes composed of weathering-products of granite. The volcanic effusions are
dated to the Sauzei and Humphriesianum Zones. (See also Kakhadżé, 1943.)

On the north slopes of the western Caucasus, in Kuban, the Bajocian is represented in a great series of sandy clay-shales at least 500 m. thick and expanding westwards. At the base occur Ludwigia murchisonae (Sow.) and many other ammonites; a long way higher occurs Oppelia subradiata (Sow.) with many Phylloceratids and Lytoceratids and Lissoceras aff. oolithicum (d'Orb.); then come 30 m. of clayey sandstones with Strenoceras subfurcatum; and finally clays with Parkinsonia. In some places, however, the whole Lower and Middle Bajocian, up to the Subfurcatum Zone, are represented by coal-bearing sandstones like those of the Lias, and the Subfurcatum Zone may be as much as 100 m. thick. The Upper Bajocian hereabouts yields interesting assemblages of Strenoceras, Garantiana and Parkinsonia, including new forms (Zatvornitzki, 1914, with 2 pls. of ammonites). The heavily-auriculate dwarf Cleistosphinctes asinus (Zat.) (pl. xvii, fig. 20) is a close relative of C. cleistus (Buckman) (1920, Type Am., pl. CLXI) from the Subfurcatum Zone of Dorset. In the north-eastern Little Caucasus the Bajocian is said to be up to 5000 m. thick, with important volcanic rocks throughout (Leontyev, 1950).

TOARCIAN AND LOWER BAJOCIAN

In the eastern Caucasus the Toarcian and Lower Bajocian are developed as immense thicknesses of shales, sandy shales and sandstones, altogether 8500 m. thick. The succession according to Golubyatnikov (1940) is as follows:—

Alternating sandstones and shales, with Ludwigia murchisonae, Graphoceras concavum, Leioceras acutum, up to 2000 m.

Alternating shales and sandstones with Leioceras opalinum, Pseudolioceras beyrichi (Schloenbach), Dumortieria moorei (Lycett), D. levesquei (d'Orb.), etc., 2400 m.

Shales with conspicuous sandstones: Grammoceras thouarsense (d'Orb.), G. fallaciosum Bayle, etc., 1000-1200 m.

Shales alternating with sandy shales and sandstones: Peronoceras subarmatum auct. (P. verticosum Young & Bird sp.?), 1000 m.

Shales with several patches of thick sandstones: Hildoceras cf. gyrale Buckman, Harpoceras cf. exaratum (Young & Bird), 2100 m.

Renz (1904) also described the black shales of Dagestan as continuing down through the Upper Lias, with Posidonia bronni and Harpoceras serpentinum (Rein). Limestones and marls of Toarcian age have been recorded from various other parts of the Caucasus.

MIDDLE AND LOWER LIAS

The lowest Jurassic beds all over the Caucasus consist of dark plant-bearing shales and sandstones with seams of coal, a facies similar to the Gresten Beds of Austria, and attaining great thicknesses. Occasionally
there are thin marine intercalations. The earliest ammonite horizon known to Neumayr & Uhlig (1892) yielded abundant Analitheus margaritatus and what appears to be a Galaticeras (pl. iii, fig. 3). A lower bed with Cardinia cf. philée d'Orb. and other lamellibranchs was also thought to be Pliensbachian or highest Sinemurian by these authors and by Renz (1904, p. 84), but Oswald (1914, p. 13) assigned it to the Hettangian. He added that the coal series lies unconformably on the Palaeozoic schists and contains pebbles of them in its basal conglomerate. The same is true in the Little Caucasus, where there is a massive basal conglomerate resting on Lower Palaeozoics (Leontyev, 1950).

In the eastern Caucasus, according to Golubyatnikov (1940) the enormously thick Toarcian shales rest upon 3000 m. of strongly metamorphosed shales known as ‘Slates of the Main Ridge’, in the upper part of which occur Upper Pliensbachian ammonites of the Apennines: Arieticares exiguum (Fucini), A. falciplicatum (Fucini), Fuciniceras bonarelli Fucini. From this he infers that the lower parts of the slates represent earlier divisions of the Lias. Oswald (1914, p. 13) also states (following Abich) that in Daghestan the lower parts of the Lias are represented by unfossiliferous calc-schists, argillaceous schists and crystalline limestones. It seems more probable that the metamorphic rocks are Triassic as suggested by Renz (1913, p. 702) and received their metamorphism in a pre-Rhaetian orogeny.

**TRANS-CASPIA**

The minor mountain and hill ranges on the east side of the Caspian Sea, on the peninsula of Mangyshlak and at Tour-Kyr, lie in Asia and may be outer ripples of the great ranges of SW. Asia, but they are generally considered a continuation of the folds of the Donetz (Arkhangelsky & Schatsky, 1933). They consist essentially of anticlines of Jurassic and Triassic beds, planed before the Upper Cretaceous and re-elevated in the Tertiary (fig. 52).

Most of the Jurassic is represented. The series begins with quartzose conglomerate and continental sandstones containing plants and coal-seams, probably representing the Lias, as in the Elburz (see below). The first marine horizon known is Upper Bajocian, with Parkinsonia and Ostrea acuminata Sow. The Parkinsonia (Eichwald, 1871, pl. 1, figs. 6, 7, and Semenow, 1896a, p. 124) was confirmed by Borissjak (1908, p. 90), but the supposed Oppelia subradiata (Semenow, 1896a, pi. ii, fig. 1) is a Callovian Hecticoceras (Sublumiloceras) cf. lahuseni Tsyt. (cf. Couffon, 1919, Callovien du Chalet, pl. xiv, fig. 5). The Callovian is the best-known stage as regards ammonites; from it have been figured Macrocephalites pila Nikitin (Semenow, 1896a, pi. ii, fig. 2), Catasigaloceras sp. (pi. ii, fig. 6), Kepplerites sp. (pi. iii, fig. 2), Reineckeia and Proplanulites (pl. ii, figs. 5, 7), Choffatia (pl. iii, fig. 3) and Pseudopeltoceras (pl. iii, fig. 5), Kosmoceras, Quenstedtoceras, etc. The Lower Oxfordian is represented by Goliathiceras andrussovi Sem. sp. (pl. ii, fig. 3). There follows

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a series of limestones and marls with numerous pelecypods and other fossils which appear to carry on high into the Kimeridgian, but ammonites are not yet known. (For discussion see Uhlig, 1911, pp. 379-80.) The Neocomian contains a well-developed Polyptychites horizon, also of northern affinities (Luppov, 1935).

Farther east, in Bokhara, exposures are few and far between and little known. A facies resembling the Alpine 'Couches à Mytilus' occurs (Borrisjak, 1910), but the only ammonite figured is the Callovian Gross­ouvria bucharica (Nikitin, 1889, pl. viii).

(Some references for this section are listed with those for European Russia.)

AZERBAIJAN

The old name Azerbaijan is the most convenient for a region of mountains south of the Caucasus and now partly in NW. Persia, partly in Turkey (Armenia) and partly in the modern Armenian and Azerbaijan republics of the U.S.S.R., where important but little-known Jurassic outcrops occur.

Julfa Gorge

Where the River Aras or Araxes, draining the highlands of Armenia, flows down between the Little Caucasus on the north and Mount Ararat on the south, it passes near Julfa on its way to the Caspian Sea by a rocky gorge. The Julfa (Djoulfa) Gorge, about 75 miles NW. of Tabriz, is just on the Russian side of the frontier with Persia. It exposes a succession from Carboniferous to Oligocene (Bonnet, 1912, 1912a, 1947).

On Lower and Middle Trias there succeeds up to perhaps 1000 m. of compact black limestones and more or less cavernous black dolomite without fossils. Owing to its likeness to the Alpine dolomites Bonnet considered this series Upper Triassic, but by comparison with Persia and Baluchistan a partly Liassic age cannot be excluded. It is overlain conformably by 100-200 m. of basalt, and that in turn, also conformably, by Middle Jurassic sediments. Then follow a conglomerate and about 700 m. more basalts and tuffs, which are interstratified with the unconformable Cretaceous.

The Middle Jurassic is about 150-200 m. thick, and consists of limestones and shaly marls with Middle Bajocian to Lower Callovian ammonites. Bonnet deciphered the following succession. In the absence of illustrations of ammonites his own nomenclature is retained, with remarks on dating in square brackets.


3-5. Grey limestones, 30-40 m., with a rich, well-preserved fauna Three ammonite levels were recognized:—

5. A level with abundant Oppelia aspidoides; also Phylloceras

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mediterraneum, Parkinsonia parkinsoni, Perisphinctes martinsi. [Evidence (or nomenclature) equivocal.]

4. A level with Oppelia fusca, Oppelia aspidoides, Lissoceras psilodiscus, Striogoceras truellei, Cadomites linguiferus, Parkinsonia parkinsoni, P. neuffensis, Perisphinctes martinsi, Phylloceras disputabile, Lytoceras adeloides, L. tripartitum. [Apparently spans Upper Bajocian (Parkinsoni Zone) and Lower Bathonian (Zigzag Zone).]

3. A level characterized by Oppelia subradiata (Sow.); with Striogoceras truellei, Lissoceras cf. oolithicum, Cadomites linguiferus, Stephanoceras humphriesianum, Parkinsonia parkinsoni, P. ferruginea, P. schoenbachii, Perisphinctes martinsi, Morphoceras cf. dimorphum, Phylloceras viator, P. deslongchampsi, P. mediterraneum, P. disputabile, P. velaini, Lytoceras pygmaeum. [Upper Bajocian, assuming Stephanoceras humphriesianum to be a misidentification.]

2. Grey shaly marls, 40-50 m., with some well-preserved ferruginous Phylloceras and other ammonites generally crushed. Phylloceras disputabile, P. circe, P. mediterraneum, P. velaini, with Posidonia alpina Gras var. striatula Gemm. [Evidence insufficient for dating.]

1b. Sandy limestone, about 15 m., containing Sonninia sowerbyi, belemnites and pelecypods. [Middle Bajocian, probably Sowerbyi Zone.]

1a. Coarse sandstone, 2-3 m., with Pecten pumilus. [Lower Bajocian?]

This rests on the basalt flows and incorporates fragments derived from them.

Lake Urmia

Fifty miles south of the Araxes at Julfa lies the great Lake Urmia (Urmii, Urumiya, Ourmiah) (for a general account and good topographical map see Gunther, 1899). The Sahend Mountains east of the lake produced Jurassic ammonites which were long ago figured by Weithofer (1890), who interpreted them as Lower Kimeridgian and Neocomian genera (Ataxioceras and Olcostephanus) with some Toarcian (Harpoceras). Von dem Borne (1891) on the basis of more material was able to confirm the presence of Toarcian but showed that the remaining fauna is neither Kimeridgian nor Neocomian but Middle Callovian (Anceps Zone). This conclusion was reconfirmed by R. Douvillé on the strength of new collections made (all from 5 m. of shales) by Mecquenem in 1905 (Mecquenem & R. Douvillé, 1908).

The ammonites so far known are as follows:—

MIDDLE CALLOVIAN (Anceps Zone)

From nodules embedded in black, bituminous, micaceous or sandy shales, also crushed in calcareous shales:—

Parapatoceras calloviense (Morris)  [Ident. R. Douvillé]
Oppelia aff. subcostaria (Oppel)  [Ident. R. Douvillé]
Oppelia aff. aspidoides (Oppel)  [Ident. R. Douvillé]
perhaps O. tsytovitchi Petitclerc ?

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Hecticoceras (Brightia) aff. metamphalum (Bonarelli) (Borne, pl. i, fig. 6)
Hecticoceras (Lumuloceras) sp. (Ludwigia lunula teste Borne)
Hecticoceras (Putealiceras) cf. punctatum (Stahl)
Hecticoceras (Putealiceras) cf. paulowi de Tsyt. (Borne, pl. ii, fig. 6)
Reineckeia straussi (Weithofer)
Reineckeia weithoferi R. Douvillé (Weithofer, pl. ii, fig. 5)
Perisphinctes (Grossouwria) curvicosta (Oppel?) Neumayr
Perisphinctes (Grossouwria) tetrameræ (Weithofer)
Perisphinctes (Grossouwria) cyrus Borne (pl. i, fig. 2, and pl. iv, fig. 12)
Perisphinctes (Indosphinctes) xerxes Borne
Perisphinctes (Choffatia) balinensis Neumayr

Von dem Borne also believed he had recognized Perisphinctes paneaticus Noetling (1887, pl. iv, fig. 5), an Oxfordian species from Mount Hermon, but whereas that seems to be an Alligaticeras, Borne's figure (1891, pl. ii, fig. 8) shows a finely-ribbed Grossouwria.

LOWER CALLOVIAN ?

Von dem Borne (1891, p. 10) recorded a fragment of large coarsely-ribbed Macrocephalites and a problematic form 'Stephanoceras stenostoma' Borne (not figured) both from a different locality from the rest of the Callovian forms. Both might perhaps be Erymnoceras, but a representative of the Lower Callovian is possible.

UPPER TOARCIAN (Jurense Zone)

Weithofer recognized and figured two fragments of Harpoceratids which he rightly assigned to the group of Dumortieria radians (Reinecke). Von dem Borne renamed them 'Harpoceras' atropatæns Borne and mediae Borne, refiguring the latter and adding a third species kapautense Borne. H. Douvillé (1904, p. 201) did not consider atropatæns specifically distinct from Grammoceras (Pseudogrammoceras) fallaciosum Bayle. In any case, they give a firm dating to the uppermost Toarcian, which is a horizon conspicuous in the Caucasus and the Elburz.

The geological relations of these fossiliferous beds are not known.

THE ELBURZ MOUNTAINS

From the region of Lake Urmia the great arc of folded mountains constituting the Elburz sweeps round the southern shore of the Caspian Sea and continues eastwards in a sigmoid curve through northern Khorassan to join up with the ranges of the Persian-Afghanistan frontier beyond Meshed. South of the Caspian the arc is convex to the south, farther east it is convex to the north. Jurassic outcrops are more or less continuous throughout the range and, except that the Lias up to the Toarcian is generally developed in a carbonaceous 'continental' facies as in the Caucasus, the series is probably complete. The great thickness

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of Jurassic does not favour comparison of the Elburz with the Pyrenees as advocated by Schroeder (1944).

There have been two major orogenies since deposition of the Jurassic rocks. The first and greatest involved overfolding and northward thrusting in the late Cretaceous, or possibly post-Cretaceous, followed by erosion and marine transgression by Eocene and Oligocene seas. Afterwards there was late Tertiary refolding and faulting and outbreak of giant Quaternary volcanoes: a history also similar to that of the Caucasus.

In general the Elburz Jurassic falls into two major lithological and palaeontological divisions: (1) the carbonaceous facies of the Lias, up to 1200 m. thick, perhaps locally much more, which may follow on marine Trias or may overstep on to Palaeozoic and even crystalline schists as near Meshed, and which may contain dense fissile limestones; (2) marine limestones, generally poor in identifiable fossils, but mainly Upper Jurassic in age but extending from at least as early as Bathonian to Tithonian, with thicknesses varying from 1000 m. near Teheran to 1500 m. farther east (Clapp, 1940). In the east the lower part of the limestones and also some sandstones and shales below are Middle Jurassic in age (Bajocian-Bathonian).

The most detailed stratigraphical work so far has been done in the region NE. of Teheran. Where the Heras and Alarm Rivers cut by gorges through the mountains near the giant Quaternary volcano of Demavend (18,600 ft.) there are complete sections. The succession in the Alarm valley is as follows (Bailey & others, 1948, p. 29):

Cretaceous limestones above

<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crumpled Upper Jurassic limestone</td>
<td>400 m.</td>
</tr>
<tr>
<td>Blue limestone with Upper Oxfordian Perispinctids as figured by Fischer (1915) (ident. L. F. Spath)</td>
<td>300 m.</td>
</tr>
<tr>
<td>Thin-bedded limestone, in part at least Middle Callovian with Reineckeia tili Fischer (ident. L. F. Spath)</td>
<td>300 m.</td>
</tr>
<tr>
<td>Shales and sandstones of the Lias</td>
<td></td>
</tr>
</tbody>
</table>

The downward succession is best known in the Jaji Rud gorge, about 14 miles ENE. of Teheran (Bailey & others, 1948, pp. 6, 10) (thicknesses approximate):

<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oligocene green beds</td>
<td>3000 m.</td>
</tr>
<tr>
<td>Eocene marine limestone</td>
<td>10 m.</td>
</tr>
<tr>
<td>Lias—</td>
<td></td>
</tr>
<tr>
<td>Shales and sandstones with Pleydellia aff. subcompta (Branco) Fischer, Pseudogrammoceras aff. fallaciosum (Bayle), and Calliphylloceras cf. nilssoni auct. (ident. L. F. Spath) (Jurense Zone, uppermost Toarcian)</td>
<td>150 m.</td>
</tr>
<tr>
<td>Lias limestone, thin-bedded, fine-grained argillaceous (cementstone), with abundant irregular concretions of pale chert. Unidentifiable ammonites</td>
<td>50 m.</td>
</tr>
<tr>
<td>Basement conglomerate of limestone, local</td>
<td>20 m.</td>
</tr>
<tr>
<td>Carboniferous Limestone</td>
<td>100 m.</td>
</tr>
<tr>
<td>Old Red Sandstone</td>
<td>150 m.</td>
</tr>
</tbody>
</table>

The following treatment attempts a summary of the palaeontological succession on the lines of that for the Caucasus, but the documentation is more meagre and many of the ammonites recorded have been figured.

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inadequately or not at all. The only satisfactory collection of photographs is that to be found in two plates by Fischer (1915). For the Bathonian and Callovian it is possible to be much more precise, thanks to collections made by Mr E. J. White and his colleagues of the Anglo-Iranian Oil Company which they have generously placed at my disposal for determination for this work. (Fig. 53, p. 373).

TITHONIAN

According to Spath (Cutch, 1933, p. 831) there is in the Elburz 'abundant evidence of the presence of Berriasella, Substeueroceras, etc., and of a complete succession from the uppermost Jurassic into the Lower Cretaceous', but if so the evidence is unpublished. The statement is, however, consistent with the record by Bogdanowitch (1890, p. 175, pl. v) of 'numerous remains' of Berriasella, and Rivière's (1932, p. 541) record of Berriasella calisto (d'Orb.) and Clapp's (1940, p. 47) record of Virgatosphinctes. In the west, in Azerbaijan, there are red radiolarites (Rieben, 1935, p. 25).

KIMERIDGIAN

Taramelliceras disceptanda (Fontannes) with an evolute Perisphinctid and a smooth Phylloceras are recorded from near Shahroud by Furon (1941, p. 254). According to Fontannes this Taramelliceras at Crussol occurs in the top beds (probably Beckeri Zone of Bavaria). Kimeridgian is also indicated by Simoceras aff. venetianum Zittel (Fischer, 1915, p. 248, pl. xx, fig. 9) from the Pelour district, and Virgatosimoceras elbursense Spath (1925, p. 131, for Bogdanowitch, 1890, pl. v, fig. 5) and Lower Kimeridgian Sutneria sp. (Fischer, 1915), and by several Kimeridgian Perisphinctids recorded by Krumbeck (1922). (In Clapp's paper, 1940, p. 45, these have been misplaced in a list of Middle Jurassic fossils.) A Perisphinctes 'plicatilis' figured by Furon (1941, p. 253, pl. iii, fig. 3) would be better determined as Ataxioceras (?) aff. praecox Spath and cannot be earlier than Bimammatum Zone but is more likely Lower Kimeridgian.

UPPER OXFORDIAN

Both the Transversarium and Bimammatum Zones seem to be well represented by numerous Perisphinctids figured by Bogdanowitch (1890, pl. vi), Fischer (1915), H. Douvillé (1904, pl. xxvi, figs. 13-15) and Rivière (1934). It would be misleading to list the names under which these have been recorded. P. morgani Fischer and P. peluricus Fischer were founded on Persian material, but with the possible exception of two of Fischer's figures (pl. xx, figs. 5, 7) the other material is unfit for specific determination, and the identifications with Indian, Portuguese and other species are unreliable. The dating, however, is unquestionably correct and is supported by a nucleus of Euaspidoceras (Fischer, pl. xx, fig. 4) and Ochetoceras canaliculatum (von Buch) (H. Douvillé, 1904, pl. xxvi,
fig. 12), as well as by a record of *Tarameliceras flexuosum* (von Buch) in Fischer. Bogdanowitch (1890, pl. iv, fig. 5) figured a *Peltoceras cf. binammatum*, and to this zone apparently belong the Perisphinctids figured by him.

**LOWER OXFORDIAN**

Probably of this age, if not Upper Callovian, are shaly marls with *Hibolites hastatus* east of Kasvin (Furon, 1941, p. 259).

**MIDDLE CALLOVIAN**

As near Lake Urmia, the *Reineckeia* beds of the Anceps Zone are well developed. Fischer records *R. aniceps* (Reinecke), *R. nodosa* Till, *R. brancoi* Steinmann, *R. dowvillei* Steinmann, *R. cf. greppini* (Oppel), to which he adds a new species, *R. tilli* Fischer; and Rivière (1934, pl. v, fig. 7) gives a good figure of a Reinekeid (not, however, *R. multicostata* Petclerc). Fischer records a *Kosmoceras* sp. indet. and *Hecticoceras lunuloides* (Kilian) and Rivière records *H. lugeoni* de Tsyt. Perisphinctids from these beds include the doubtful *P. persicus* Fischer and *P. (Subgrossouvria) stahli* Fischer. It is noteworthy that Fischer (1915, pp. 227-9) records four species of Phylloceratids from these beds, including two new species, *IPtychophylloceras hafisi* (Fischer) and *Sowerbyceras firdusi* (Fischer).

From 22 m. above the base of the Jurassic limestone at Abandan, NE. of Teheran, E. J. White and his colleagues collected a fauna consisting mainly of *Grossouvriae* which is the same assemblage as that figured by Weithofer and von dem Borne from near Lake Urmia. The dominant ammonite (23 specimens) is *Grossouvria cyrus* (von dem Borne) (= *Perisphinctes lothari* Weithofer, = *P. poculum*, v.d. Borne, = *P. pseudolothari* Loczy). Next comes *G. bucharica* (Nikitin) (10 specimens, agreeing best with Siemiradzki's 1894, pl. xxxix, fig. 5); with *G. curvicosta* (Oppel), *Choffatia cf. balinensis* (Neumayr), *Reineckeia straussi* (Weithofer), *R. tetrameres* (Weithofer non Borne), *Hecticoceras metomphalum* Bonarelli (auct., exactly as in Borne, pl. i, fig. 4; = *H. salvadori* Couffon 1919 non Parona & Bonarelli), and *H. paulowi* de Tsyt. Some of the same fauna was also found 37-38 m. above the base of the limestone at Abandan, *Grossouvria cyrus* still predominating and *Subgossowvria cf. ornatilobata* Spath added.

**LOWER CALLOVIAN**

The only indication of this so far is a record of *Macrocephalites cf. pila* (Nikitin) 10 miles NW. of Jukar (Clapp, 1940, pp. 46, 47). *M. pila* is a *Pleurocerhalites* of late Macrocephalus or perhaps Koenigi Zone.

**LOWER BATHONIAN**

From scree from the basal 18 m. of the Jurassic limestone south of Pardeh Mah, E. J. White collected a splendid series of ammonites which

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could have come from the Zigzag Zone anywhere in Europe. The list is as follows:—

Oppelia (Oxycerites) fallax (Guéranger)
Oppelia (Oxycerites) limosa (Buckman)
Oppelia (Oxycerites) cf. radiatiformis Wetzel
Oppelia (Oxycerites) aff. waterhousei (M. & L.)
Oecotraustes densescostatus Lissajous
Lissoceras inflatum Wetzel
Morphoceras multiforme Arkell
Ebrayiceras pseudoanceps (Ebray)
Ebrayiceras jactatum Buckman
Cadomites deslongchampsi (d’Orb.)
Parkinsonia pachypleura Buckman
Parkinsonia aff. acris Wetzel
Parkinsonia dorni Arkell
Procerites cf. clausiprocerus Buckman
Procerites cf. funatus in Lissajous, 1923, pl. ix, fig. 2
Planisphinctes aff. planilobus Buckman
Planisphinctes cf. acurovatus (Wetzel)
Siemiradzkia berthae (Lissajous)
Siemiradzkia pseudo-rjazanensis (Lissajous)
Siemiradzkia cf. bajociformis Arkell

A few of these forms had already been recorded and figured from 67 miles east of Teheran, in the valley of the Delitchai, by Erni (1931) and Rivière (1932, 1934), and in addition Nannolytoceras pygmaeum (d’Orb.).

UPPER BAJOCIAN

According to Erni and Rivière the Bathonian ammonites at their locality occur in a bed 20-28 m. above the base of the limestones, mixed with the following forms which are Upper Bajocian: Oppelia cf. subradiata, Oecotraustes cf. genicularis Waagen, Morphoceras dimorphum (d’Orb.), and a small Normannites (Rivière, 1934, pl. vi, fig. 8). The bed seems to be equivalent to beds 3 and 4 (and 5?) in the Julfa gorge (p. 365). There was one Phylloceratid.

The section according to Erni is as follows:—

4e. Thick series of Upper Jurassic limestones with chert, well bedded, with intercalations of marl. Perisphinctes sp. Seen to 40 m.

4d. Shaly marl, 1 m.

4c. Grey hard limestone with beds of greenish-grey marl; fossils rare: Perisphinctes and belemnites. c. 25 m.

4b. Ammonite bed: grey, well-bedded limestone with intercalations of marl, rich in fossils. (From this bed come the Upper Bajocian and Bathonian ammonites.) c. 8 m.

4a. Grey marls with rare beds of limestone. c. 20 m.
3. Black shales with geodes, no fossils. 80-100 m.
2. Black sandstones with *Trigonia* cf. *costata*, *Astarte*, and plant remains. c. 40 m.
1. Shales with geodes containing *Ludwigia*; 'of considerable thickness'.

**LOWER BAJOCIAN**

In the Delitchai section 67 miles east of Teheran, tabulated above, *Ludwigia* is recorded about 150 m. below the Lower Bathonian and Upper Bajocian ammonite bed. A good specimen figured by H. Douvillé (1904, p. 201, pl. xxvi, fig. 9) is close to *L. murchisonae*, though much more finely ribbed on the inner whorls than var. *obtusa* Buckman, to which Douvillé compared it. He was certainly correct to date it to the Lower Bajocian (Murchisonae Zone).

**TOARCIAN**

*Pleydellia aalensis* (Zieten) was recorded by Fischer (1915, p. 223) from Stahl's Elburz collections, and he figured (1915, pl. xix, figs. 2-5) several other species of *Pleydellia* and *Leioceras* which Spath (1936, p. 17) considers to be all of the Moorei-Aalensis Subzones of the Jurense Zone. To the same zone also belongs a fragment figured by H. Douvillé (1904, pl. xxvi, fig. 7) as *Grammoceras fallaciosum* Bayle. Lower zones of the Toarcian are indicated by *Hildoceras* and *Dactylioceras*, if correctly identified (Rivière, 1934, pp. 31, 112, pl. v, fig. 4). *Hildoceras* cf. *boreale* (Simpson) also was recorded by Krumbeck (1922).

Several nuclei of ammonites collected in the Heras valley at a lower level than the bed alleged to contain 'Grammoceras fallaciosum Bayle, *Ludwigia murchisonae* Sow., and *Hildoceras bifrons* Brug.' were figured by H. Douvillé (1904, p. 200, pl. xxvi, figs. 1-6) and identified by him as *Ammonites normannianus* d'Orbigny, 'Lias moyen'. In consequence, Domerian or Middle Lias has persistently been recorded as among the proved stages in the Elburz (e.g. Furon, 1941, p. 252; Clapp, 1940, p. 40). How inadmissably wide a view of *A. normannianus* Douvillé took is indicated by his placing the very different *Harpoceras antiquum* Wright in synonymy. The nuclei figured by Douvillé agree much better with Upper Toarcian forms such as *Grammoceras thouarsense* (d'Orb.) and *G. costigerum* (Buckman) (cf. e.g. Buckman, Type Am. vi, pls. DCCLXXIV, DCLXXXVI), of about Striatulum Subzone.

**LIAS**

The carbonaceous facies of the Lias in the Elburz consists mainly of sandstones, quartzites, and shales with plants and coal in seams and lenses. North of Teheran coal occurs on 12 horizons up to 1 m. thick and the total thickness of the series may be about 500 m. (Rivière, 1936). In other places the thickness is said to increase up to 1200 m. (Clapp, 1940, p. 40) or even 3600 m. (E. J. White *in lit*). Near Meshed the beds overstep on crystalline schists. Elsewhere they often rest on marine Trias.

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Professor T. Harris, who has determined material collected by E. J. White, informs me (in lit.) that the flora is probably Lower Liassic. NE. of Teheran is a basal conglomerate resting on Carboniferous Limestone, and the lower 30 m. of the Lias above this consists of cementstones with indeterminable ammonites (see p. 368).

It appears that only these plant-beds swing round with the strike of the mountain ranges by Meshed and eastwards across Afghanistan. The marine limestones probably continue northward under the Kara Kum or Turkmen depression, to join up with the Upper Jurassic outcrops of Trans-Caspia on the one hand and Bokhara and the Pamirs on the other. All this region was open, like the Caucasus, to the northern sea of Russia.

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RANGES OF SOUTH-WEST ASIA

THE ZAGROS AND OTHER SOUTH-WEST MARGINAL RANGES OF PERSIA
AND KURDISTAN

From the surroundings of Lake Urmia two great systems of fold-mountains diverge: the Elburz running eastwards and showing in its internal structure signs of folding and thrusting directed towards the sunk foreland of the Caspian Sea; and the Zagros and its parallel and continuing ranges running south-eastwards and folded and thrust towards the sunk fore-deep of Mesopotamia and the Persian Gulf.

On the second and greater mountain arc, which extends from near Lake Urmia for 1300 miles to the Arabian Sea, a flood of light has been thrown by geologists of the Anglo-Persian (later Anglo-Iranian) Oil Company. Their late Chief Geologist, Dr G. M. Lees, F.R.S., most generously provided, especially for this book, transcripts of the Company's unpublished reports dealing with Jurassic stratigraphy, and the map of Jurassic outcrops (fig. 53). Where not otherwise stated, the facts summarized below are taken from reports by J. A. Douglas, B. K. N. Wyllie and P. E. Kent, which synthesize information obtained by Messrs G. M. Lees, F. D. S. Richardson, B. K. N. Wyllie, J. V. Harrison, K. W. Gray, N. L. Falcon and other geologists. The identifications of ammonites were by Dr L. F. Spath. He also supplied identifications for the Iraq Petroleum Company, whose geologists have done considerable work in the northern areas, especially in Kurdistan.

Structurally, these mountains are divided longitudinally into two parallel bands along a line running approximately NW.-SE. near the towns of Kermanshah and Shiraz (Lees & Richardson, 1940). The mountain ranges to the SW. of this line, and the foothills, constitute the normally folded zone. They consist of large anticlines and synclines similar to those of the French Jura but on a larger scale, and there are also some great thrust faults which appear to have developed from simple folds, but these are subordinate. The ranges to the NE. of the divide constitute the zone of overthrusting, where the whole country is carved out of overthrust nappes and the complicated structure and topography contrast sharply with those of the simple fold-mountains farther south-west. Metamorphic rocks, largely of unknown age, comprising schists and sheared crystalline limestones, partly Palaeozoic and partly Jurassic (Dehghan, 1947), occupy much of the NE. part of the zone of overthrusting, and in places are thrust south-westwards over part of the normally folded zone. The thrusting occurred at two distinct periods, Upper Cretaceous (probably Senonian) and Upper Tertiary.

Differences of facies and stratigraphy in the Mesozoic rocks show that at least as early as the Jurassic these two tectonic zones were becoming differentiated from one another, and from the third and much wider tabulate zone of Arabia where the sediments were laid down on the gently-shelving margin of the Arabo-Nubian massif or shield (see p. 284).
There is no great change in thickness of Jurassic rocks as a whole in passing from the west to the east side of the Persian Gulf, for while in Arabia the marine Jurassic is about 1000 m. thick, the thickness in the normally folded zone is about 800-900 m. or less. But whereas the earliest Jurassic marine fauna in central Arabia is Toarcian and the latest Kimeridgian, the earliest on the Persian side (at least in the south) is Sinemurian and the latest is highest Tithonian, with rich ammonite faunas providing a passage up into the Berriasian. The facies, moreover, is very different. In the normally folded zone the dominant Jurassic rocks are marls, thin-bedded limestones and bituminous shales. In general shales tend to predominate in the north and limestones in the south.

In the zone of overthrusting the predominant non-metamorphic facies consists of radiolarian cherts and calcareous and siliceous shales, which pass up from Upper Trias to Middle Cretaceous like the ‘comprehensive series’ of SW. Anatolia, and they are associated with masses of basic igneous rocks, both intrusive and extrusive, recalling the ophioloite zone of the southern Alps.

As in other geosynclinal regions, at least in the Jurassic, however, overgeneralization must be avoided. Deeps and shallows existed side by side. For instance, in Bakhtiariland and Kuhgalu the chert-limestone-basic igneous series seems to be absent and is at least locally replaced by varicoloured shales and sandstones, sometimes conglomeratic, and by reef limestones and dolomites. Some extrusive igneous rocks are interbedded locally with the sandstones. ‘The greatest thickness measured seems to be 900 m.+ but the total may be four or five times as great’ (Wyllie, 1937). This area with the reef limestones is farther north-east than any of the others and probably represents the edge of, or a protrusion from, the ‘median mass’ of the Central Iranian Plateau (see p. 379).

It is a curious fact also that the Mekran hinterland, where the Lower Lias is marine, seems to belong to the opposite (eastern) side of the geosyncline, for the rest of the Jurassic is represented by varicoloured shales with lavas and ash beds. This region will therefore be described with the Central Plateau.

The following ammonite faunas have been recognized in the normally folded zone. Outcrops of Jurassic occur mainly as scattered inliers at the heart of, or surrounding an older core of, anticlines in Cretaceous limestones. How small an area they cover, relative to the Cretaceous, may be seen from the coloured map of the Middle East by Dubertret (1942). At the same time they are not absent altogether at the surface except in one locality near Kermanshah as indicated on the coloured map by Furon (1941), which is so over-generalized as to be misleading (see Lees, 1946). Some of the inliers are tectonic windows, carved by erosion through nappes of the radiolarite facies which have been thrust as much as 30 miles south-westwards (Gray, 1950).
**TITHONIAN AND KIMERIDGIAN**

In the northern extremity of Iraqi Kurdistan several periclins expose inliers of fossiliferous Upper Jurassic rocks which have been studied by R. Wetzel of the Iraq Petroleum Company. The numerous ammonites have been studied by Dr L. F. Spath, from whose paper (1950) is compiled the following section at Jebel Gara, near Amadia (about 50 miles NNE. of Mosul). Similar faunas were collected near Zakho, about 50 miles farther west.

<table>
<thead>
<tr>
<th>Bed</th>
<th>Thickness</th>
<th>Ammonoids</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>4.8 m.</td>
<td><em>Berriasella calisto</em> (d’Orb.), (Basal Cretaceous)</td>
</tr>
<tr>
<td>...</td>
<td>4.8 m.</td>
<td>No ammonites</td>
</tr>
<tr>
<td>t, u</td>
<td>?</td>
<td><em>Berriasella, Parodontoceras, Protacanthodiscus</em></td>
</tr>
<tr>
<td>...</td>
<td>18 m.</td>
<td>No ammonites</td>
</tr>
<tr>
<td>s</td>
<td>?</td>
<td><em>Parodontoceras</em> and uncoiled ammonoids</td>
</tr>
<tr>
<td>k-r</td>
<td>43.5 m.</td>
<td>No fossils</td>
</tr>
<tr>
<td>j</td>
<td>13.5 m.</td>
<td><em>Haploceras, Substeueroceras, Gravyceras</em> similar to forms in the Spiti Shales</td>
</tr>
<tr>
<td>i</td>
<td>9.9 m.</td>
<td>Black bituminous limestone and shale with <em>Oxylenticeras, Glocchiceras, Pseudolissoceras, Phanerostephanus, Nanno-stephanus, Nothostephanus, Proniceras, Protancyloceras, Cochlocricoceras</em> (described Spath, 1950)</td>
</tr>
<tr>
<td>d-h</td>
<td>39 m.</td>
<td>No fossils</td>
</tr>
<tr>
<td>a-c</td>
<td>?</td>
<td><em>Ataxioceras inconditum, Aulacostephanus</em> aff. <em>phorcas</em> (Fontannes)</td>
</tr>
</tbody>
</table>

Beds a-c are Lower Kimeridgian (Pseudomutabilis Zone). It is noteworthy with how small a gap the Tithonian fauna follows on. According to Dr Spath’s ideas on the correlation of the Tithonian faunas there is a major disconformity somewhere in beds d-h.

Tithonian fossils have been collected in various other places: in central Fars from some part of a 600 m. unit of limestone and dolomite are recorded *Berriasella* sp., *Steueroceras* sp., *Streblites auriculatus* and *Neolissoceras* *grasianum* (Douglas, 1937; Gray, 1950, p. 196); and in the Bakhtiari country *Haploceras* and *Proniceras*.

In the Zagros ranges proper, the Upper Jurassic consists of thick-bedded massive limestones and dolomites without ammonites and poor in all macrofossils, passing up without a break into similar limestones of Neocomian age. In the anticline of Kuh-i-Surweh the limestones begin with about latest Callovian and the Upper Jurassic portion is over 400 m. thick. Upper Oxfordian pelecypods and brachiopods have been recognized (Kent, 1952).

**MIDDLE CALLOVIAN**

*Erymnoceras* and *Pachyceras*, with a neritic pelecypod fauna, were obtained from shales interbedded with limestones in the Bakhtiari country.

**LOWER CALLOVIAN**

*Macrocephalites*, with *Eligmus rollandi* and Myacea, was obtained at Kuh-i-Surweh.

BATHONIAN
Probably present, but no ammonites yet found.

UPPER BAJOCIAN
In Kurdistan this is transgressive in some places on to Lias and possibly Trias, and condensation and overlaps below this horizon are suspected farther south, notably at Kuh-i-Surweh. Upper Bajocian shales with Posidonia occur in Kurdistan. In the Kermanshah district, Lees found the Jurassic to be apparently no more than 75 m. thick and probably all Middle and Lower Jurassic. Presumably the Upper Jurassic is locally removed by erosion. He divided the sequence as follows (Douglas, 1937; Wyllie, 1937):

3. An upper group of chocolate-coloured and black bituminous shales interbedded with thin limestones.
2. A middle group of thin-bedded, black, foetid limestones with Posidonia cf. alpina and thin black chert beds, with grey shale and thin grey limestones containing Bajocian ammonites: Parkinsonia sp., Oppelia sp., Morphoceras sp., Sphaeroceras sp., Sonninia sp. and Stephanoceras 'of coronatum type'.
1. A lower group of grey limestones, the upper part with abundant Rhynochonellids suggestive of a Middle Lias age, small oysters and other polecypods. A fragment of a jaw of a teleosaurian crocodile.

LIAS
Sinemurian ammonites occur in the south, in the Mekran hinterland and interior plateau (see p. 380), but in the main ranges in the centre and north no Liassic ammonites have been found. At the base of the Jurassic over large areas, however, is a bed (up to 20 m. thick) of the problematic pelecypod Lithiotis, which is so abundant and widespread that it is a useful horizon-marker. It seems to provide a link with the Lias of southern Europe. The brachiopods in bed 1 of the sequence mentioned under Bajocian above are also believed to be Liassic.

Three representative sections in the district of Shiraz, central Fars, in the neighbourhood of the tectonic window of Dalnashin, give an idea of the stratigraphy of the inner part of the normally folded zone at its contact with the zone of nappes (Gray, 1950):

<table>
<thead>
<tr>
<th></th>
<th>(1) Metres</th>
<th>(2) Metres</th>
<th>(3) Metres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eocene</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top Cretaceous (in part perhaps Eocene)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Cretaceous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Cretaceous</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jurassic-Cretaceous transition beds, with Berriasella</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jurassic: massive grey limestones, etc., with Lithiotis at or near base</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Trias</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>600</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>510</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1440</td>
<td>1500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>750</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>510</td>
<td>240</td>
<td>270</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c. 690</td>
<td>c. 450</td>
</tr>
<tr>
<td></td>
<td></td>
<td>570</td>
<td>240</td>
</tr>
</tbody>
</table>
On the other hand, in parts of the Bakhtiari country the Jurassic is much thinner. In the SW. scarp of Zardeh Kuh, shown in plate 19, the whole Jurassic is only about 300 m. thick. The succession exposed in this cliff, measured by N. L. Falcon, J. V. Harrison and A. H. Taitt, is as follows (thicknesses as usual converted into metres from feet in round numbers).

<table>
<thead>
<tr>
<th>Formation</th>
<th>Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle Cretaceous limestone (under snow)</td>
<td>600</td>
</tr>
<tr>
<td>Lower Cretaceous limestones and shales (nearly to base of the snow)</td>
<td>675</td>
</tr>
<tr>
<td>Jurassic—</td>
<td></td>
</tr>
<tr>
<td>Bedded limestones with <em>Erymoceras</em> 30 m. below top (mostly under snow)</td>
<td>90</td>
</tr>
<tr>
<td>Massive limestones (top of the scarp feature)</td>
<td>24</td>
</tr>
<tr>
<td>Well bedded oolitic limestones</td>
<td>90</td>
</tr>
<tr>
<td>Massive dark limestones with <em>Lithiotis</em> near base</td>
<td>90</td>
</tr>
<tr>
<td>Massive dark limestone (bottom of scarp)</td>
<td>30</td>
</tr>
<tr>
<td>Triassic thin limestones and shales</td>
<td>390</td>
</tr>
<tr>
<td>Permo-Carboniferous limestones</td>
<td>570</td>
</tr>
<tr>
<td>Cambrian shales and sandstones</td>
<td>900</td>
</tr>
</tbody>
</table>

**OMAN (EASTERN ARABIA)**

The mountain arc of Oman, with heights of up to 10,000 ft., from the point of view of both topography and geology is a foreign element intruded upon the Arabian sub-continent. With its arcuate shape, convex to the SW., fronting the flat sand desert of the Empty Quarter, which seems to be the prolongation of the Persian Gulf fore-deep, the Oman mountains stand out of their context as an outlying loop of the Zagros ranges. Whether this arc continues southwards under the Arabian Sea as some have held, or joins on to the Kirthar ranges of the Indus arc as the surviving topography suggests, is still an open question. Certain is it only that the Oman ranges belong geologically to Asia, both stratigraphically and structurally, though with differences.

The stratigraphic column for the Mesozoic as determined by Lees (1928) is as follows, omitting phyllites of unknown age which everywhere rest on a thrust sole plane and probably correspond with the metamorphic rocks of the zone of overthrusting in SW. Persia:—

Cenomanian to Maestrichtian limestones.
Semail Igneous Series: a mass of lavas and intrusive rocks forming a thrust nappe.
Hawasina Series of shales, sandstones, detrital limestones and groups of red and green chert or radiolarite, with immense sheets of lava interbedded. Thickness probably of the order of 1500 m.
Musandam Limestone, largely barren of fossils, c. 1500 m.
Elphinstone Beds (Triassic), c. 150 m.
(Permian below)

Clues as to the ages of these rock groups are scanty, as in the zone of overthrusts in Persia, of which the radiolarite and igneous rocks are no doubt a continuation. From the middle region (his bed 7) of the Musandam Limestone, however, Lees collected three corals which

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PLATE 19.—Zardeh Kuh, Persia. The whole Jurassic system crops out as a pale band in the lower part of the cliff.
Kühn (1929) was able to identify as approximately Upper Oxfordian to Kimeridgian in age. They indicate a shallow sea of Central European type extending southward from Persia, and unconnected with that of Cutch. From marl beds in the upper part he also collected a small assemblage of fossils (no ammonites) of Lower Cretaceous type, probably Barremian. On the basis chiefly of Foraminifera, the Lower Musandam Limestone is regarded now as ranging from Lias to Tithonian. Examination of the Radiolaria of the Hawasina Series (Davis, 1950) gives an approximate date Tithonian-Neocomian.

More detailed work on the northern peninsula of Oman, the Ruus al Jibal, published while this book was in proof, has produced much new information (Hudson, McGugan & Morton, 1954). Although there were pre-Aptian and Upper Cretaceous movements, the main thrusting was Neogene, and the structures are a continuation of the thrusts in the normally folded zone of the Zagros. The stratigraphy is also found to agree better with this zone than had been supposed, and it also shows connexions with central Arabia, despite absence of ammonites in Oman.

**The Plateau of Central Persia and Afghanistan**

The series of high plateaux, separated by minor mountain ranges, which form the inner core of Persia and Afghanistan and fall in great steps to the Mekran coast of the Arabian Sea, have been referred to as a 'Zwischen-Gebirge' or median mass, between the greater mountain arcs of the Elburz-Hindu Kush on the north and the Zagros-Kirthar ranges on the south. Although the surface consists mainly of desert plains in internal drainage basins (graphically described and illustrated, for instance, by Harrison, 1943), the underground structure is complicated.

In the Persian part, in a triangle with 500-mile sides, its corners on the towns of Kerman and Isfahan and a point about 150 miles north of Tabas, Jurassic rocks play an important part, cropping out along the sides of mountains which have Triassic and Palaeozoic cores, and buried by superficial deposits under the plains. There are also outcrops in the Mekran hinterland and not many miles from the coast at the Strait of Ormuz.

Over this large area the Jurassic rocks naturally vary a great deal, but there is everywhere a marked difference from the surrounding mountain chains of the Elburz and Zagros systems. In the first place the Jurassic as a whole is relatively thin and predominantly of continental type, with carbonaceous shaly beds much in evidence. Secondly the marine episodes are earlier than in the mountain systems: in the south and centre there are Sinemurian and Lower Bajocian marine phases instead of ? Domerian, Toarcian and Upper Bajocian-Bathonian. Thirdly, the whole Upper Jurassic is missing over large areas and in other places represented by a carbonaceous series like the Elburz Lias. Fourthly, in the south there are massive extrusions of lava interbedded in the Jurassic sediments.

As in the Elburz, the Lias occurs in two main facies, carbonaceous

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shales or sandstones, with plant-remains, and foetid black limestones which locally may contain ammonites. Near Tabas the lower carbonaceous series rests unconformably on Uralo-Permian limestones (Furon, 1941, p. 259). In places it contains workable coal seams. Liassic plants have been obtained from the series between Kerman and Ravar (Clapp, 1940, p. 41). In other parts of the same area the series comprises up to about 150 m. of foetid black limestones (Pilgrim, 1924, p. 57). Almost due east of Isfahan, near Yezd, Jennings and Gray collected an ammonite identified as *Vermiceras* aff. *scylla* (Reynès) (Douglas, 1937), which would indicate earliest Sinemurian.

In the Mekran hinterland 'the Jurassic is represented almost entirely by a great pile of lava and ashbeds, with red, purple and green shales, which continue probably to Middle Cretaceous time' (Wyllie, 1937). The lavas are both subaerial and submarine. At Sargaz, about 110 miles NE. of Bandar Abbas, the Jurassic begins with a thin quartz conglomerate resting on mica-schists and consists of no more than 45 m. of calcareous sands, pink limestone and marlstone, overlain by lava flows and ashbeds. A 6-metre limestone near the base yielded the Sinemurian ammonites *Eoderoceras* and *Oxynoticeras*, together with *Phylloceras*, *Lytoceras* and *Atractites* (Douglas, 1937).

In the higher parts of the lower carbonaceous series, above the main coal seams, near Neju Oasis, about 25 miles east of the town of Yezd, occur lenticles of red marine limestone with a brachiopod, coral and pelecypod fauna thought to be of about Middle Lias age (Kühn, 1938).

In the hills near Ravar, 150 miles NNW. of Kerman, Tipper found a brown sandy limestone full of ammonites and broken belemnites, bed 3 in the following sequence:

7. Turonian-Senonian Hippurite Limestone: strong unconformity
6. Red grits, shales and conglomerates
5. Green shales, grits and conglomerates with plant remains
4. Violet shales with thin limestone bands
3. Brown sandy limestones with ammonites and belemnites
2. Grey limestones, thicker-bedded than bed 1
1. Black limestones, thin-bedded

Tipper saw no lower beds; the outcrop is shown in his section as concealed by talus. According to the observations of Pilgrim (1924) in the Kerman area Tipper's bed 1, the thin-bedded black fetid limestone, is the lower carbonaceous series, and is up to 150 m. thick. There are, however, anomalies in the stratigraphy which may be due to tectonic causes, for the area has been subjected to recumbent folding (Pilgrim, p. 57, fig. 9) and overthrusting which has brought Trias over Jurassic (Kühn, 1938; see also Douglas, 1929, p. 626).

The ammonites from bed 3 of Tipper's section were taken by him for Upper Liassic, but they have been revised and figured by Spath (1936) who has shown them to be Lower and Middle Bajocian. The matrix is a
compact brown sandy limestone recalling that of Cape San Vigilio on Lake Garda and, like that, a condensed deposit. Spath’s determinations are:—

Humphriesianum Zone

*Stephanoceras* sp. ind. (‘*Dactylioceras*’ of Tipper ?)

Sauzei or lower Humphriesianum Zone

*Otoites* aff. *contractus* (Sow.)

Sowerbyi Zone

*Witchellia* aff. *pavimentaria* (Buckman)

Murchisonae Zone

*Brasilia opalinoidea* (Mayer) Vacek sp.

*Brasilia* sp. nov.?

*Euaptetoceras* sp. ind.

*Eudmetoceras* cf. *eudmetum* Buckman

*Graphoceras* aff. *formosum* (Buckman) (‘*Harpoceras*’ of Tipper)

*Planammatoceras* sp. nov.?

Opalinum Zone

*Leioceras* cf. *opalinum* (Reinecke) and 3 other spp. (‘Oxynoticeras’ of Tipper)

Nothwithstanding Spath’s revision, Tipper’s determinations as *Oxynoticeras, Dactylioceras* and *Harpoceras*, are repeated in lists of fossils from eastern Persia (Clapp, 1940, p. 44).

Except for Tipper’s and Pilgrim’s sections near Ravar and Kerman, mentioned above, hardly anything is known of post-Bajocian Jurassic on the Persian-Afghan plateau. Douglas (1929, p. 627) mentions limestone with clavellate *Trigoniae* of Upper Jurassic aspect from west of Naiband (SE. of Tabas), and ‘Middle and Upper Jurassic’ are reported in the vicinity of Kerman by Clapp (1940, p. 41). Over large areas of Afghanistan it is likely that crystalline rocks either form the surface or are directly overlain by Cretaceous and Eocene flysch, and by Neogene and Recent continental deposits of the internal drainage basins.

Along the north of the plateau, from Khorassan in eastern Persia by Meshed and Herat, eastwards across Afghanistan by way of the tectonic valley of the Heri Rud towards Kabul, there runs a discontinuous band of outcrops marked as Jurassic on the maps. These, however, are all continental sediments of Angara type (shale, sandstone, grit and conglomerate), a continuation of the plant series of Persia and likewise containing coal seams. They rest indifferently on the crystalline basement, on Palaeozoic formations, or on marine Trias (Trinkler, 1928, p. 26; Furon, 1941, pp. 254-5). At the east end, near Kabul, the outcrops bend NE. and follow along the north of the Hindu Kush. After this region they have been called the Saighan Series. Here they rest on volcanic rocks presumed to be of Triassic age and pass up into an unfossiliferous formation called the Red Grit Series, probably of Cretaceous age, which is in turn overlain by Upper Cretaceous limestones, usually with marked unconformity (Hayden, 1911, pp. 30-34). (Fig. 56, p. 395).
CHAPTER 14

THE INDIAN PENINSULA, WITH CUTCHE AND THE SALT RANGE

THE FORELAND OF THE INDIAN* PENINSULA

Like the African shield and its extension the Arabo-Nubian massif, peninsular India was dry land throughout the Jurassic. Its ancient surface of pre-Cambrian and early Palaeozoic rocks had been denuded and faulted in Upper Palaeozoic and Triassic times and has remained above sea ever since. The Jurassic sea lay to the north-west, west and east and there were minor marginal floodings in the Lower Cretaceous along the present east coast and in the Upper Cretaceous there and on the NW. Finally, at the end of the Cretaceous (probably Danian) came fissure-eruptions in the NW., producing vast lava flows, the Deccan traps (fig. 54). Although the lavas have been exposed to denudation since the beginning of the Eocene, they still cover about 200,000 square miles and near Bombay they reach a thickness of about 2 miles. The similarity to the Abyssinian lavas is striking, in both geological setting and age.

Nearly a third of the ancient surface of the peninsula is covered by the Deccan traps, which conceal any Jurassic marginal sediments that may have been deposited there and have survived Cretaceous erosion. To the north an even larger area is buried below the Ganges alluvium, which is known to extend at least 1000 ft. below sea-level, but has never been bottomed. Although Archaean rocks come to the surface to the north of it at many points along the Himalayan chain almost continuously, they have there been upheaved and eroded. It is possible that Jurassic and other Mesozoic rocks exist under the alluvium of the Ganges, where there has been subsidence and protective deposition at least since Tertiary times, but for reasons mentioned in the next chapter any such occurrence is unlikely.

THE GONDWANA SYSTEM

There are preserved considerable sedimentary records of the fluvial erosion undergone by the peninsula from Upper Palaeozoic times to the outpouring of the Deccan traps. In trough faults at scattered points, mainly in the north but intermittently as far south as Madras and Ceylon, are thousands of feet of clastic sediments of continental facies, grouped together as the Gondwana system. The beds, largely sandstones, were laid down in deltas and lake basins in areas of subsidence. The commonest fossils are plants, locally aggregated into coal seams; they supply nearly

* As always in this book, established English geographical terms are used without political implications and may often cut across national frontiers.

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all the coal worked in India. At the base is the famous Talchir boulder bed, interpreted as a glacial tillite, which is overlain by a marine bed providing evidence of Permo-Carboniferous date. The next marine intercalations are of Lower Cretaceous (Upper Neocomian) date. Correlation of the intervening continental strata from basin to basin and with the standard geological sequence is difficult and uncertain, since it must rely largely on palaeobotanical evidence.

The Gondwana system contains only two main floras, the earlier characterized by Glossopteris, the later by Ptilophyllum. On these grounds the Geological Survey of India (see especially Fox, 1931) has advocated a twofold subdivision into Lower and Upper Gondwana. Unfortunately, however, the change of floras takes place in the middle of beds (Panchet & Mahadeva: see the accompanying table, p. 384) proved by their vertebrate fossils to be Triassic. This did not matter seriously when it was possible to imagine that the beds with the Ptilophyllum flora represented continuous sedimentation from Upper Triassic to Cretaceous, and when a whole series of imaginary Jurassic stages could be written in column alongside the Indian formations (e.g. Fox, 1931, pl. 9). The position has been completely changed by Dr Spath's discovery (1933, pp. 826-9) that the lowest Gondwanas next above the Mahadeva (Maleri) stage are not Liassic as previously supposed but Upper Neocomian. Geologists have been slow to accept the implications of this revolution, and the old imaginary classification still appears in some of the latest text-books (Krishnan, 1949, pp. 246-7, 272). But now that, in Dr Spath's words, 'it seems probable that there is an enormous gap between the Lower Gondwanas and the Rajmahal plant beds . . . involving at least the whole

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Jurassic and perhaps not only the Rhaetic but also the lowest Cretaceous', it is necessary to return to the threefold division of the Gondwana system as advocated by Vredenburg (1910) and adopted in the earlier text-book by Wadia (1926). According to this classification the Lower Gondwanas are Upper Palaeozoic, the Middle are Triassic and the Upper are Cretaceous. In Table 17 an attempt is made for the first time to rearrange the classification in accordance with palaeontological evidence. The correlations in the left-hand column are all that is possible from existing knowledge, omitting pure speculation. Dating of the Jabalpur is based on plant correlation (Fox, 1931, pp. 113, 235) with the Umia plant beds of Cutch, which according to Nath (1932) overlie the marine Aptian (see p. 387).

Comparison with NE. Africa thus becomes much closer. Once again we have intermittent Cretaceous transgressions, fingerling out in continental sandstones, overstepping across much older continental sandstones and marine beds of Upper Palaeozoic and Triassic age, with the Jurassic palaeontologically unrepresented. Peninsular India repeats the history of the Nubian Sandstone.

**MARINE COASTAL FACIES ON THE FORELAND: CUTCH**

On the coast between Bombay and Karachi, east of the mouth of the Indus, lies the classic area of Cutch (Kutch, Kachh), probably the most

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### Table 17.—Correlation of the Gondwana System

<table>
<thead>
<tr>
<th>Correlation</th>
<th>Formations</th>
<th>Faunas, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>? APTIAN AND LATER</td>
<td>Upper Gondwana</td>
<td>Tripetty group, with <em>Trigonia</em>, etc. 'a retrouver'; Chikida and Pavalur beds</td>
</tr>
<tr>
<td>UPPER NEOCOMIAN</td>
<td>Jabalpur</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rajmahal</td>
<td>Buddavada, Ragavapuram, Sripurmatur beds, all with Upper Neocomian ammonites</td>
</tr>
<tr>
<td>JURASSIC</td>
<td></td>
<td>Major non-sequence</td>
</tr>
<tr>
<td>UPPER TRIASSIC</td>
<td>Middle Gondwana</td>
<td>Maleri Beds with Upper Triassic vertebrates</td>
</tr>
<tr>
<td>LOWER TRIASSIC</td>
<td>Mahadeva</td>
<td>Triassic vertebrates</td>
</tr>
<tr>
<td>PERMIAN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPPER CARBONIFEROUS</td>
<td>Lower Gondwana</td>
<td>Umaria marine bed with Carbo-Permian brachiopods, etc., between Talchir boulder bed and Damuda Series</td>
</tr>
<tr>
<td></td>
<td>Damuda</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Talchir</td>
<td></td>
</tr>
</tbody>
</table>

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favoured locality in the world for Upper Jurassic ammonites, by reason of abundance, good preservation and ideal exposures. The Upper Jurassic rocks form an island world rising partly direct from the shallow sea and marshes (the Rann) and partly from alluvial lowlands, with a fringe of Deccan traps and Tertiary sediments along the south side. The islands represent the remains of three E.-W. anticlines corrugated by minor transverse folds to form irregular domes. Within the domes erosion has exposed successively lower formations in a series of small concentric scarps.

The southern anticline, in which lies Bhuj, the capital of Cutch, is the largest and most complete, with a length of 120 miles. Owing to a longitudinal fault on the south side much of it is repeated in the adjoining ridge of the Charwar and Katrol Hills. The central mass of Wagur, lying to the NE., is 50 miles long from east to west and is possibly continued beneath the Rann. The northern anticline has been reduced to four separate domes more or less completely islanded in the Rann, but still with a total length of nearly 100 miles (fig. 55).

The Upper Jurassic rocks are of neritic marine facies and contain many formations crowded with mollusca, especially ammonites and pelecypods. The exposed and fossiliferous part ranges from lowest Lower Callovian (with *Macrocephalites*) and probably some Upper Bathonian (without ammonites) at the base, up to Lower Tithonian, and is succeeded by a great thickness of sandstones and shales of continental facies, with plant beds and at least two marine horizons, one
(without ammonites) doubtfully Neocomian, the other (with ammonites) Aptian. The total thickness of the Mesozoic series is over 1800 m., of which the Jurassic part measures about 1000 m. The junction with earlier formations is nowhere exposed, but gneiss is believed to lie only a short distance beneath (Wynne, 1872; Waagen, 1875, p. 236).

The main subdivisions were named and correlated with the European succession, and the principal ammonites were described and figured, in the classic monograph by Waagen (1873-5), which has been revised in

**Table 18.—The Jurassic of Cutch**

<table>
<thead>
<tr>
<th>WAAGEN</th>
<th>SPATH (emended) *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formations</td>
<td>Stages</td>
</tr>
<tr>
<td>OOMIA (UMIA, AMIU) (510 m.)</td>
<td>TITHONIAN</td>
</tr>
<tr>
<td>KATROL (445 m.)</td>
<td>KIMERIDGIAN</td>
</tr>
<tr>
<td>CHAREE (CHARI) (455 m.)</td>
<td>OXFORDIAN</td>
</tr>
<tr>
<td>PUTCHUM (PATCHAM) (Kuar Bet Beds)</td>
<td>CALLOVIAN</td>
</tr>
<tr>
<td>(Kuar Bet Beds)</td>
<td>BATHONIAN</td>
</tr>
</tbody>
</table>

* i.e. The classification used in this book, applied in accordance with Dr Spath’s determinations of ammonites.

great detail by Spath (1927-33). Important changes in the order of succession of the higher beds were introduced by Raj Nath (1932), and were in the main confirmed in 1939 by Dr A. Allison, working for the Burmah Oil Company, whose report has been kindly made available. Waagen established that the zones succeed one another in much the same order as in central Europe, despite abundance of Phylloceratids and many Lytoceratids more characteristic of Mediterranean faunas, and that they range in time from Bathonian to Portlandian. His conclusions have been modified only in details.

Much remains to be done in ascertaining the lateral changes of the various formations and tying down some of the lesser known assemblages of ammonites to their proper places in the sequence (e.g. the *Hildoglochiceras kobelli* beds). Some notable lacunae in the ammonite succession, moreover, may still be due to collection failure. The most surprising of the gaps in the sequence are: (1) the uppermost Upper Oxfordian Perispinctid fauna of the Bimammatum Zone found in Abyssinia; (2) the Lower Kimeridgian fauna of *Ataxioceras, Streblites, Glochiceras, Aspidoceras*, etc., found in Arabia and East Africa and known to be transgressive.
Table 18, opposite, shows the formations and their correlation as established by Waagen (1873) and as now accepted, chiefly as the result of the revision by Spath (here modified as to terminology). The column on the left shows original and subsequent spellings. Thicknesses apply only to the main southern outcrop, where they were measured by Dr Allison. His ammonites are now in the Sedgwick Museum.

Succession in Cutch

[Aptian and Later Cretaceous]

Bhuj Series (Umia Plant Beds), yielding a Ptilophyllum flora comparable with, and having a number of forms identical with, the Jabalpur group of the highest Upper Gondwanas (Fox, 1931, pp. 235-8).

Ukra Beds. Calcareous shales with large Australiceras, already correctly assigned to the Aptian by Waagen. (30 m.).

[? Neocomian]

Umia Beds (about 500 m. excluding the ammonite beds below).

Unfossiliferous shales and sandstones, 300 m. or more (Nath, 1932, p. 171).

Trigonia Beds of Umia, composed mainly of T. crassa Kitchin, with T. ventricosa Krauss, a form found in the Valanginian Uitenhage Beds of South Africa. At least four of the species of Trigonia (including T. smeei Sowerby) figured by Kitchin (1903) as from these beds were misplaced owing to faulty stratigraphical information and have proved to belong to beds of either highest Oxfordian or lowest Kimeridgian age (Spath, 1935). T. smeei has thus turned out to be Upper Jurassic, instead of Cretaceous, in both Cutch and Tanganyika (see p. 335).

Under the Trigonia Beds are up to 90 m. of sandstones (Nath, 1932, p. 170).

Tithonian

Umia Ammonite Beds (c. 15 m.). Three beds of green oolite, highly fossiliferous, with abundant ammonites, also brachiopods, etc., and a coral (Stylina). The chief element is large Virgatosphinctes, some up to 2 ft. in diameter, especially V. denseplicatus (Waagen) with four named varieties, also Aulacosphinctes occultefurcatus (Waagen), Micracanthoceras aff. microcanthus (Oppel), M. sp. aff. fraudator (Zittel), Umiaites rajnathi Spath, U. minor Spath, Ptychophylloceras tithonicum Spath, Holcophylloceras silesiacum (Oppel), Hemilytoceras cf. montanum (Oppel), H. aff. sutile (Oppel). (For list see Spath, 1933, p. 797). With these occur Trigonia retrorsa Kitchin and a form hardly (if at all) separable from T. ventricosa Krauss of the Valanginian.

Upper Katrol Shales with Hildoglochiceras. These shales were formerly (Spash, 1933, p. 865) called the Zamia Shales, but according to Raj Nath (1932, pp. 167, 172) the true Zamia Shales form the base of the Umia
Plant Beds, his Bhuj Series, and are later than the Aptian Ukra Beds. The *Hildoglochiceras* beds of Nurrha and Gudjinsir (Gajansar) (Spath, 1933, pp. 741, 795) are best grouped (with Nath) provisionally in the top of the Katrol Beds, but their stratigraphical relations have still to be determined. The commonest ammonite is *Haploceras elimatum* (Oppel), which is associated with *Hildoglochiceras* (6 spp.), *Subdichotomoceras* (2 spp.), a *Streblites, Holcophylloceras mesolcum* (Dietrich), *Ptychophylloceras* (3 spp.), and *Phylloceras* (2 spp.). This fauna correlates with the *kobelli* beds of Antsalova in Madagascar and the *Trigonia smeei* beds of Tendagura (pp. 335, 338). Spath (1933, pp. 795-7) has discussed its age at length and concludes that it is approximately Portlandian, and he places it between the known Upper Katrol and Umia faunas mainly on negative evidence—the absence of cosmopolitan earlier forms. In Madagascar *Hildoglochiceras* spp. occur both in the *Virgatosphinctes* beds and below (Besairie, 1936; see p. 339).

**Upper Katrol Sandstone (270 m.).** So far as known this thick formation is barren, but *Aulacosphinctoides meridionalis* Spath (1933, p. 794), believed to have come from an ironstone band somewhere in the Upper Katrol, is considered by Spath to be Upper Kimeridgian (i.e. Lower Tithonian as understood in this book).

**Middle Kimeridgian?**

**Middle Katrol red sandstones.** The stratigraphy of these beds still remains to be elucidated. Spath recognizes two successive faunas (with perhaps a third), all Middle Kimeridgian. The later (second Katrol assemblage, 1933, p. 791) contains three or four times as many species of Perisphinctids as of all other forms together, and many more times in terms of individuals. Spath assigns them to *Torquatisphinctes* (3 spp.), *Pachysphinctes* (11), *Subplanites* (5), *Metagravesia* (1), *Katrolliceras* (12, including *K. pottingeri* (Sow.) which also occurs in Kenya), *Subdichotomoceras* (2), *Aulacosphinctoides* (4). There are also *Aspidoceras* (6), *Hybonoticeras* (2), *Streblites* (1), *Hemilytoceras rex* (Waagen), and a couple of Phylloceratids. This assemblage may correspond approximately to the upper part of the Steraspis Zone (= Gravesia Zones) of Europe, but recent evidence from Kenya suggests that it is earlier.

**Lower Katrol Beds,** mainly shales with ammonites at base preserved in dark phosphatic grit. This (the 'basal Katrol bed', Spath, 1933, p. 788) is considered to be 'intimately allied' to the other and also Middle Kimeridgian. Perisphinctids, however, are much scarcer, except for *Torquatisphinctes*. Instead there is a great quantity of Oppeliids—*Taramelliceras* (12 spp.), *Streblites* (4), *Glochiceras* (5), *Heminaploceras* (1)—and also *Aspidoceras* (5 spp., all different from those in the Middle Katrol) and *Hybonoticeras* (5, including *H. beckeri* Neumayr sp.) and many Phylloceratids. This assemblage is approximately, at least, of the age of the Beckeri Zone of SW. Germany (lower part of the Steraspis Zone), which is absent from NW. Europe, possibly represented by a non-sequence.

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between the Gravesia and Aulacostephanus Zones at Kimeridge. At the same time it contains a number of forms which, as Spath pointed out, are suggestive of the Pseudomutabilis and upper Tenuilobatus Zones.

**LOWER KIMERIDGIAN**?

*Belemnite Marls of Jurun* (Spath, 1933, pp. 747, 787). A small, rather colourless, assemblage from these marls, which are not yet tied in stratigraphically, are assigned doubtfully to the Lower Kimeridgian. Otherwise there is no definite Lower Kimeridgian fauna in Cutch; another point of resemblance to Madagascar.

**UPPER OXFORDIAN**

Bimammatum Zone. *Kantcote Sandstone*. This formation yields a rich ammonite fauna listed and assigned to the Bimammatum Zone by Spath (1933, p. 784; 1935, p. 186, footnote 3), and from it have been collected *Trigonia smeei* Sow. and three other species which were formerly believed to have come from the Umia *Trigonia* beds and to be Cretaceous. The greater part of the fauna consists of numerous Perisphinctids, the most important of which are *Discosphinctes* and *Dichotomosphinctes*; the other forms need generic and subgeneric revision in the light of subsequent work on the Upper Oxfordian Perisphinctids of NW. Europe. There are also *Euaspidoceras* (‘*Neaspidoceras’*) (4 species), a *Taramelliceras*, a *Ptychophyllloceras* and a long list of late Mayaitids, *Epimayaites* and *Prograyiceras*.

Transversarium Zone. *Dhosa Oolite*. Brown and green oolites with an extremely rich invertebrate fauna of the Transversarium Zone (= Plicatilis Zone), though of the numerous *Perisphinctes*, *Euaspidoceras* and *Peltoceratoideae* hardly one is identical with a European species. There are also many of the ‘late Macrocephalitids’—*Mayaites*, *Epimayaites*, *Dhosalsites* and *Paryphoceras*, altogether 22 species, including the true *Epimayaites polyphemus* (Waagen), after which the ‘*Polyphemus Limestone*’ of Mazar Drik was unfortunately named as result of a misidentification. Oppeliids are represented by *Campylites*, *Proscaphites* and *Pseudobrightia*, and there are three Phylloceratids and a Lytoceratid. The Upper Dhosa Oolite yields a small fauna including Perisphinctids which are said to show some affection with those of the Kantcote Sandstone.

**LOWER OXFORDIAN**?

*Ochetoceras* (Campylites), some supposed *Alligaticeras*, *Epimayaites subkobyi* and the numerous *Peltoceratoideae*, suggest that a representative of the Cordatum Zone may be condensed in the lower part of the Dhosa Oolite, but there is no definite evidence and the earlier Mariee Zone is represented, if at all, in the underlying fauna.

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UPPER CALLOVIAN (Athleta Beds) (up to 21 m.).

The upper part of the Chari group below the Dhosa Oolite or its shales consists of gypseous shales and marls known as the Athleta Beds, with an extremely rich ammonite fauna. Spath (1933, pp. 775-9), mainly on grounds of preservation, recognizes an upper and lower athleta fauna, which he equates with the Lamberti and Athleta Zones respectively. Both contain Oppelids, Perisphinctids, Peltoceratids, Aspidoceratids and Phylloceratids, making lists too lengthy even to summarize. The lower fauna differs from the upper by including several late Reineckeids (Collotia spp.), late Proplanulitids (Obtusicostites, Kinkeliniceras, Hubertoceras), more Peltoceras s.s., and an Erymnoceras. The upper fauna is characterized by several forms typical of the Lamberti Zone of England, such as Distichoceras bicostatum (Stahl), Horioceras baugieri (d’Orb.), with some even later elements more often associated with the Lower Oxfordian; e.g. Euaspidoceras douvillei (Collot) and Properisphinctes bernensis (de Loriol).

MIDDLE AND LOWER CALLOVIAN (Anceps, Rehmanni and Macrocephalus Zones)

Next below follow limestones and shales with two slightly different faunas, both characterized by numerous Reineckeia spp. and assigned to the Anceps Zone. ‘Species of Hubertoceras occur in both . . . but in the lower beds they are associated with Reineckeia of the anceps group and Kinkeliniceras angygaster and allies, and in the higher beds the first Peltoceratids are accompanied by Reinecketes of the crispus-multicostatus group’ (Spath, 1933, p. 769). The long lists again contain some familiar European forms, such as Oecoptychius refractus (Reinecke) as well as the Phylloceratids, amidst a swarm of peculiar Indian elements. Here too occurs Kinkeliniceras kinkelini (Dacqué), a link with Tanganyika, where, however, its associates suggest rather an Upper Callovian date (p. 329). Perisphinctids—Grossouwria, Subgrossouwria, Choffatia and Orionoides—are abundant. It is one of the ironies of world correlations that the only Indian Erymnoceras known occurs in the Athleta Beds.

The lower part of the Callovian is probably more fully developed in Cutch than anywhere else in the world. The combined Lower and Middle Callovian are estimated to be 300 m. thick. The junction of Lower and Middle Callovian cannot be drawn confidently at any precise horizon, for exact correlation of the expanded succession of largely local oriental elements with the usually more or less condensed sequence in Europe is impossible. Spath regarded the Rehmanni Beds as equivalent to the Callovienne and Koenigi Zones, but Callomon has shown that they are more likely of the age of the Jason Zone, therefore early Middle Callovian. I have myself found a fragment indistinguishable from R. rehmanni in the Jason Zone at Peterborough. In the Rehmanni Zone of some localities occur bands of Golden Oolite, but these are not developed at Jumara.

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The fullest succession was worked out in the Jumara dome by Raj Nath (in Spath, 1933, p. 740):

<table>
<thead>
<tr>
<th>STRATA</th>
<th>TYPICAL AMMONITES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Rehmanni Beds (yellow limestone)</td>
<td>Reineckeia tyranniformis</td>
</tr>
<tr>
<td></td>
<td>Sivajiceras kleidos</td>
</tr>
<tr>
<td></td>
<td>Idiocycloceras singularare</td>
</tr>
<tr>
<td>Lower Rehmanni Beds (yellow limestone)</td>
<td>Reineckeia rehmanni</td>
</tr>
<tr>
<td></td>
<td>Kellawaysites greppini</td>
</tr>
<tr>
<td></td>
<td>Sivajiceras aff. fissum</td>
</tr>
<tr>
<td></td>
<td>Idiocycloceras singularare</td>
</tr>
<tr>
<td>Upper Macrocephalus Beds (limestones)</td>
<td>Macrocephalites spp.</td>
</tr>
<tr>
<td></td>
<td>Dolikephalites subcompressus</td>
</tr>
<tr>
<td></td>
<td>Kamptokephalites cf. magnumbilicatus</td>
</tr>
<tr>
<td>Middle Macrocephalus Beds (shales with</td>
<td>Dolikephalites subcompressus</td>
</tr>
<tr>
<td>ferruginous nodules)</td>
<td>Nothocephalites semilaevis</td>
</tr>
<tr>
<td></td>
<td>Kamptokephalites aff. magnumbilicatus</td>
</tr>
<tr>
<td></td>
<td>Macrocephalites chariensis</td>
</tr>
<tr>
<td></td>
<td>Kamptokephalites dimerus</td>
</tr>
<tr>
<td></td>
<td>Indosphinctes spp.</td>
</tr>
<tr>
<td></td>
<td>Macrocephalites chariensis</td>
</tr>
<tr>
<td></td>
<td>Paroecotraustes sp.</td>
</tr>
<tr>
<td></td>
<td>Parapatoceras sp.</td>
</tr>
<tr>
<td></td>
<td>Macrocephalites chariensis</td>
</tr>
<tr>
<td></td>
<td>Kamptokephalites dimerus</td>
</tr>
<tr>
<td></td>
<td>Pleurocephalites habiens</td>
</tr>
<tr>
<td>Lower Macrocephalus Beds (white limestones,</td>
<td>Macrocephalites triangularis</td>
</tr>
<tr>
<td>with shale between)</td>
<td>M. madagascariensis</td>
</tr>
<tr>
<td></td>
<td>Sivajiceras aff. congener</td>
</tr>
<tr>
<td>Upper Patcham (coral limestone)</td>
<td>Macrocephalites sp.</td>
</tr>
<tr>
<td></td>
<td>Sivajiceras congener</td>
</tr>
<tr>
<td></td>
<td>Procerites hians</td>
</tr>
<tr>
<td>Lower Patcham (shelly limestone)</td>
<td>Macrocephalites triangularis</td>
</tr>
<tr>
<td></td>
<td>Macrocephalites spp.</td>
</tr>
</tbody>
</table>

**UPPER BATHONIAN**

The Kuar Bet Beds, near Khera (Cox, 1935, p. 2), are rich in pelecypods, especially *Corbula lyrata* Sow. and species of *Protocardia*, *Pseudotrapezium* and *Eomiodon*. The same assemblage has been found in the Attock district of the northern Punjab and in Madagascar, and is now referred to the Upper Bathonian. In all these places the beds are transgressive. The only ammonite recorded in Cutch is an undetermined Stephanoceratid.*

Much has been written about the correlation of the thick *Macrocephalites* beds. They are all intimately linked together by ranging species (the full lists show this to be truer even than appears from the foregoing synopsis),

* Recorded (as *Cadomites*) by Spath, 1939, Journ. Roy. Soc. West. Australia, vol. xxv, p. 126. There is no resemblance to the 'Lower Bathonian of Sicily'.

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and there is no reason to consider any of the beds between the top of the Kuar Bet Beds and the base of the Rehmanni Zone as anything but parts of expanded Macrocephalus and Callovienne Zones. Comparison with the English Upper Cornbrash is difficult because that deposit is so thin and the Macrocephalitidae have not yet been monographed, but recent work shows more horizons within even the English Lower Callovian than has been supposed (p. 26).

Spath’s decision to class the Indian Macrocephalus Zone in the Bathonian was unfortunate because it has caused misunderstandings and has led to such absurdities as the labelling of the whole of the Patcham group, with *Macrocephalites* spp., as ‘Lower Bathonian’ (Spath, 1933, p. 872) and thence even ‘Inferior Oolite’ in an up-to-date and excellent text-book (Krishnan, 1949, pp. 378, 379, 381).

Geological maps still show an area of about 1000 square miles in the north of the Kathiawar peninsula coloured as Jurassic, but the only Mesozoic rocks there are continental sandstones and shales now known to be Cretaceous. They may be as much as 450 m. thick and the base is not seen. The plant beds yield the *Ptilophyllum* flora and probably correlate with the Umia plant-beds (Bhuj Series) and Jabalpur Gondwanas, and so are Aptian or later. They are overlain conformably by marine strata resembling the Bagh Beds, which are Albian or Cenomanian (Fedden, 1884, p. 78).

### Jaisalmir

About 200 miles north of the Cutch Jurassics, an equally large inlier, and some smaller masses, of Mesozoic rocks protrude through the vast expanse of recent deposits in the Rajputana desert. In the centre of the area is the town of Jaisalmir. The following are the formational names introduced by Oldham (1893, p. 226) to which are added thicknesses measured by A. Allison in 1939 (unpublished report to the Burmah Oil Company), and age-determinations resulting from examination by Spath (1933, pp. 799-801) of ammonites found by previous collectors.

<table>
<thead>
<tr>
<th>Formation</th>
<th>Age</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abur group, with a 1 metre ammonite bed: abundant Lower Aptian ammonites, earlier than those of Ukra Hill in Cutch</td>
<td>96 m.</td>
<td>690 m.</td>
</tr>
<tr>
<td>Parihar Sandstones (unfossiliferous)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bedeser group, with ammonites of the Umia ammonite bed and also some of those from the Upper Katrol: therefore Tithonian</td>
<td>300 m.</td>
<td></td>
</tr>
<tr>
<td>Jaisalmir Limestones, with ammonites of Upper Oxfordian and Upper and Middle Callovian dates (Anceps and Athleta Zones)</td>
<td>30 m.</td>
<td></td>
</tr>
<tr>
<td>Balmer Sandstones. Hard sandstones with some pelecypods, fossil wood, a rich gastropod bed, and fish teeth (A. Allison, 1939). Seen to</td>
<td>223 m.</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1330 m.</td>
</tr>
</tbody>
</table>

Interesting features of this succession are the condensation of the Callovian and Oxfordian stages and the intercalation of 690 m. of unfossiliferous sandstone between the equivalents of the Umia Ammonite Bed and the lowest Aptian.

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SALT RANGE

SALT RANGE

Another 400 miles due north of Jaisalmir the Jurassic system reappears, lifted above the alluvial plains of the Indus and its tributaries in the great south-facing scarp of the Salt Range. It is also exposed immediately to the north in the Attok district. The Punjab Salt Range crosses the Indus from the east at Kalabagh and thence swings west and then south in the Trans-Indus Salt Range to make a hairpin loop about 40 miles deep. The scarp exposes Cambrian and representatives of all systems from Carboniferous to Tertiary. On the Punjab side Jurassic rocks begin to come in only at the west end of the range, near Amb and Sarkesar, and although they thicken beyond the Indus they are never complete, owing to an erosional unconformity and overstep by the Neocomian. The Salt Range Jurassics, ‘though very much reduced and badly developed’ were long ago recognized to be similar to those of Cutch, more than 600 miles away (Waagen, 1875, p. 236). In particular, the Callovian Golden Oolite, like that of Khera Hill in Cutch, occurs on both sides of the Indus (Wynne, 1880, p. 31). The overstepping Neocomian comprises the Belemnite Beds, marls from which a condensed Valanginian and Berriasian ammonite fauna has been monographed (Spath, 1939).

The eastward wedging out of the Jurassic, however, is not due to overstep alone, but also to intra-formational thinning. Near the east end of the outcrop on the Punjab Salt Range, about Amb and Sarkesar, the Neocomian Belemnite Beds rest on an eroded surface of limestones with Nerinea and Rhynchonella assigned tentatively to the Upper Jurassic; but the whole of the beds assigned to the Jurassic (including 20 m. of oolitic limestone with Trigonia) are only 77 m. thick, below which are sandstones and dolomites supposed to be Triassic (Koken, 1903). Beyond the Indus, however, Wynne (1880, p. 31) recognized bands of dolomite within the Jurassic. In the Trans-Indus range he considered the Jurassic (with the thin Neocomian) at least 450 m. thick. ‘The lower part is chiefly made up of variegated soft red and white sandstones with grey and coaly shales and numerous obscure plant remains, while the upper part consists of variegated light-coloured and generally thin-bedded limestones full of marine fossils, both divisions containing bands of magnesian limestone’.

Very little palaeontological classification of these rocks is yet possible, though ammonites occur. Callovian is indicated by the Golden Oolite and by a few species of Macrocephalitids in old collections (Spath, 1933, p. 802). These indicate Cutch assemblages of the Macrocephalus and Anceps Zones, in Cutch facies. Most come from near the Chichali Pass. It was also found, in working the fauna of the condensed and transgressive Valanginian beds, that they contain a number of derived Upper Jurassic ammonite fragments which indicate the former presence of the middle Spiti Shales (Chidamu beds) (Spath, 1939, p. 152). Old records by Oppel of ammonites which await rediscovery suggest the presence of Upper Oxfordian also. This stage occurs in the Attok district not far to the north (see p. 400).
According to current theory, during the middle and late Tertiary the Indian shield, carrying intact upon its back the infaulted tracts of Gondwana sediments and the carapace of Deccan traps, and along its north-eastern edge the marginal Upper Jurassic marine beds of Cutch, Jaisalmar and the Salt Range, ploughed its way northward into the central Asian geosyncline. The effect of this tremendous event was to compress the geosyncline, stowing up the packed and crushed sediments into the greatest mountain ranges of the world and the highest plateau—the Himalayan ranges and Tibet. The orogeny was geologically so recent that denudation has not yet reduced these wrinkles to the extent that it has other Tertiary ranges, such as the Alps; much less their Altaid predecessors. Most of the elevation, in fact, took place after the Miocene period. Nummulitic Eocene is found up to 20,000 ft. above the sea.

At the NW. and NE. corners of the shield, in Kashmir and Assam, two rigid spurs of Archaean rocks with a thin sedimentary cover penetrated deeply into the geosyncline, producing two syntaxes or ‘troopings’ of ranges, one behind the other like frozen sea waves. The western syntaxis troops together the Himalayas, Hindu Kush, Karakorum, Kuen Lun and other ranges, and extends back to the Pamirs. The eastern syntaxis is much larger and produces the vast troop of high ranges at the angle where the eastern Himalayas turn south into Burma, dividing the valleys of many of the world’s greatest and swiftest rivers—the Brahmaputra, Irrawaddy, Salween, Mekong and upper Yang-tse-Kiang. Between the two syntaxes, in a continuous sagging curve 1400 miles long, run the Himalayas, backed by the Trans-Himalayas and the high Tibetan plateau. On either side, east and west, the ranges of Burma and Baluchistan bulge forward in open arcs against the shield, their strike-lines running in general north and south. The festooned pattern, reminiscent of a drapery pinned up at two points, is simple in outline, but within the folds there is extreme complexity and much still remains to be elucidated.

Internally the Himalayan structure resembles that of the Persian Zagros, but there are important differences. Superficially the fore-deep represented by the Gangetic plain resembles the Persian Gulf and Mesopotamia; but although the Gangetic alluvium is immensely thick (how thick is not known) and doubtless conceals Tertiary sediments, there is no reason to suspect great thicknesses of earlier formations; in fact the position of the Aravalli Archaean inliers near Delhi make this extremely improbable. The mountain front itself, however, is divided as in the Zagros and other fold ranges into an outer autochthonous fold belt and an

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inner nappe zone in which older and largely crystalline rocks are exposed. The front edge of each belt is a thrust fault, the inner fault, bounding the nappe zone, being by far the most important. Upon it vast bodies of rock from within the mountains have been carried horizontally over the autochthonous folds, as in the Alps (Wadia, 1931, pp. 214-15).

In this chapter we shall enquire what peculiarities (if any) characterized the area during the 50 million years or so of Jurassic time. Beginning in the west, we pick up the broken strands of the mountain chains on the coast of Baluchistan, severed by the Arabian Sea from their probable continuations in Oman and south Persia, which we left in Chapter 13.
By far the greater part of Baluchistan, the western areas, with the Mekran coast and its hinterland, consists of folded Tertiary beds, mainly in the monotonous flysch facies of sandstones and shales. East of longitude 66°15' E. are south-north ranges of entirely different aspect, formed mainly of Jurassic and Cretaceous rocks. The dominant feature in this tract is a vast deposit of Lower and Middle Jurassic black, dark grey or brown, hard limestone, altogether at least 2000 m. thick. Folding as a highly competent formation, and opposing stubborn resistance to the forces of denudation, its broad domes and anticlines stand up as mountain ranges, while the intervening synclines have become valleys. (Vredenburg, 1909, with geological map, pi. 12). This type of country extends from the coast near Karachi for at least 500 miles inland, through Las Bela State and past Kalat and Quetta. All of it belongs to the region of autochthonous folds. There are thrust-faults, but if there is any zone of nappes it lies buried under the flysch to the west, or in the unmapped regions of Afghanistan; more likely such a zone is absent. Finds of Jurassic ammonites give promise of a sequence of rich Lower and Middle Jurassic faunas.

'The Lias consists of 3000-4000 ft. of black limestones, some of them oolitic, and calcareous shales, with some highly fossiliferous bands, in which the principal subdivisions of the European series have been identified. They are succeeded by an equal thickness of massive limestones of Middle Jurassic age, which constitute the lofty peaks that surround Quetta. This massive limestone is unconformably overlaid by the Lower Cretaceous . . .' (Vredenburg, 1907, p. 50). The Lower Cretaceous is developed as black Belemnite Shales as in the Salt Range, but much thicker (up to 400 m.), followed by Lower Cretaceous limestones brilliantly striped red and white, which form lesser escarpments ringing round the black Jurassic domes and ridges.

Geologists of the Burmah Oil Company on reconnaissance expeditions in 1938-9 obtained measurements which indicate that the Jurassic limestones may be in places double the thickness estimated by Vredenburg (i.e. up to 4000 m.), but the effects of isoclinal folding and thrusting can prepare many pitfalls. In thin-bedded limestones at Mazar Drik, at the top of the massive limestones, occurs the Lower Callovian fauna of the Macrocephalus Zone of the Lower Chari in Cutch. The vast thicknesses of underlying massive limestones are therefore dated to Middle Jurassic at latest.

Sequence in Baluchistan

[BERRIASIAN OR VALANGINIAN

Belemnite Shales (up to 400 m.) with Hibolites subfusiformis and H. pistilliformis, as in the Salt Range.]
Tithonian

On the Windar River, Las Bela State, Dr W. L. F. Nuttall in 1924 collected fragments of *Virgatosphinctes denseplicatus* (Waagen) and *V. cf. subquadratus* Uhlig (now in the Sedgwick Museum, Nos. F778-781 and F782-3).

Lower Callovian

*Mazar Drik Limestone* (Mari Hills): alternations of rather thin-bedded limestones and shales, containing ammonites of the Macrocephalus Zone of Cutch, monographed and correctly dated by Noetling (1897) and revised by Spath (1933, p. 808). *Macrocephalites, Dolikephalites, Indocephalites* and *Pleurocephalites* spp., with *Indosphinctes aff. errans* Spath and *Choffatia aff. recuperoi* (Gemm.). Large *Indocephalites* were mistaken by Noetling for the similar *Epimayaites polyphemus* (Waagen), which, however, is of Upper Oxfordian date. The original name of Polyphemus Limestone for this group has therefore had to be changed (Arkell, 1951, Mon. English Bathonian Am., Pal. Soc., p. 36).

Upper Bathonian

*Mazar Drik Limestone* (presumably lower part). Noetling on his pl. vi figured two typically Upper Bathonian ammonites, *Bullatimorphites bullatus* (d'Orbigny), which he correctly identified and recognized as pre-Callovian, and a 'Harpoceras' which Spath (1933, p. 808, and pl. cxxx, fig. 3) renamed 'Oppelia baluchistanensis', but which is an Upper Bathonian *Clydoniceras*. Some of Noetling's *Choffatiae* also resemble Bathonian forms more closely than Callovian. It would therefore appear that, like the English Cornbrash and the condensed limestone of Mount Strunga in Rumania, the Mazar Drik Limestone bridges the Upper Bathonian and Lower Callovian (Arkell, 1951, loc. cit., p. 36). It will be interesting to see whether more careful collecting in the future proves the two faunas to be distinct stratigraphically as in the Cornbrash.

'Middle Jurassic'

'Massive grey limestones several thousand feet thick' (Vredenburg, 1909, p. 200). No ammonites known.

'Liassic'

'Dark-grey, almost black, regularly stratified limestones, several thousand feet thick, sometimes interbedded with richly fossiliferous dark calcareous shales' (Vredenburg, 1909, p. 200). Within this series the following ammonite faunas have so far been recognized.

Lower Toarcian

Black shales near Kelat and on the Natrani River, Las Bela, have yielded an abundant well-preserved ammonite fauna of the Italian Lower Toarcian, including various species of *Phylloceras, Juraphyllites, Lytoceras*,

RANGES OF SOUTH-EAST ASIA

Dactylioceras, Porpoceras, Fuciniceras, Protogrammoceras and Polyplectus, with the peculiar genus Sphenarpites (Holland, 1909; Spath, 1936). At a lower level near Kelat and on the Porali River, Las Bela State, occur Boulieceras and an associated fauna of Fuciniceras and abundant Spiriferina and Pecten ambongoensis Thevenin, as found in Madagascar and Jebel Tuwaiq in central Arabia. There are also many other brachiopods, etc. (Holland, 1909, p. 27).

SINEMURIAN

Crinoidal limestones and shaly beds in the Shirinab valley, south of Mastung, yielded Arietites aff. bisulcatus (Bruguière) (Holland, 1909, p. 26). Since Sinemurian Arietitids are known in southern Persia and in Tibet this record is not improbable, but it would be more satisfactory if verified by an ammonite specialist, in view of the homoeomorphy of certain Fuciniceras, with strongly carinate-bisulcate venters, found in the Lower Toarcian of Baluchistan.

(Unconformity, teste Burmah Oil Company geologists)

[PERMIAN OR CARBONIFEROUS

Limestones with Productus, etc., locally NW. of Kelat (Vredenburg, 1909, p. 201).]

WAZIRISTAN AND THE SAMANA RANGE

If it is a correct hypothesis that in the Tertiary era peninsular India moved northwards, it follows that the Jurassic geosynclinal deposits of Waziristan and adjoining areas to the north would have been squeezed and pinched between the approaching Indian shield and the smaller horst of Afghanistan. The Jurassic belt is, in fact, much narrower and more discontinuous here than farther south, in Baluchistan. The diminution in width and the discontinuity caused Fox (1931, pl. 10) in his palaeogeographic map to show a NW.-SE. land-bridge joining Afghanistan with peninsular India during the Jurassic. That such a bridge cannot have existed is proved by the Jurassic outcrops of the Samana Range, which strike right across it. There can be no doubt that the seaway passed continuously round the projection that caused the Kashmir syntaxis, from Baluchistan, through Waziristan, into the Karakorum, as indicated by Wadia (1931, pl. 3).

The festooned trend-lines of the Kirthar and Sulaiman Ranges, repeated on a smaller scale in Waziristan and the Trans-Indus Salt Range, are consistent with the postulated northward drive of the Indian shield. If the movement was as great as supposed there should be extensive tear faults and perhaps discontinuities among the narrowed Mesozoic outcrops of Waziristan. Detailed survey in the future should be able to detect these if they are present. So far little is known of the Jurassic of Waziristan. In the south, shales containing Virgatosphinctes of the Chidamu Beds of

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the Spiti Shales are reported, overlain by 'a mighty plant-bearing series (Janjal Series) and Neocomian belemnite beds (Spath, 1939, p. 136).

The Samana Range, between Kohat and Thal, in the North-West Frontier province, has so far proved highly intractable to collecting, consisting largely of the barren types of deposit developed extensively in Baluchistan and the Himalayas. It is a large simple anticline, built up of alternating masses of monotonous sandstone and limestone, with subordinate clays. From near the top of a great thickness of such beds, which may extend down into the Trias, eight specimens of a single species of brachiopod have been obtained. They are identified as Rhynchonelloidea arenata (Quenstedt) and believed to indicate Upper Bathonian or Lower Callovian (Muir-Wood, 1930, p. 26). On these beds follows the dark grey, almost black, Samana Suk limestone, 120-150 m. thick, probably Upper Jurassic in age; and this in turn is overlain by 9-15 m. of glauconitic sandstone locally crowded with Neocomian belemnites (Davies, 1930).

**Attock District and Hazara**

To the east of the Samana Range, on the opposite side of the Indus, is the Potwar Plateau, lying between the Indus and the Jhelum and bounded on the south by the Salt Range and on the north by the Himalayas of Hazara. Most of the surface of the plateau consists of Tertiary rocks, but from the double bend of the Indus below Attock, where Alexander the Great crossed the river by a bridge of boats in 331 B.C., there runs east and west a belt of anticlines which bring up Mesozoic rocks (Cotter, 1933, with geological map, pl. 19). At the east end this belt curves northwards parallel to the Jhelum, where it runs into the western boundary of the projecting horst of Tertiary-covered rigid rocks mapped by Wadia (1931, pl. 8), which points into the syntaxis of the NW. Himalayas. Both the Attock and Hazara Jurassic outcrops closely adjoin the spur on its west side. The lithological and, in the main at least, the palaeontological succession, however, are the same as in the Himalayas of Spiti and Niti, 5° of longitude farther east.

In both Attock and Hazara the three following traditional formations of the Himalayan Mesozoic are recognized:—

- Giumal Sandstone, up to 36 m. (Neocomian and Albian)
- Spiti Shales, up to 60 m. (Upper Jurassic)
- Kioto Limestone, up to 480 m. (Upper Triassic, Liassic)

In Hazara there is a change of facies from the Himalayan type in the north to the Salt Range type in the south, with successive overlaps within the Mesozoic formations. The Kioto Limestone overlaps southward, cutting out Permo-Carboniferous rocks which are present in Hazara and coming to rest on the Attock Slates, which are probably pre-Cambrian. The Spiti Shales overlap the Kioto Limestone, which develops an eroded and bored surface; the bottom ferruginous layer of the Spiti Shales covers

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the step-like outcropping edges of the Trias after the manner of a stair-carpet' (Middlemiss, 1896, p. 29). Farther south, and in the greater part of the Attock district, the Spiti Shales in turn are overlapped by the Giumal Sandstone, which takes on a shelly facies and incorporates at the base, or rests on condensed representatives of, certain Oxfordian horizons which belong low down in the Spiti Shales.

The Attock and Hazara districts thus provide a section across the southern edge of the Himalayan trough and must have been moved bodily with the underlying shelf of pre-Cambrian rocks if the Indian peninsula underthrust northward as postulated. A similar marginal section may be preserved north of Mount Everest (see below).

The following stages have been identified:—

Succession in the Attock District and Hazara

Upper Tithonian and Berriasian

Ammonites of the genera *Spiticeras*, *Blanfordericas* and *Himalayites* have been recorded in limonitic poor preservation in sandy limestones of the Attock district wrongly correlated with the Giumal Sandstone of the Himalaya, and from Hazara is known a *Neocosmoceras*. These are all genera typical of the Upper Spiti Shales (Lochambel Beds, see p. 407) (Spath, 1933, pp. 803-4). Similar rocks in both Hazara and the Attock district have yielded numerous *Trigonia ventricosa* Krauss (Middlemiss, 1896, p. 34; Cox, 1935, pp. 2, 17, pl. ii, fig. 14).

Lower Tithonian

*Virgatosphinctes frequens*, a species of the Middle Spiti Shales (Chidamu Beds) is recorded from several places in Hazara (Middlemiss, 1896, pp. 33, 34; Spath, 1933, p. 804).

Upper Oxfordian

In the Attock district, where a condensed, marginal, shelly facies of the Spiti Shales is overlapping the Kioto Limestone and is itself almost overlapped by Giumal Sandstone, a highly interesting ammonite assemblage of the Transversarium Zone occurs. It consists mainly of *Perisphinctes* of strong Cutch affinities (though some are cosmopolitan), with which are associated some *Mayaites*, including *M. polyphemus* (Waagen), the whole indicating direct sea-connexion with Cutch (Spath, 1934; subgeneric attributions of the Perisphinctids require revision). With them occur *Gryphaea balli* (Stefanini) and *Exogyra fourtau* Stefanini, two oysters first described from Somaliland, and other common pelecypods (Cox, 1935).

Upper Bathonian

The Kuar Bet Beds of Cutch (see p. 391) are represented by a number of pelecypods preserved in grey rubbly limestone, presumably from the local top of the Kioto Limestone. *Protocardia, Eomiodon* and *Corbula* have been figured (Cox, 1935).
Lias

Proof that at least some part of the Lias is represented in the Kioto Limestone is provided by typical Liassic pelecypods: *Eopecten velatus* (Goldfuss), *Lima gigantea* (Sow.), *Plicatula spinosa* (Schloth.), figured by Cox (1935).

[Trias]

Dr Cox (1935, p. 3, pl. i, fig. 1) recognized from the Kioto Limestone a single specimen of the Upper Triassic genus *Indopecten* Douglas. The specimen is of special importance because it had been argue from the supposed absence of this conspicuous genus from the Himalayan region and its abundance in eastern Persia and the East Indies that there must have been in Triassic times another migration route across what is now the Indian Ocean.

Pamirs and Fergana

No equivalent section across the northern shore of the Asian Tethys is yet on record. The most northern Tertiary fold mountains of the Himalayan system are the Pamirs. In general they consist of a series of arcuate ranges convex northwards. They are the outer wrinkles of the great syntaxis, stowed up against older Palaeozoic (Altaid) ranges, with intense folding (often isoclinal), thrusting, and magmatic injection which has locally metamorphosed the strata, converting Mesozoic shales into micaschists (Tipper, 1923; Yudin, 1932). The extent of such metamorphicJurassics is unknown; but in Chitral Tipper obtained Jurassic belemnites from schists in the Arkari valley at 16,000 ft. This area has peaks rising to 25,000 ft. and many glaciers, making 'detailed work practically impossible'.

It appears that the Angara plant-beds, the Saighan Series of Afghanistan (see p. 381), pass on north-eastwards along the north side of the Hindu Kush and through the extreme NE. corner of Afghanistan, where they have been reported at Faizabad on the upper Amu Darya. Thence their outcrop swings round eastwards with the strike of the mountain ranges, crossing the central Pamirs in a belt about 30 miles wide. In the central Pamirs the thickness reaches 3000 m., mostly dark grey and black shales, with ripple-marks in places and plant remains, especially cycads, ferns and Equisetales (Yudin, 1932). On the north side of the Amu Darya the same series contains coal measures in the Hissar Mountains and east Fergana, and in these places and at Naryn have been found marine intercalations with *Cardinia* spp. as well as a marine microfauna. 'Middle Jurassic ammonites' are also reported (Shabarov, 1939, p. 550). In the eastern Pamirs the thickness diminishes: the Angara Beds, consisting of shales and quartzites, often false-bedded, and resting directly on gneisses and ancient crystalline schists, are there overlapped by transgressive Cretaceous beds (Asklund, 1922, p. 173). Angara Beds have been
recognized on the north flank of the Karakorum as far as latitude 77° 8' E. (Norin, 1946, map, pl. A).

In the central and southern Pamirs the Angara Beds are succeeded, like the similar Liassic plant-beds of north Persia, by a thick Middle-Upper Jurassic limestone, 600-800 m. thick, called by Hayden (1916) the Pamir Limestone. Resting unconformably on this, at least in the central Pamirs, are up to 675 m. of red sandstones and conglomerates, with Lower Cretaceous pelecypods near the base; in places there is a basal conglomerate composed of Jurassic limestone (Yudin, 1932). This series recalls and probably is equivalent to the Red Grit Series of Afghanistan (see p. 381), the Pamir Limestone being an intercalation between it and the Saighan Series and absent from Afghanistan.

![Fig. 57.—Jurassic outcrops in the Himalayas and Tibet. After the Geological Survey map of India.](http://jurassic.ru/)

So far three distinct Jurassic ammonite faunas have been reported from the Pamir Limestone. In a valley called Kekchaki (37° 33': 74° 55'), Hayden (1916, pp. 307-9) found a bed with many poorly-preserved Perisphinctids, associated with Reineckeia and Oppelia. He likened the Perisphinctids to Kimeridgian species but felt confident enough of the Reineckeia to infer that the age of the bed is Callovian. The general aspect of the multitudes of Perisphinctids from the Reineckeia beds of the Anceps Zone of the Elburz is sufficiently like the forms cited by Hayden to produce strong probability that Hayden found the equivalent of this horizon, which was also encountered by the Filippi expedition in the Karakorum (see pp. 370, 405). It may be recalled that the same Perisphinctid assemblage was mistaken for Kimeridgian at Lake Urmia by Weithofer (see p. 366).

Confirmation of the presence of a rich Middle Callovian ammonite fauna was obtained by a Russian expedition in the south-eastern Pamirs

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in 1933. Despite its poor preservation, Vyalov (1935)* was able to recognize at least four species of *Hecticoceras*, which he compared to Russian and Caucasian species and perhaps a Cutch species (*H. cf. dynastes* Waagen), *Distichoceras aff. fornix* (Sow.), also a Cutch species, and various Grossouvrids. Beneath this fauna was collected an assemblage of Perisphinctids compared chiefly to Bathonian *Siemiradzkia* spp. Beneath this again were further ammonites compared to the Bathonian forms *Oppelia aff. aspidoides* (Oppel), *Prohecticoceras cf. primaevum* (de Gross.) and more *Siemiradzkia* spp. Finally, the lowest assemblage found appeared to be Middle to Upper Bajocian, with crushed and distorted ammonites compared to *Oppelia cf. subradiata* (Sow.), *Lissoceras cf. oolithicum* (d'Orb.), *Dorsetensia cf. regrediens* (Haug), ?*Ermoceras* sp., *Lytoceras* sp. From another locality was recorded *Emileia cf. polyschides* (Waagen).

From Gajdna, in the southern Pamirs, a Russian expedition in 1927 made a small collection of fragmentary ammonites which appear to denote an Upper Bathonian horizon close to that of Lechstedt, near Hildesheim (Khudiaev, 1931). The Pamir Limestone is here 600-800 m. thick and the ammonites were collected near the base from marly limestone bands several tens of metres thick. They are associated with a rich and varied fauna, mainly pelecypods. Ammonites are rare and poorly preserved. The fragments figured by Khudiaev were compared by him to *Prohecticoceras retrocostatum* (de Grossouvre), *P. costatum* (Roemer), *Bullatimorphites suevicus* (Roemer) and *Siemiradzkia obliqueraudiata* (Jüssen). The material is so poor that from the illustrations these comparisons can be neither contested nor confirmed, but they may well be correct. The top of the limestone is locally full of corals, *Nerinea*, etc. (Yudin, 1932).

According to Hayden's observations (1916) the lower part of the Pamir Limestone is Triassic. The evidence adduced, however, is not quite convincing, in view of the superficial resemblance (stressed by himself) between various shale and limestone groups of different ages, and the extreme complexity of the structure. There is here an inconsistency which only future research can resolve.

Yudin (1932) was impressed by the resemblance between the Jurassic sequence in the Pamirs and that in the Caucasus and northern Persia. In view of what is now known of the Pamirs and Karakorum there can be no doubt of the correctness of Nikitin's hypothesis (1889, p. 142), adopted by Uhlig (1910a, pp. 41-4), of a Jurassic seaway connecting this region across Bokhara with the Aralo-Caspian depression, south Russia, and the Elburz Mountains of Persia. The sea did not, however, cover Afghanistan as shown in the map by Stefanini (1928).

*I am indebted to Mr E. P. Tyrrell for a complete translation of this important paper from the Russian.*

http://jurassic.ru/
Karakorum

Beyond the great syntaxis, of which the Pamirs are as it were the key­stone, a vast sea of mountain ranges fans out eastwards in the mightiest virgation on earth. The most southerly range of the virgation is the Himalaya, the most northerly the Kuen Lun. Between the two is the Karakorum; high but relatively short, its sedimentary (Tethyan) part dying out by about longitude 79° E. into the plateau of northern Tibet.

The Kuen Lun is composed of Palaeozoic and older sediments which were folded and consolidated in the Altaid (Variscan) orogeny and raised again by the Alpine orogeny (fig. 58). The outer Himalaya likewise consists of pre-Cambrian and Lower Palaeozoic rocks upheaved and overthrust southward in the late Tertiary. Between the two, amid vast areas of similar rocks and of granites and gneisses, are left small scattered outliers which are relics of a shallow Mesozoic seaway, the Tethys. Farther east, in Tibet, thousands of square miles of Jurassic and Cretaceous sediments deposited in this seaway still survive, but in the west, in the closely trooped fold ranges of the great virgation, nearly all the Jurassic has been destroyed by erosion. West of the longitude of Spiti (the classic locality described in the next section) the only outliers known are in the Karakorum and the adjoining Aghil ranges.

The fascination of this spectacular and inaccessible region has drawn a

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series of major expeditions, to whose collecting we owe what little is known. The first to bring back Jurassic fossils was the de Filippi expedition of 1913-14, which crossed the Karakorum Pass and descended into the Tarim basin, returning by way of Yarkand, Kashgar and Tashkent. A vivid idea of the country may be obtained from the first-rate description and hundreds of superlative photographs (de Filippi, 1932). From a small valley, tributary to the Shyok River, immediately south of the Karakorum Pass, about 125 specimens of ammonites were collected from a marly limestone. They are mostly fragments and the preservation is poor, but they suffice to identify the Anceps Zone of the Middle Callovian (Stefanini, 1928). With them occur foraminifera and a cosmopolitan assemblage of pelecypods—Chlamys, Lima, Ctenostreon, Pholadomya, Goniomya, Oxytoma, some Rhynchonellids and Terebratulids, foraminifera and sponge spicules. The locality was called the Valley of Ammonites. The assemblage of fragments figured by Stefanini comprises Gounouvia, Choffatia, Reinekeia, Oxyscerites and Hecticoceras, and is unmistakably the same as that known from Lake Urmia and the Elburz Mountains of north Persia (see pp. 366, 370). In particular, Hecticoceras (Brightia) aff. metomphalum Bonarelli and H. (Putealiceras) paulowi Tsyt. occur in all three areas. Like the Lower Bathonian of the Pamirs, this fauna seems to demand a seaway across Bokhara from the north-eastern Elburz. (With Spath (1933, p. 806) I would reject Stefanini’s identifications of Kosmoceras (pl. viii, fig. 5), Villanya (pl. xi, fig. 4), and the rolled fragment of a (Spiti Shale?) Perisphinctid (pl. x, fig. 4)). Four more Pseudoperisphinctinae from the same locality have since been figured (Frebold in Norin, 1946, p. 196, pl. xxii: fig. 4, Choffatia sp.; fig. 5, Poculisphinctes sp.; fig. 6, Indosphinctes sp.; fig. 7, Gounouvia sp.).

The Trinkler expedition of 1927-28, following an earlier synthesis of the Himalayas sensu lato (Trinkler, 1922), produced another great work on the Karakorum and Kuen Lun (de Terra, 1932). No Jurassic ammonites were found, but from near longitude 78° a small assemblage of pelecypods in a neritic broken-shell limestone includes Variamussium pumilum (Lam.), Camptonectes lens (Sow.), Pseudolimnea duplicata (Sow.), Ostrea calcarea Zieten, Trigonia formosa Lycett and other common European species, and seems to indicate Bajocian (Staesche in de Terra, 1932, p. 145, pls. xxi, xxii).

In the Aghil ranges, about 40 miles north-west of the Karakorum Pass, Mason (1928, pp. 97-8) found Spiticeras aff. scripta (Strachey), S. spitiense (Blanford) and Virgatosphinctes aff. denseplicatus (Waagen), which proves that at least the middle and upper faunas of the Spiti Shales are represented.

Since three expeditions have all found different faunas, it is evident that these mountains may still have many Jurassic surprises in store.

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The famous locality of Spiti is a small isolated area, only 40 miles long in the direction of strike and less than half as wide, surrounded by extensive tracts of Triassic and Palaeozoic rocks. The Niti area, rather more than 100 miles farther south-east along the strike, is somewhat larger. Both Jurassic outcrops are relics of dissected synclines within the Himalayan Mountains north of the main crystalline range.

From ancient times splendidly preserved ammonites were brought down by traders to be sold to Hindu pilgrims in the holy places of India. They were called Salagrams and were used as charms. The first to discover their source in the Spiti Shales were the Strachey brothers, but it was a long time before geologists elucidated the stratigraphy or collected any ammonites in situ. The earliest collections were formed by purchase and exchange, and the figures of isolated specimens by Gray, Oppel (1863) and Salter & Blanford (1865) (the first and third revised by Crick, 1903, 1904), gave rise to lively polemics among leading specialists of the day, especially between Neumayr and Nikitin. Stoliczka (1866) and Griesbach (1891) laid the groundwork of the stratigraphy, and Hayden (1904) published a more authoritative account of the Spiti area, correcting mistakes made by Stoliczka owing to inaccurate palaeontology.

In both areas the Upper Triassic and Jurassic rocks consist of a thick mass of dark grey or black limestone (Kioto Limestone, 150-700 m.), overlain conformably by the Spiti Shales (about 90-150 m.). The Kioto Limestone forms forbidding cliffs along the valleys of the Spiti and other rivers, while the Spiti Shales tend to weather into black, rolling, bare downs. The Kioto Limestone is almost unfossiliferous, except locally near the top.

The first, and still the only, attempt to collect ammonites in place from the Spiti Shales was made on an expedition in 1892 sent specially to investigate the stratigraphy of the Mesozoics of what is here called the Niti area (Johar and Hundes). It was sponsored by the Geological Survey of India who sent their officers, Middlemiss and Griesbach, accompanied by C. Diener of Vienna, who took part at the instigation of Professor E. Suess. In his account of this expedition, Diener (1895, pp. 582-8) first named the three divisions of the Spiti Shales already recognized by Griesbach (1891, p. 76), in ascending order the *Belemnites gerardi* Beds, Chidamu Beds and Lochambel Beds (both after places in the Niti area), and the collections made are still the main basis of our knowledge of the ammonite succession. The ammonite fauna of the Spiti Shales was later monographed by V. Uhlig (1903-10) and exhaustively discussed by him from every aspect (1910a). The other mollusca were monographed by Holdhaus (1913).

The charge can never be brought against the British that during their occupation of India they either neglected scientific opportunities or kept a corner in scientific investigations. The splendid series of palaeonto-
PLATE 20a.—The Castle of Bayburt, eastern Anatolia: Upper Jurassic limestones. (See Fig. 50.)

PLATE 20b.—Exotic blocks in the Kiogars. L, red Lower Lias limestone; P, Permo-Carboniferous limestone; 4b, Upper Flysch, black shales; 5, basic igneous rocks. (See Figs. 60, 61.)
Plate 21.—The Upper Spiti valley; cliffs of Kioto Limestone with Spiti Shales at top.

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logical and geological memoirs of the Geological Survey of India bear witness to the first statement; for the second it is only necessary to recall that W. Waagen of Munich, a pupil of Oppel's, was entrusted with monographing the Jurassic fossils of Cutch, that C. L. Griesbach, an Austrian, became Director of the Survey, that E. Suess of Vienna was invited to nominate palaeontologists to help collect and to monograph the classic fauna of Spiti, which thus came to be published by V. Uhlig, a pupil of Neumayr's at Munich (himself a pupil of Oppel's) and K. Holdhaus, a pupil of Diener's; while the wealth of Triassic ammonites was entrusted to Diener and Mojsisovics. The policy, for which stratigraphers and palaeontologists the world over have cause to be thankful, was to enlist the best-qualified experts available, irrespective of nationality.

The succession in Spiti and Niti resulting from Uhlig's work (see especially Uhlig, 1910a, pp. 26-32, with lists) touched up only in mere details, is as follows:—

Succession in Spiti and Niti

**Middle Neocomian**

*Giumal Sandstone* (up to 150 m.). Flysch facies passing down gradually into the Spiti Shales. (Giumal is a locality in the Spiti area.)

**Upper Tithonian, Berriasian and Valanginian**

*Lochambel Beds* (*Upper Spiti Shales*). Black lustrous shales with fossiliferous concretions, many having an ammonite at the centre. From these beds come the magnificent ammonites of uppermost Tithonian and Berriasian age figured in Uhlig's monograph (1903-10), belonging to the genera *Spiticeras, Berriasella, Blanfordiceras* (Cossmann, 1907, = *Blanfordia* Uhlig, preoccupied), *Aulacosphinctes, Paraboliceras, Himalayites, Kossmatia, Neocomites, Acanthodiscus, Kilianella, Sarasinella*, etc., all of which were founded by Uhlig. The uncoiled genus *Bochianites* also occurs. The dating of this and the other parts of the Spiti Shales remains the same as was established by Nikitin (1889, p. 125) and Waagen before him (1875), except that Uhlig was the first to recognize the Neocomian element. Representation of the European Tithonian was recognized by Zittel as early as 1868.

**Lower Tithonian and Upper Kimmeridgian**

*Chidamu Beds* (*Middle Spiti Shales*). Black lustrous shales with numerous black limestone nodules, many of which have an ammonite at the centre. The lithology is similar to that of the Lochambel Beds but the fauna is quite different, being overwhelmingly one of Perisphinctids, especially the genera *Virgatosphinctes* and *Aulacosphinctoides* (Uhlig, 1903-10, pls. xlix-lvi). Among them is *V. denseplicatus* (Waagen), characteristic species of the Umia Ammonite Bed in Cutch. In these beds also occur the few Phylloceratids and Lytoceratids found in Spiti, as well as Oppeliidae (*Uhligites*) and Haploceratidae. Future collecting will probably establish

[Link: http://jurassic.ru/]
the presence of at least two distinct assemblages, for among the Haplaceratidae is *Hildoglochiceras kobelli* (Oppel), which, as Uhlig (1910a, pp. 12, 27) pointed out, occurs in the Katrol Beds of Cutch, and is presumed to be Kimeridgian (see p. 388).

Gap representing the Lower and Middle Kimeridgian.

**UPPER OXFORDIAN**

*Belemnopsis gerardi* Beds (Lower Spiti Shales). Grey shales with occasional limestone bands and a few unfossiliferous nodules. *B. gerardi* is abundant, but it ranges up through the Chidamu Beds (Uhlig, 1903-10, pp. 386-8); also coarse-ribbed *Inocerami*. The only ammonites known are a few specimens of ‘Macrocephalitids’ which Waagen and Uhlig (1903-10, pp. 269, 388, and pl. lxvi, figs. 1-4) considered to be what are now called *Mayaites*, and they dated them as Upper Oxfordian. This is confirmed by Spath (1933, p. 804).

Non-sequence, denoted by conglomerate

**CALLOVIAN**

*Belemnopsis sulcacutus* Beds. At Niti Pass these beds consist of 45 m. of sandstone with belemnites and pelecypods, overlain by conglomerate. At Shalshal Cliffs the thickness is only 6 m. and there is at the top a layer of ferruginous oolite or pisolite, from which Diener (1895, pp. 583, 856) recorded ammonites identified by F. E. Suess as *Macrocephalites* cf. *pila* (Nikitin), *Kepplerites* cf. *galilaei* (Oppel) and *Sphaeroceras* n.sp. Subsequent finds indicate that the Lower, Middle and Upper Callovian are represented, all highly condensed; for at Laptal have been recorded *Macrocephalites* cf. *triangularis* Spath, *M. cf. flexuosus* Spath, *Reineckeites aff. waageni* (Till), *R. douvillei* Steinmann and *Distichoceras* cf. *bicostatum* (Stahl), the last denoting the Athleta Zone (Heim & Gansser, 1939, p. 142).

In some places the Callovian is cut out and the Spiti Shales rest directly on Laptal Beds or Kioto Limestone (fig. 59).

In view of the results obtained by Heim & Gansser, there must be some mistake about the level of the ‘*Stephanoceras coronatum*’ said to have been found by von Krafft at Tera Gadh near Giumal, between 105 and 120 m. below the base of the Spiti Shales, which was figured by Uhlig (1903-10, p. 269, pl. lxvii, fig. 5) as a *Macrocephalites*, an identification confirmed by Spath (1933, p. 804) after handling the specimen.

**LIAS**

Between the condensed Callovian and the Kioto Limestone, Heim & Gansser (1939, pp. 139-40) recognize 80-90 m. of thin-bedded limestones containing shell-beds of pelecypods, including *Trigonia*, which they call the Laptal series and assign to the Lias. It appears that these beds were included in the Tagling or Upper Kioto Limestone of earlier authors (total c. 450 m.), from which Stoliczka (1866, pp. 66-83) recorded numerous
Liassic Mollusca, including an ammonite which he identified as *Alocolytoceras germaini* (d'Orb.), of the Toarcian. Details of the stratigraphy at Shalshal Cliff are given by Diener (1895, pp. 583-6), and at Laptal by Heim & Gansser (1939, pp. 140, 143), who show the Laptal Beds as cut out in some places by the disconformity below the Spiti Shales. In view of the discovery of Liassic pelecypods in the Kioto Limestone of the Attock district (p. 401) it seems possible that the Laptal Beds may prove to be a lateral facies of the Upper Kioto (Tagling) Limestone.

The surprisingly imperfect correspondence between the ammonite faunas of Spiti and Cutch is evidently due largely to lack of correspondence in dates (Buckman's 'doctrine of dissimilar faunas'), as was pointed out already by Nikitin (1889, pp. 126-7).

**Fig. 59.—Details of the Triassic-Jurassic junction in some Himalayan sections. After Heim & Gansser, 1939.**

5, Upper Kioto Limestone; 6, Laptal Series; 7, Callovian ironshot oolite; 8, Lower Spiti Shales.

[RHAETIAN]

To this stage mainly, should probably be assigned the bulk of the Kioto Limestone (150-700 m.), which Diener compared to the Dachsteinkalk of the Alps.]

**TAL VALLEY, OUTER HIMALAYAS**

Near the exit of the Ganges from the mountains, in SW. Garhwal, are outliers of grits and quartzites, often calcareous, and passing into limestones in places, sandwiched between Eocene and Palaeozoic rocks. These, the Tal Beds, are the only Mesozoic deposits known on the southern side of the main Himalayan range. They contain fragmentary fossils, among which have been recognized corals, belemnites, pelecypods and gastropods, but they could be either Jurassic or Cretaceous (Oldham, 1893, p. 230). These outliers should be searched further, bearing in mind the possibility that they represent a shore facies of the Upper Jurassic on the southern edge of the Tethys.

**TIBETAN FACIES OF THE EXOTIC BLOCKS**

The Kiogar area, some miles south of Niti Pass (in the literature referred to as 'Kiogar', or 'Malla Johar in the Bhot Mahals of Kumaon', or 'Niti'), near the frontier of India and Tibet, is one of the most interesting geological
areas in the world. In it is a wonderful development of klippen and exotic blocks of all sizes, up to large mountain summits, associated with basic igneous rocks, and exhibiting astounding differences of facies. The phenomena have been described and discussed by von Krafft (1902), Griesbach (1904), Heim & Gansser (1939) and Bailey (1944).

The Spiti Shales are followed by a great thickness of flysch—chiefly sandstones—of Cretaceous age. The Lower Flysch or Giumal Sandstone is 500-700 m. thick and begins with the uppermost Valanginian, according to a record of *Olcostephanus (Rogersites)* cf. *atherstoni* (Spitz, 1914), but

![Fig. 60.—Sketch-map of the Kiogar area. From Bailey, 1944, after Heim & Gansser, 1939.](http://jurassic.ru/)

its upward date-limit is uncertain. (Spitz's records of Aptian and Upper Albian ammonites are discredited by Spath, 1939, p. 136). The Upper Flysch consists of another 500-700 m. of shales, followed by 300-400 m. of siliceous sandstones and siliceous shales with radiolarian cherts, all assigned to the Upper Cretaceous (Heim & Gansser, 1939, p. 147). Upon the Upper Flysch rests a great sheet of basic igneous rocks, including pillow lavas and interbedded with more radiolarian cherts, in and on which float broken masses of limestone forming the craggy peaks of the Kiogar range. The crags are true klippen and resemble those of the Carpathians and Alps, especially the Mythen. They are of a facies unknown in the autochthonous 'Himalayan' sequence upon which they and the igneous rocks rest (figs. 60, 61).

The succession is:

Grey siliceous limestone (12 m.) full of Radiolaria and sponge-spicules, probably Cretaceous.
Kiogar Oolite (50 m.): violet oolitic limestone with pink marly and white limestone layers, containing Calpionella alpina and therefore Upper Tithonian or Berriasian.

Reddish marl and limestone (8 m.).

Kiogar White Limestone, no fossils (200-300 m.).

Basic igneous rocks with some interbedded radiolarian cherts.

Upper Flysch, chiefly radiolarian cherts towards top (Upper Cretaceous), shales below, containing exotic blocks (800-1100 m.).

The basic igneous rocks intrude and vein the overlying Kiogar Limestone but have been contorted with the limestone. From this and the presence of pillow lavas and interbedded radiolarian cherts, it is concluded that thrusting movements took place during the extrusion of submarine lavas and that the Kiogar Limestone and Oolite and part at least of the lavas constitute a nappe which has been thrust from the north along a plane within the lavas. Since the nappe can only have come from the north or north-east, the Kiogar exotics are known as the Tibetan facies.

From our point of view of still greater interest are certain exotic blocks which are incorporated in the shales of the Upper Flysch. Some resemble the unfossiliferous Kiogar White Limestone of the klippen, and some are of similar igneous rocks, but all the other exotics are entirely different from anything either in the Kiogar nappe or the autochthonous foreland underneath. They too are considered of Tibetan facies, although (like the klippen) they have not been traced to any formations yet known in situ. Most consist of either Permian crinoidal limestone or red Triassic limestones, some of which contain Ceratites, others ammonites of the Carnian stage. But there are also blocks of red Liassic cephalopod limestone like the Adneth Beds of Salzburg and Anatolia. In them the ammonite assemblage is likewise Alpine, with preponderant Phylloceratids and Lytoceratids. The list, identified by Diener (1908), is as follows:—Phylloceras (4 spp.), Schistophylloceras (1), Juraphyllites (2), Analytoceras, Pleuroacanthites, Euphyllites, Ectocentrites (1 sp. each), Schlotheimia (2), Arietites (4) and an oxycone. Diener remarked of this bed: 'No palaeontologist would be surprised if it had been found in Sicily Greece instead of on the Tibetan frontier.'
The origin and mode of emplacement of these blocks in the flysch is problematic. Many are more or less linked together by blocks or wisps of igneous rock, including pillow lavas, like those overlying the flysch. Bailey (1944, p. 13) has suggested that they were detached from the bottom of the overriding thrust sheet and intruded mechanically into the basement flysch, which may have reacted plastically to the moving load above; but this does not account satisfactorily for the different materials of the flysch blocks, most of which do not occur in the Kiogar nappe. It appears rather that they represent a slice or remnant of another thrust sheet torn from a lower stratigraphical level—a tectonic ‘lower storey’, as Heim & Gansser believed (1939, p. 157). On this view the exotic blocks are a mere streak, and the flysch that lies above them must be a semi-local thrust sheet, repeating part of the flysch succession and in turn overridden by the Kiogar nappe.

The problems become less baffling if the white Kiogar Limestone of the main Kiogar nappe is taken provisionally for Lower Tithonian, instead of Triassic as supposed by Heim & Gansser on purely lithological grounds. Since the Kiogar Oolite with its Calpionella alpina can only be Upper Tithonian at earliest, and indicates an Alpine environment, a thick white Tithonian limestone immediately below seems a much more likely occurrence than Triassic Dachsteinkalk; nor would a thickness of 200 m. be prohibitive. On this assumption, Heim & Gansser’s triple facies table (1933, p. 161) can be simplified to two columns, as in table 19:

<table>
<thead>
<tr>
<th>System</th>
<th>Himalayan Facies</th>
<th>Tibetan Facies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cretaceous</td>
<td>Basic igneous rocks and Upper Flysch Lower Flysch (Giumal Sandstone)</td>
<td>Grey radiolarian limestone</td>
</tr>
<tr>
<td>Jurassic</td>
<td>Spiti Shales</td>
<td>Kiogar Oolite with Calpionella alpina Kiogar Limestone</td>
</tr>
<tr>
<td></td>
<td>Callovian oolite</td>
<td>?</td>
</tr>
<tr>
<td></td>
<td>Laptal Beds</td>
<td>Adneth Limestone with Hettangian and Sinemurian ammonites</td>
</tr>
<tr>
<td>Triassic</td>
<td>Kioto Limestone Kuti shale Kalapani limestone Chocolate shale</td>
<td>Red limestone with Carnian ammonites Red limestone with Ceratites</td>
</tr>
<tr>
<td>Permian</td>
<td>Kuling shale</td>
<td>Crinoid limestone with brachiopods</td>
</tr>
</tbody>
</table>
TIBET AND NEPAL

The exotic blocks and klippen seem to provide a tantalizing glimpse of a faunal province lying to the north, in the geologically unexplored regions of Tibet. Uhlig (1910a, p. 50) was convinced that somewhere there must be a Tibetan facies of the Upper Jurassic, corresponding to the Alpine facies of the Lower Lias in the exotic blocks, and perhaps containing such Alpine genera as Simoceras and Pygope. These genera have not yet been found, nor any Upper Jurassic Tethyan ammonites, but Uhlig’s forecast has been to some extent fulfilled by the discovery of Calpionella alpina on the klippen summits of the Kiogars.

Subsequent exploration of Tibet, however, has limited the field of speculation. A very large region farther east is now known geologically, a great deal of it consisting of Jurassic rocks. Instead of the expected ‘Tibetan facies’, normal Spiti Shales are everywhere developed. Practically continuous outcrops of Jurassic sediments stretch from longitude 82° for at least 500 miles through northern Nepal, southern Tibet, Sikkim and Bhutan, at least as far as Lhasa and longitude 92° E. (Geological Survey map of India). From the main outcrop, which occupies the valley of the River Tsangpo and the mountains on both sides, extensions run northward into the central Tibetan plateau almost to latitude 32° N. The outcrops cover a total area of many thousands of square miles.

Our knowledge of this vast region is still sketchy. The principal sources are Hayden’s excellent account (1907) and the travels of Sven Hedin (1915-22; and see Hennig, 1915). Hayden’s synthesis of widely-scattered sections is as follows (1907, pp. 35-6):

| Upper and partly Middle Jurassic | Spiti Shales |
| Bajocian | Shale and quartzite |
| Lias | Lungma Limestone |
| | Slate, quartzite and conglomerate |
| | Crinoid limestone |
| | Slate and quartzite |
| | Brachiopod limestone |

‘This, however, is based on such imperfect data that it can be regarded merely as a suggestion for a temporary working hypothesis’ (Hayden).

Apart from the Spiti Shales, the only formation from which Hayden was able to record identifiable ammonites was the Lungma Limestone, a band about 15 m. thick which crops out near Kampadzong. It is a hard, shelly, mottled, patchily ironshot limestone, full of well-preserved shells. The determinable ammonites collected by Hayden are Somninia cf. dominans Buckman, Witchellia aff. platymorpha Buckman, W. tibetica Arkell, Dorsetensia cf. romanoides (Douvillé), D. cf. regadiens (Haug), D. haydeni Arkell and Emileia (Frogdenites) sp. This fauna proves that the limestone is wholly Middle Bajocian and comprises condensed representatives of the Sowerbyi and Sauzei Zones and perhaps also the

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Humphriesianum Zone. The lithology also suggests a condensed deposit. The faunal affinities are mainly European, but there is one ammonite species in common with the Pamirs and another with western Australia (Arkell, 1953).

The Spiti Shales contain the same ammonite fauna as the Chidamu and Lochambel Beds of the type area. From Muktinath, at 13,100 ft., on the Gandak River in eastern Nepal, behind the main crystalline range of the Himalayas, a number of ‘Salagram’ ammonites are known, and the river has the alternative name of Salagrammi (Reed, 1908). The collection is in the Sedgwick Museum. My identifications are as follows: As internal casts: Blanfordiceras wallichi (Gray), Paraboliceras cf. sabineanum (Oppel), Virgatosphinctes denseplicatus (Waagen), Aulacosphinctoides tibetanus (Uhlig), A. perrin-smithi (Uhlig), A. parvulus (Uhlig), A. uhligi Spath. As external moulds: Aulacosphinctes cf. mörikeanus (Oppel), A. cf. hollandi Uhlig, Aulacosphinctoides cf. subtorquatus (Uhlig), A. cf. radiatecostatus (Steiger), Uhligites griesbachi (Uhlig). There are three or four different kinds of preservation. Uhligites griesbachi (Uhlig) and a fragment of Kamptokephalites were also picked up in southern Tibet by Odell (1925, p. 311) and identified by Spath (1933, p. 806).

Determinable fossils tend to disappear southward in the vicinity of the great crystalline range on which stand Mount Everest and Kanchenjunga, and some distance from it the shales are isoclinally folded southwards. Hereabouts shales are developed in great thickness and embrace the Trias and even the top of the Permian; much work will be needed to disentangle them and the various more or less altered limestone formations. At a locality called Hielung, 20 miles north of the summit of Mount Everest, there is at the base of the shales a band crowded with Spirifer and Productus of about Upper Permian age (Heron, 1922, p. 232). It is presumed to belong to the underlying group of Permo-Carboniferous limestones and shales which rise southwards and form the calc-schists, crystalline limestones and banded hornfels of Everest summit (Heron, 1922, p. 233; Odell, 1925, p. 297; Hayden & Heron, 1934, pp. 329-30; Wager, 1939; Odell, 1943, p. 151). On Everest they are tilted up into the sky and run out, underlain by the gneisses of the crystalline range. The great wall so formed is the truncated root zone of an enormous thrust sheet, of which the base (under limb of the original recumbent fold) extends almost to the Gangetic plain and forms an inverted mass of gneisses and phyllites resting on inverted Carboniferous rocks near Darjeeling (Auden, 1937; Heim & Gansser, 1939).

BURMA AND WESTERN YUNNAN

The great eastern syntaxis, where the spur of Assam thrusts into the Tethys and throws the strike of the ranges into a hairpin bend like the Kashmir spur in the north-west, is still almost blank on the geological map. Gregory (1929, pp. 3 (map) and 29-30) maintained that the Himalayan Alpid system was continued eastward across China to the Pacific.

http://jurassic.ru/
the N.-S. ranges being Altaid, and only the westernmost Burmese-Malayan arc 'an off-lying loop' of the Tertiary system. This interpretation is not accepted by Lee (1939, map pp. 246-7), however, who, like Suess before him, shows the N.-S. system as Tertiary. Hardly anything is yet known of the Jurassic deposits of this region, but that they swing round the syntaxis southward across the Chinese border is indicated by the existence of thick marine Jurassic in the valley of the Lukiang (Upper Salween) in western Yunnan (Lee, 1939, p. 170). Professor Lee informed me in 1951 (in lit.) that no further information has been obtained about this occurrence; but that at least the Bathonian is represented is proved by brachiopods and pelecypods collected in Yunnan by Coggin Brown (Reed, 1924, 1927; first attributed to the Kimeridgian, but later recognized to be Bathonian, Reed, 1936, p. 2).

![Fig. 62.—Sketch-map to show position of the known Jurassic outcrops in Burma and west Yunnan.](http://jurassic.ru/)
Farther west, in the Northern Shan States of Burma, a few small relics of Jurassic rocks, the Namyau Limestones, are marginal deposits transgressive across the edge of the Indian shield. Though they rest upon Palaeozoic limestones, not on the crystalline basement, with relics of Rhaetian marine beds here and there, they are comparable in mode of occurrence with the marginal shelf deposits of Cutch, Jaisalmir, the Salt Range, Attock and Hazara. Moreover, their age is Upper Bathonian and they belong to the pelecypod-brachiopod facies, without cephalopods, already familiar as a transgressive horizon in Cutch (Kuar Bet Beds, p. 391), in various parts of East Africa (pp. 311, 341), in Egypt (p. 287) and in southern Tunisia (p. 282). The absence from Burma of succeeding marine Jurassic formations may be due either to subsequent retreat of the sea or to Cretaceous erosion, but probably a combination of the two. The occurrence is in this respect closely comparable with Khashm el Galala in Egypt (p. 287).

Makers of palaeogeographical maps (e.g. Stefanini, 1928, p. 17; Grabau, 1928, pp. 133, 250) are accustomed to showing the Jurassic geosynclinal sea or trough of deposition as bending round southward from the Himalayas across Assam and the mouths of the Ganges and Irrawaddy and through the Bay of Bengal. There seems no warrant for this view to be derived from the geological map, and the thick marine Jurassic in the upper Salween valley in western Yunnan seems to make it both unnecessary and improbable. If the hypothesis that the Indian shield moved northward in the Tertiary orogeny is correct, the N.-S. geosynclinal outcrops of Yunnan must be expected to be squeezed, drawn out and perhaps largely discontinuous remnants, as postulated for Waziristan. The outer Burman arc on this hypothesis is a festoon analogous with the Sulaiman range on the other side of India. A great deal of geological mapping in regions difficult of access is still needed. The conventional view is therefore still shown in fig. 81.

The Namyau Beds occur as large outliers upon the thickly wooded Palaeozoic limestone plateau, beginning near Hsipaw, about 95 miles NE. of Mandalay. Owing to dense vegetation exposures are scarce and it is not possible to arrive at even a rough estimate of the thickness, though it is believed to amount to 'several thousand feet'. Locally there are strong basal conglomerates consisting of well-rolled pebbles of the underlying limestones and other older rocks; but these may be of any age. The Namyau Beds proper consist of a dark red or purplish series of sandstones and shales, which weather to a labyrinth of trackless ridges and ravines, densely forested. In the lower part of the series are some shelly limestone bands, the Namyau Limestones, never more than a few feet thick, but uniform and persistent for many miles. They form no conspicuous physical features and can usually be seen only in stream beds. Mapping is made still more difficult by the strong disturbance the strata have undergone, dips being generally steep and often vertical (La Touche, 1913, pp. 303-8).
It is from these thin limestone bands near the base of the Namyau Beds that have been collected the many brachiopods and pelecypods described respectively by Buckman (1918) and Reed (1931, 1936). Both palaeontologists arrived independently at the conclusion that, although more than one horizon may be present, all are Upper Bathonian. Buckman based on the material a highly elaborate and detailed classification of the Terebratulids and Rhynchonellids. Reed (1936) had collections from two successive horizons, but both are Bathonian. The higher contains elements of the Upper Bathonian shelly beds familiar in East Africa, Arabia and Sinai: *Gryphaea balli* Stefanini, *G. cf. costellata* Douvillé, *Elignum cf. rollandi* Douvillé, *E. cf. polytypus* Eudes-Desl., *E. cf. weirii* Cox, with more than 20 other pelecypods, largely of familiar European Bathonian species. The lower horizon contains at least 35 species, among them new species of the genus *Eomiodon*, which is found in the Kuar Bet Beds of Cutch and in the Great Oolite of NW. Europe and England.

The overlying red sandstones and Namyau Shales have not yet yielded fossils but they are probably Cretaceous. Coal Measures near Kalaw in the Southern Shan States have yielded a flora comparable to that of the ‘Umia’ [*i.e.* Bhuj] plant-beds and Rajmahal Gondwanas, now known to be Cretaceous (see p. 387), and associated red beds near Kalaw contain Upper Cretaceous ammonites (Fox, 1930). This makes it more likely that patches of red sandstones and conglomerates near Amherst and in the Mergui district in the extreme south of Burma (latitude 12° N.), which have been tentatively assigned to the Jurassic (Chhibber, 1934, pp. 200-203), are really Cretaceous.
CHAPTER 16

JAPAN AND KOREA

The three island festoons which stretch along the Pacific coast of Asia from Formosa through the Ryukyu Islands, Japan proper and the Kurile Islands to Kamchatka represent the tops of sunken mountain arcs. They are not, however, all of one date. While the folding of the Ryukyu and Kurile arcs is of Tertiary origin, the folding of the Japanese arc is essentially Mesozoic. The north island of Hokkaido (Yezo) goes with the Kuriles and has complex Tertiary nappe structures, but in the main island of Honshu and the southern isles of Shikoku and Kyushu (fig. 63) Tertiary folding has taken place mainly along echeloned axes oblique to the islands (Otuka, 1937). Here the main orogenies were Middle Triassic (post-Ladinian, pre-Carnian: the Akiyoshi orogeny) and Lower Cretaceous (the Oga and Sakawa orogenies), though evidences of lesser phases in the late Jurassic are not lacking (Matsumoto, 1949). Movement was outwards from Asia and presupposes a sunken rigid foreland under the Pacific deeps. The foreland seems to have contributed no sediments to the Mesozoic formations of Japan and therefore is inferred to have been already submerged (Kobayashi, 1935b; 1937; 1938; 1941).

Professor T. Kobayashi, to whose tremendous industry over the past quarter century we owe an entirely new picture of Japanese geology, postulates that after the Middle Triassic orogeny and Carnian transgression, pre-Liassic epeiric movements warped up a gentle arch of folded and thrust Palaeozoic and Lower Triassic rocks along the central axis of south-western Japan. He calls this ancient hypothetical land Eo-Nippon. During the Jurassic and Cretaceous epochs there formed on either side, and were gradually filled, two more or less separated geosynclinal troughs. Deposition on the outer (Pacific) side was mainly marine, with coarse clastic and plant-bearing intercalations; on the inner (Asiatic) side it was mainly lacustrine and deltaic, probably in more or less separate basins, with marine intercalations representing temporary incursions of the Jurassic and Cretaceous sea through breaches in the intervening barrier.

During the Jurassic there occurred on both sides epeiric movements which greatly reduced and perhaps altogether halted sedimentation in the Middle Jurassic: no definite Middle or Upper Bajocian or Bathonian faunas have yet been found in Japan. After active and prolonged Upper Jurassic sedimentation, with marine influence strong in both troughs, there occurred two Lower Cretaceous orogenies. The first (Oga) is equated with the Jurassic-Cretaceous interval. Its sphere of influence was the inner trough and it produced Germanotype tectonics with thrusting and imbricate structures along the inner side of the Eo-Nippon barrier.
There followed an Upper Neocomian transgression which laid down a Neocomian-Aptian-Albian suite of sediments, beginning with a polygenetic conglomerate, on the outer side of the barrier. Finally, this suite was in turn intensely deformed by an Alpine-type orogeny (the Sakawa) in the outer trough, the movements being completed before a late-Cretaceous (Senonian) transgression.

The Cretaceous diastrophism was accompanied by intense igneous activity, especially in the area of the inner trough, which covered also much of Korea. Granite batholiths and porphyritic dykes were intruded, and volcanoes erupted extensive andesitic and basaltic lavas and tuffs.

In the Jurassic, the only evidence of igneous activity yet proved is the existence of thin lenses of acid tuffs interbedded in an early-Upper Jurassic sandstone in Rikuzen, NE. Honshu (Mori, 1949, p. 138) and in the Tetori Series of the Hida plateau (Iwaya, 1940). It has been suggested that red shales in Shikoku and other parts of SW. Japan may consist partly of decomposed volcanic ash (Yehara, 1930, p. 29); but these may be Triassic or Cretaceous.

The Jurassic sediments of Japan are overwhelmingly in the facies of shales and sandstones. The only limestone of any extent is the lenticular Torinosu Limestone, of Upper Jurassic age, developed transgressively on the south slope of the Eo-Nippon barrier and locally in reef facies. This and older Jurassic beds which come in seawards beneath it are believed by some geologists to pass towards the Pacific into shales and
radiolarites of deeper-water facies and devoid of recognizable fossils. Except perhaps for this outer coastal fringe in the south-west and its probable continuation in Hokkaido, the whole of the Japanese islands in the Jurassic occupied a marginal belt oscillating between marine and continental sedimentation. The region is of special importance for dating the Mesozoic floras of continental Asia, since in Japan it is possible to establish their relationships to marine horizons with ammonites. Extensive heterochronous homotaxy is thus revealed. For instance, the so-called Rhaetic-Lias flora of Asia and Europe, originally dated in western Eurasia, occurs in Japan beneath marine beds with Entomonotis ochotica and is of Norian age. The inference is that this flora migrated westward during the Triassic epoch (Kobayashi, 1938a, 1938b, 1939a, 1942).

Shales and sandstones like those in Japan and probably in part Jurassic occur on both sides of the axial mountain range of Formosa (Kanehara, 1926, p. 33), while in the central range of Hokkaido there are radiolarites of Lower Cretaceous and in part Jurassic age (Kobayashi, 1944, p. 237; Hashimoto, 1952).

In the following description the Japanese Jurassic is illustrated by successions first in the inner geosyncline (Nagato, northern Kyushu, Korea, central Honshu), then in the outer (Torinosu Series of the Pacific coast), and finally in the isolated outcrops of north-eastern Honshu.

NAGATO PROVINCE (YAMAGUCHI PREFECTURE)

In the peninsula of Nagato, forming the western tip of the main island of Honshu, the Jurassic is represented by a group of sandstones and shales, up to 900 m. thick, with a polygenetic basal conglomerate, resting unconformably on Palaeozoic phyllites. It was called by Yabe the Toyora Group and has been described by Kobayashi (1926) and carefully revised by Matsumoto and Ono (1947). (See also Matsumoto, 1949.) From some part of the group eight Toarcian ammonites—Dactylioceras, Peronoceras, Harpoceras and Hildoceras—were figured and correctly dated by Yokoyama (1904). The revisers have much reduced the original estimates of thickness and have proved palaeontologically that almost the whole 900 m. are Liassic and the highest 570 m. or so Toarcian with doubtful Lower Bajocian. Both in facies and in thickness this development is comparable with the Caucasus (p. 363).

I am much indebted to Professor T. Matsumoto for sending me on loan the type specimens figured in his and Mr Ono's important paper, and to Mr J. R. McEwan of King's College, Cambridge, for translating the paper from the Japanese. The following is a tabulated summary, substituting my own zonal attributions and incorporating some emendations to nomenclature and revised determinations. The principal changes are: (1) Their 'Echioceras Zone' is in my opinion based, not on Echioceras, but on the homoeomorphous Fontanelliceras Fucini, a genus found in the

http://jurassic.ru/
Italian Domerian: (2) Their ‘Grammoceras Zone’ is in my opinion based on forms similar to Grammoceratidae but belonging in reality to other genera of the early Toarcian. The beds are designated by Matsumoto & Ono’s symbols (Ut-Ne).

? LOWER BAJOCIAN

Opalinum Zone. Upper Utano formation. 30–40 m.
Ut. Holcophylloceras sp.
Uz. (barren)
Uh. Hammatoceras (Planammatoceras) cf. kitahamiense (Shimizu) (pl. 2, fig. 4)
? Dumortieria sp.
Calliphylloceras cf. nilssonii (Hébert)

TOARCIC

Jurense Zone. Lower Utano formation. 100–150 m.
Ub. Haugia aff. japonica (Neum.) (pl. 2, fig. 5)
Up. Posidonia beds with
Phymatoceras toyanum (Mat.) (pl. 2, fig. 1)
Pseudolioceras ? sp. (pl. 2, fig. 2)
Calliphylloceras cf. nilssoni (Hébert)

Commune and Falcifer Zones. Upper Nakayama formation. 200 m.
Na. Dactylioceras aff. helianthoides Yok.
Nd. Dactylioceras helianthoides Yok. (pl. 1, fig. 10)
Peronoceras subfibulatum (Yok.)
Hildoceras chrysanthemum Yok.
Hildoceras densicostatum Yok.
Hildoceras inouyei Yok.
Protogrammoceras cf. nipponicum (Mat.)
Harbotoceras okadai (Yok.) (pl. 1, fig. 8)

? Tenuicostatum Zone. Middle Nakayama formation. 30–50 m.
Ng. Protogrammoceras nipponicum (Mat.) (pl. 2, fig. 3)
Fuciniceras cf. laviniunum (Menegh.) (pl. 1, figs. 4, 5)
Harbotoceras okadai (Yok.) (pl. 1, fig. 8)
Lioceratoides yokoyamai (Mat.) (pl. 1, fig. 9)
Hildoceras densicostatum Yok.
Dactylioceras helianthoides Yok.
Calliphylloceras cf. nilssonii (Hébert)
Lytoceras sp.

UPPER PLIENSCHIAN

Lower Nakayama formation (30 m.), highly fissile shale, perhaps plus part of the Nagano formation.
Ne. Fontanelloceras cf. fontanellense (Gem.) (pl. 1, fig. 1)
Sequentia cf. parodii Fucini (pl. 1, fig. 2)
Fuciniceras primordium (Mat.) (pl. 1, fig. 3)
Protogrammoceras cf. normanii (d’Orb.)
Paltarpites cf. paltus Buckman (specimen sent)
Paltarpites toyanum (Mat.) (pl. 1, fig. 6)
Calliphylloceras cf. nilssonii (Hébert)
Lytoceras sp.

UNDATED LIAISSIC

Nagano formation (250–300 m.). Basal conglomerate and sandstone, passing up into sandy shale. Shallow-water fauna with pelecypods and gastropods, few ammonites. From the highest 50 m. is recorded Arietites (Coroniceras ?) sp., and from the basal member a Juraphyllites.

The assemblage from the ‘Ng’ horizon, laminated shale 30–50 m., with ammonites, resting on 20–30 cm. of sandstone, is of outstanding interest for the light it throws on the stratigraphical position of certain
species of tricarinate *Funiciceras* and *Protogrammoceras*. ‘Pseudogrammoceras nakayamense’ Matsumoto (their pl. i, figs. 4, 5) shows three strong keels and seems specifically indistinguishable from *Funiciceras lavinianum* (Men.) the type species of *Funiciceras*. The type specimen of ‘Grammoceras’ nipponicum Matsumoto (pl. ii, fig. 3) is probably a distinct species, but some smaller specimens sent me as varieties of it seem indistinguishable from Italian species such as *Protogrammoceras isseli* (Fucini) and *P. inseparabilis* (Fucini). These forms, originally supposed by Fucini to be Domerian, are found in Japan in company with *Lioceratoides* (pl. i, fig. 9) (= ‘Praelioceras’ Fucini) and *Harpoceras okadai* (Yokayama, 1904) (pl. i, fig. 8) which seems identical with *H. praeplanatum* Fucini (1924) and hardly distinguishable from involute forms of the common Whitby Toarcian *Harpoceras exaratum* (Young & Bird), and Toarcian forms such as *Hildoceras densicostatum* Yok. and *Dactylioceras helianthoides* Yok. From the close resemblance of the last to *Dactylioceras tenuicostatum* (Young & Bird) and its upward range into the typical Commune and Falcifer assemblage of bed Nd, the assemblage of bed Ng can only be placed at the base of the Toarcian.

The mixture of Italian and English elements in the underlying Upper Pliensbachian beds (Ne) is instructive.

At various horizons in the Toyora group there is an extensive flora allied to floras usually considered Upper Jurassic elsewhere; and in the Utano formation are two endemic species of *Inoceramus* (Kobayashi, 1926, with plate). Above the Utano formation Kobayashi included a further series of sandstones and shales (Nanami formation) with plants only, which Matsumoto & Ono consider partly a lateral equivalent of the Utano formation and partly the Toyonishi group, mentioned below.

The Jurassic Toyora Group is overlain disconformably, and locally unconformably, by conglomerate and coarse pebbly sandstone, which pass up into a further group of sandstones, shales and conglomerates, the Toyonishi Group, of Lower Cretaceous and perhaps Upper Jurassic age (Matsumoto, 1949, 1954). In the upper part of the group are the Yoshimo Beds, with a brackish-water fauna of pelecypods and gastropods. They include early Corbiculids and large Turritellid gastropods suggestive of the Aptian *Cassiope* of Spain (Kobayashi & Suzuki, 1939). These beds are unconformably overlain by equivalents of the Wakino formation (see below) and Inkstone Group of the Lower Cretaceous, with igneous rocks (Matsumoto, editor, 1954). Kobayashi (1938) considered the Inkstone Series Upper Neocomian and the Yoshimo Beds Wealden.
Sandy shale and greywacke

Interbedded sand, stone and shale

Brackish and freshwater fossils

**FIG. 64.—Correlation table for Japan, specially drawn by Prof. T. Matsumoto, 1954 (simplified).**

Vertical lines indicate rocks imperfectly known.

Thickness in metres. Hashiura group dated as in Matsumoto & Ono M.S.

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![Correlation table for Japan](http://jurassic.ru/)
The stratigraphy of this area has undergone much revision (Matsumoto, editor, 1954). The shales of the Wakino Series contain a remarkable fauna of freshwater mollusca, including peculiar genera of Unionids, Anodontas, Corbiculids and *Trigonoioides*, with the gastropod *Brotiopsis* (Kobayashi & Suzuki, 1936; Suzuki, 1943). Similar faunules occur at various places in eastern Asia, and despite its superficially Purbeckian appearance it is now considered to be Lower Cretaceous (Suzuki, 1949).

**KOREA**

The Mesozoic basin of deposition in which these thick coarse clastic sediments were laid down, called the basin of Tsushima after the straits (fig. 63), extended also over at least the southern part of Korea. There similar sandstones, shales and conglomerates cover a large area, resting unconformably on the crystalline basement and on Palaeozoic rocks and retaining in broad outline something of their original basin shape despite subsequent diastrophism.

Locally the lower part (Lower Daido Formation) is Jurassic, but not marine, so far as known. A record of *Hildoceras inouyei* Yok. if confirmed would prove a continuation on to the mainland of the Toarcian of Nagato, but I am informed by Professor Matsumoto that no reliance can be placed on the record. A rich flora occurs (Kawasaki, 1926, p. 118). There are also several higher floras, the most celebrated of which is the Nakong flora, which characterizes a continuation of the Wakino Series of Kyushu, with some of the peculiar freshwater shells. The beds are ripple-marked and sun-cracked and contain some intercalated ash beds. This seems to herald the volcanism recorded on a large scale in the overlying equivalents of the Inkstone Series. Correlation is as follows:

<table>
<thead>
<tr>
<th>Korea</th>
<th>Japan</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Daido, Upper Keisho, and Shiragi formations</td>
<td>Inkstone series and Shimono-seki formation</td>
<td>Cretaceous</td>
</tr>
<tr>
<td>Middle Daido or Nakong formation</td>
<td>Wakino formation</td>
<td></td>
</tr>
<tr>
<td>Lower Daido formation</td>
<td>Nakayama (Middle Toyora)</td>
<td>TOARCIAN</td>
</tr>
</tbody>
</table>

In North Korea is found in places a rich freshwater molluscan faunule believed to be early Jurassic. It differs from all the faunules in Korea and Japan but has its counterpart in Manchuria (Suzuki, 1949, p. 94).

**CENTRAL HONSHU**

On the northern side of the supposed Eo-Nippon barrier in the central part of the mainland of Honshu there was irregular subsidence during the Jurassic and Lower Cretaceous, with deposition of great thicknesses of shales, sandstones and conglomerates, of facies similar to that in the more westerly parts of the geosyncline. But while the Lias is here represented...
(so far as yet known) only locally in the eastern half of the area by marine shells in plant-beds, the Upper Jurassic sea spread over much of the western half of the area and left ammonite-bearing Callovian, Oxfordian and Kimeridgian intercalations among the barren sediments and plant-beds.

Both the Lower Callovian and the Upper Oxfordian marine strata contain *Corbicula*, *Unio*, *Viviparus*, *Pila*, *Melanioides* and other freshwater shells (Kobayashi & Suzuki, 1937). They are believed to have been brought into a shallow and perhaps brackish sea by rivers and streams from neighbouring land (Suzuki, 1949, p. 93). Several prolific plant-beds are also intercalated with them. The conglomerates of the Upper Jurassic partly fill valleys eroded in the basement gneiss and completely overlap the plant-bearing Lias. During the latest Jurassic and Lower Cretaceous a series of intermontane basins were shut off from the sea and only plant-remains and freshwater mollusca were entombed in the deposits. Locally erect silicified stumps of coniferous trees are found, among much fossil wood (Ogura, Kobayashi & Maeda, 1951). These are post-Kimeridgian and regarded as late Jurassic. The floras of the Upper Jurassic and Cretaceous beds (in which tuffs appear towards the top) are extremely rich. (For revision of the floras and extensive literature, see Oishi, 1940.)

The greatest development and the best exposures of the Jurassic and Lower Cretaceous rocks occur in the Hida plateau and neighbouring mountains round the headwaters of the Tetori and Kuzuryu Rivers, especially in the old provinces of Echizen, Kaga and Hida (fig. 63). The Upper Jurassic and Lower Cretaceous formations are grouped together as the Tetori Series. The Liassic plant-beds, correlated by their flora with the Toarcian of Nagato, occur only in the north-east corner of the Hida plateau and still farther to the east, in Gunma Prefecture. The occurrence of *Cardinia* (Kobayashi, 1935a) suggests that Lower Lias is represented also; and I am informed by Professor Matsumoto that this has now been confirmed by finds of ammonites. The generalized stratigraphy is as follows (Kobayashi, 1927; 1935a; Kobayashi & Suzuki, 1937; Maeda, 1952):

<table>
<thead>
<tr>
<th>Upper Tetori</th>
<th>Ohmichidani Shales, with flora and tuffs Akaiwa Sandstone (barren)</th>
<th>Cretaceous</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>—disconformity—</td>
<td></td>
</tr>
<tr>
<td>Middle Tetori</td>
<td>Itoshiro formation, with chief plant-beds and erect tree stumps</td>
<td>? Late Jurassic</td>
</tr>
<tr>
<td></td>
<td>—unconformity—</td>
<td></td>
</tr>
<tr>
<td>Lower Tetori</td>
<td>Kuzuryu formation, with plant-beds, Corbicula beds and ammonites</td>
<td>Kimeridgian</td>
</tr>
<tr>
<td></td>
<td>—Supposed unconformity (precise relation uncertain)</td>
<td>Oxfordian</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Callovian</td>
</tr>
<tr>
<td>Kuruma formation, with flora of the Nakayama formation of Nagato</td>
<td>? Toarcian and earlier</td>
<td></td>
</tr>
</tbody>
</table>

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Measurements in the Hida plateau total 2700 m., of which 1100 m. (not bottomed) appear to be Jurassic, and there are layers of interbedded acidic tuff (Iwaya, 1940).

Palaeontologically and stratigraphically, interest centres on the Lower Tetori. Two ammonite horizons have been found in situ, both containing or passing laterally into brackish strata with Corbiculae (of two different species). The sole ammonite represented in the lower ammonite bed is the boreal genus Seymourites, previously known only from the Pacific coastal regions of Canada and Alaska, from Montana and from Greenland and Spitsbergen. The specimens figured (Kobayashi, 1947) are almost identical with American species (e.g. Imlay, 1948, U.S. Geol. Surv. Prof. Paper 214B, pl. ix), but it should not be forgotten that Seymourites may be indistinguishable in a crushed state from certain Stephanoceratids of both Lower and Middle Bajocian dates (cf. Buckman, Type Ammonites iii, pl. CCL, and iv, pl. CCCXI); and that Stephanoceratids extend through the Tethys in force to Western Australia and Indonesia.

The higher ammonite beds yielded six species figured by Yokoyama (1904) from a shale in the plant-beds. My revised determinations, which indicate a late Upper Oxfordian date, are as follows (figures of Yokoyama's plate i):—

Fig. 1.—Perisphinctes (Arisphinctes or Kranaosphinctes) matsushimai Yok. (Cf. Boehm's forms from Wai Galo, Sula Islands.)
Figs. 2, 3.—Per. (Mirospinctes) hikii Yok.
Fig. 4.—Per. (? Kranaosphinctes) kaizaranus Yok. (nucleus).
Fig. 5.—Decipia kochibei (Yok.) (Cf. Arkell, Mon. Am. Engl. Corallian Beds pl. lxxviii, fig. 12).
Fig. 6.—Per. (Dichotomoceras ?) cf. procedens Oppenheimer.
Fig. 7.—Glochiceras ? echizenicum (Yok.).

A specimen of Katroliceras, obtained from a loose boulder from the Tetori Series in Echizen, indicates the presence of a third ammonite horizon of Middle Kimeridgian date (Kobayashi & Fukada, 1947b). The presence of this Indian genus agrees with the Kranaosphinctes spp. in pointing to direct connexion with Indonesia and Cutch and the southern sea, and is difficult to reconcile with the interpretation of the earliest Tetori ammonites as Seymourites.

SOUTHERN SHIKOKU, SOUTHERN KYUSHU AND KII PENINSULA

On the southern side of the Palaeozoic barrier of Eo-Nippon there prevailed in the Jurassic a totally different sedimentary regime. In contrast to the deltaic type of deposition in intermontane basins in the northern geosyncline, the southern received coastal and reef limestone, perhaps passing southwards into open-sea muds and radiolarian oozes. The shales and radiolarites, which reach great but unknown thicknesses, are called the Akigawa formation. They comprise red and green shales, radiolarian cherts, some sandstones and some limestones. The only

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fossils besides Radiolaria are a few corals in the limestones. The shales may be coloured partly by decomposed volcanic ash, but this has not yet been established. The formation bears a strong resemblance to the Danau formation of Borneo, and its age is equally problematic. It occupies most of the southern parts of the islands of Shikoku and Kyushu and the Kii peninsula at the southern extremity of Honshu. On Shikoku it has been described and mapped by Yehara (1930), who considered it all Upper Jurassic, but owing to the lack of fossils other than Radiolaria, and bearing in mind the history of the Danau formation of Borneo, I have not shown the outcrops as Jurassic on fig. 63.

The Akigawa formation is bounded on the north by a straight line of thrusts, directed southward, along which it is overridden by the Torinosu Limestone formation, and that in turn is overthrust from the north by Palaeozoic rocks. The Torinosu Limestone formation has a narrow strip-like outcrop (shown generalized and exaggerated in fig. 63) between thrust boundaries imposed in the Cretaceous Sakawa orogeny (named after the town of Sakawa, near the middle of southern Shikoku). The formation consists of shales and limestones with some radiolarian cherts which Yehara (1930) and Kobayashi (1935, p. 84) first believed to be interbedded, but which according to Kobayashi's later conclusions (1941; 1944, p. 234) are part of the underlying Permo-Triassic systems intercalated tectonically. On this view, based on remapping, the whole Torinosu outcrop is a band of imbrications, complicated by many tear-faults, between large nappes, and the Torinosu formation rests unconformably on Permo-Triassic radiolarites and shales (Kobayashi, Huzita & Kimura, 1945). Moreover, lenses of limestone like that yielding Upper Jurassic fossils in the Torinosu formation occur in the overlying Lower Cretaceous Ryoseki Series, which is separated from the Jurassic by a basal conglomerate. In the Lower Cretaceous a regime of deltas extended over the southern side of Eo-Nippon, as the result of active erosion of high relief structures beginning to be formed by the Sakawa orogeny. The celebrated Cretaceous Ryoseki floras were entombed, as in the northern geosyncline, in shales and sandstones between thick sheets of conglomerate.

In the Torinosu formation there are various kinds of limestone, some unfossiliferous, some with ammonites and pelecypods, others in small irregular and unstratified lenses or reef-like masses, abounding in hexacorals (Eguchi, 1951), stromatoporoids (Yabe & Sugiyama, 1935), milleporoids and calcareous algae (Yabe, 1932). The Pectens and Limas are specifically distinct from European species but of similar aspect and belonging to cosmopolitan genera (Kimura, 1951). There are also brachiopods, Cidarids, gastropods, belemnites and sharks' teeth (Kobayashi, 1935).

The ammonites hitherto found in the Torinosu formation belong to two assemblages, one Upper Callovian, the other Lower Kimeridgian. The Callovian fauna, found in a shale interstratified with the limestones,
comprises the genera *Hecticoceras* and *Horioceras*, and two Perisphinctids. One is a ‘nucleus’ (or young) correctly likened by Kobayashi (1935, pl. xiii, figs. 4, 5) to *Properisphinctes*. The other is a larger fragment incorrectly assigned by him (1935, pl. xiii, figs. 7, 8) to *Sigaloceras*, for from the photographs it is apparent that the primary ribs are too long and the venter too wide for *Sigaloceras*, and the fragment seems to be some form of *Binatisphinctes* or Poculisphinctes (‘Trinisphinctes’).

The Lower (in part perhaps early-Middle) Kimeridgian faunule comprises *Lithacoceras tarodaense* Kob., *Aulacosphinctoides* cf. steigeri (Shimizu) and (found separately) *Ataxioceras kurisakaense* Kob. & Fukada. These Perisphinctids are all known only from poorly-preserved fragments, but their general age cannot be doubted. (Figures in Shimizu, 1927; 1927a; 1930; Kobayashi, 1935; Kobayashi & Fukada, 1947). Other fragments, too poor to be worth discussing, have been figured, also an indeterminable Oppeliid (Yehara, 1927; Shimizu, 1931). The age indicated by the ammonites is confirmed by the occurrence of spines of *Balanocidaris glandaria* (‘Cidaris glandifera’) which characterizes Lower Kimeridgian deposits in East Africa and the eastern Mediterranean. The sole indication of a later date is a pelagic crinoid, *Pseudosaccocoma japonica*, belonging to a genus of the European Tithonian.

**NORTH-EASTERN HONSHU**

*(a) Southern Kitakami massif (mainly Rikuzen Province)*

About 350 miles north-east of the Hida plateau and Tetori River area, there is an isolated group of Jurassic outcrops near the north-east coast of Honshu, in the Kitakami Mountains and near Shizukawa Bay, in the old province of Rikuzen (now Miyagi Prefecture). Hettangian and Sinemurian genera of ammonites were long ago figured from here (Yokoyama, 1904a).

General descriptions have been published by Mabuti (1933) and Mori (1949), and a revision based on more ammonites has been undertaken by Matsumoto & Ono, who in 1951 most kindly sent me a draft of their unpublished paper, with figures of some of the ammonites. For this friendly collaboration I am most grateful.

The Kitakami Jurassics belong tectonically to the outer or Pacific suite, but they combine stages represented on both sides in SW. Japan, with some additions.

The thickness of the Jurassic in the Kitakami massif was estimated by Mabuti (1933) and Mori (1949) at about 1000 m. The revised measurements by Matsumoto & Ono (1951 MS.) make it 700 m.; but in a neighbouring area it has been estimated at 2000 m. (Shiida, 1940). The stratigraphical nomenclature is confusing because there are several physically separate and tectonically distinct groups of outcrops, for which successive authors use new or emended formation names, to suit local developments. In the following table the names used by Mabuti (1933)

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are compared with those used by Mori (1949) and Matsumoto & Ono (1951 MS.) in different areas. Shiida (1940) has a completely different set of names based on another area.

From the Sodenohama formation Professor Matsumoto collected a Perisphinctid which could be an *Aulacosphinctoides*, and *Aulacosphinctoides* cf. *steigeri* (Shim.) is recorded from the Hashiura area (Mori, 1949, p. 319). From the Arato formation, sensu stricto, Professor Matsumoto showed me two Parkinsonia-like ammonites which seem to me to be *Idoceras* spp. allied to Mexican forms of the Lower Kimeridgian. From the Arato Shale, sensu lato, Mori (1949) records Kimeridgian and Upper Oxfordian ammonites. Among Upper Oxfordian Perisphinctids recorded are *Kranaosphinctes* cf. *matsushimai* (Yok.), *Perisphinctes* s.s. *ozikaensis* (Fukada, 1950) and *Discosphinctes* (Kobayashi & Fukada, 1947c; but the published fragments are not really determinable with finality). Fukada states that there is a sequence of Upper Oxfordian Perisphinctids which indicates that the English Corallian Beds are condensed. *Posidonia* beds occur, and *Seymourites* has been recorded.

Liassic stages from Hettangian to Upper Toarcian are represented among the ammonites recorded from the Hosoura formation. They include Hettangian *Schlotheimia* (Yokoyama, 1904a, pl. i, fig. 6), Sinemurian *Asteroceras* and *Oxynoticeras* (Matsumoto & Ono MS., and see Yokoyama, 1904a, pl. ii, fig. 11), various Toarcian Harpoceratids and the Upper Toarcian *Phymatoceras chibai* (Yokoyama sp., 1915, pl.). Recently *Tnetoceras* has also been figured (Sato, 1954), so Lower Bajocian is present.

From the Niranohama formation, Matsumoto & Ono record 'a single well-preserved *Alsatites*', with many *Trigoniae* and other pelecypods; belemnites and corals also occur, and there are poorly-preserved plants.

<table>
<thead>
<tr>
<th>Locality Hashiura (Mori, 1949) c. 1000 m.</th>
<th>Generalised (Mabuti, 1933) c. 1000 m.</th>
<th>Locality Shizukawa (Matsumoto &amp; Ono) 700 m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jusanhama Group, 300 m. (? Tithonian)</td>
<td>Tukihame Sandstone, 200 m.</td>
<td>...</td>
</tr>
<tr>
<td>Hashiura Group, 600 m.</td>
<td>Arato Shale sensu lato, &gt;520 m. slight unconformity</td>
<td>Sodenohama Formation, c. 200 m.</td>
</tr>
<tr>
<td></td>
<td>Aratosaki Sandstone, 200 m.</td>
<td>Arato Formation, sensu stricto, 300 m.</td>
</tr>
<tr>
<td>Shizukawa Group, 90-110 m.</td>
<td>Hosoura Sandy Shale, 30 m. Niranohama Beds, 40 m.</td>
<td>Aratozaki Formation, 60-100 m.</td>
</tr>
</tbody>
</table>

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(b) Soma Area, Fukushima Prefecture

In this coastal area Middle and Upper Jurassic rocks occur which are similar in lithology and fauna both to those in the southern Kitakami Mountains and to the Torinosu series. Ammonites recorded include ?Parkinsonia, Indosphinctes, Pseudopeltoceras, Perisphinctes, Aspidoceras, Streblites, Taramelliceras, Aulacosphinctoides and Paraboliceras ? (Masatani, 1950). There are also plant-beds. The total thickness is about 1500 m.
This area measures about 2500 miles across and contains some of the most difficult and complicated geology in the world. By far the greater part of the area is covered by sea, and the land surface is decayed by deep tropical weathering and mantled in dense vegetation. Jurassic sediments of widely varied facies occur at numerous scattered points, but the outcrops are separated on different islands and there are virtually no sections. Splendid collections of ammonites and other fossils, from Hettangian to Tithonian in age, have been made at many places in the Indonesian islands, from loose nodules in stream-beds or among the ejectamenta of mud-volcanoes. To the student of the Jurassic, therefore, the area is full of possibilities and tantalising uncertainties. Instead of its almost complete suite of Jurassic faunas helping to check the universality or otherwise of the standard sequence elsewhere, the isolated elements have to be pieced together solely from a knowledge of the succession in other parts of the world.

Thanks chiefly to sixty years of enterprising work by Dutch geologists, some limited generalizations are possible. It appears that there was continuous sedimentation throughout the Mesozoic in a sinuous trough or geosyncline, which may have originated in the Permian, from eastern Celebes through Buru, Ceram, Jamdena and Timor, and recent discoveries in NW. Australia suggest that it continued southward into the Broome and Derby districts. In this trough all the stages of the Lower and Upper (but not the Middle) Lias are represented by prolific ammonite faunas of European genera and in some cases even species. Neritic Lower Lias sea also spread at least over NW. Borneo, Indo-China and the fringe of southern China (Hong Kong). It may also have overspread Sumatra and Java, but the Mesozoic rocks there have been converted by dynamo-metamorphism into phyllites and schists. Eastwards in New Guinea, so far as known, the first Jurassic transgression was in the Toarcian, after which there was more or less continuous deposition in a wide belt stretching through central New Guinea and probably connected by sea with New Caledonia and New Zealand. The Toarcian transgression is also recorded in Cochin China.

In an area that has been affected by such intense disturbance both (locally) before the Cretaceous transgressions of various ages and during the Tertiary, where nummulitic Eocene limestone can be converted into schist and Pleistocene coral reefs may be elevated (as in central Timor) to over 1200 m. and Pliocene sediments (as in Ceram) to at least 3000 m. above the sea, it is of doubtful value to attempt detailed reconstructions.
of Mesozoic palaeogeography. If, as is supposed by current theory, the Sunda arc with its adjacent deeps is an embryo mountain range advancing against the foreland of Australia (or Australia an advancing shield under-thrusting the arcs), the whole area must be still plastic. The repeated orogenies of the past must have produced tremendous distortion, the history of which perhaps can never be unravelled.

Fig. 65.—Sketch-map to show position of the Jurassic outcrops in Sumatra, Borneo, Indo-China and Hong Kong.

From at least the Oxfordian to the Tithonian the trough of deposition in eastern Indonesia and New Guinea was in direct communication with that of the Himalayas, as is attested by identity of faunas. At least two of the three subdivisions of the Spiti Shales, the Oxfordian Belemnopsis gerardi Beds and the Lochambel Beds, with identical Buchia [Aucella] and coarse-ribbed Inoceramus shells as well as ammonites, are
found in Spiti Shales facies in eastern Indonesia. Where the connecting seaway ran, however, is unknown; for in the intervening tracts of Indo-China and Borneo only Lias and more doubtful Middle Jurassic (with a small and incomplete Kimeridgian exception in Sarawak) is known. This led Grabau (1928, pp. 133, 250) to postulate a connexion across Assam into the Bay of Bengal and thence via the Indian Ocean; a concept criticized above. If it is a correct hypothesis that India moved northward in the Tertiary orogeny, a continuous outcrop of marine Jurassic from west Yunnan to the Gulf of Siam or Tonkin need not be sought, for these regions previously would not have lain so far apart; the Himalayan and Indonesian troughs could be disrupted parts of an originally almost continuous geosyncline. Whether the requisite system of tear-faults exists and, if so, where it runs, are problems for future field-work.

**Hong Kong and Indo-China**

Small patches of marine Lias are known at scattered points over this area. At Hong Kong the Lower Sinemurian is represented by a Schlotheimiid genus, *Hongkongites* (Grabau, 1928, p. 774, pl. ix; Davis, 1952, pp. 77-84, and plate facing p. 32) (= *Sulciferites*?), and at Na Cham in Tonkin there are *Cardinia* beds, without ammonites but obviously Hettangian or early Sinemurian (Mansuy, 1919).

In Indo-China (Fromaget, 1937), at Hun Nien, in the province of Kwang Nam, Annam, marine beds yield a faunule of small pelecypods and gastropods largely identical with species of the French Hettangian, and an ammonite compared to *Waehneroceras ?* longipontinum (Oppel) (Counillon, 1909). *Gryphaea arcuata* and *Uptonia jamesoni* are also recorded from other places (Fromaget, 1952, p. 69). In the south, in Cochin China, Upper Toarcian appears at Trian, about 30 miles NE. of Saigon, developed as shales with *Dumortieria lantenoisi* (Mansuy, 1914). The photographs show this to be close to *D. nicklesi* Benecke, of the uppermost Jurense Zone in Europe. At Chepon in Laos, on about the latitude of Hue and midway between the sea and the Siamese frontier, are red sandstones with occasional beds of limestone and shale in which occur teeth of *Lepidotus, Acrodus* and *Plesiosaurus*, believed to be of Upper Lias age. This formation is directly overlain by the Upper Cretaceous (Senonian) (Hoffet & Le Maitre, 1939). In NE. Laos, in the Sam Neua region, are shales containing some of the Upper Bathonian brachiopods of the Namyau Beds of Burma and Yunnan (Mansuy, 1920).

**Malaya**

No evidence for Jurassic beds has been found. An assemblage of pelecypods and plants near Singapore, which Newton (1906) thought possibly Middle Jurassic, has turned out to be pre-Rhaetian (Scrivenor, 1931, pp. 65-7).
INDO-CHINA AND INDONESIA

**Sumatra**

In several parts of the island there are patches of phyllites and silky slates with interbedded sandstones, quartzites and occasional limestone lenses, which at first were taken to be Palaeozoic or earlier. Like the Alpine Bündnerschiefer which yield stretched belemnites, however, they have proved to contain remains of Mesozoic fossils. The best faunule, from a lens of limestone in the Jambi district (see fig. 65), yielded *Astarte, Opis, Lucina* and *Cypricardia*, pelecypods which seem to be of Middle Jurassic age (Tobler, 1923; Frech & Meyer, 1922). In several places also lenses of reef limestone with only recrystallized fossils are attributed doubtfully to the Upper Jurassic, while Lower Jurassic is suggested by an oolite lens with *Pentacrinus*, corals resembling *Montlivaltia*, and belemnites (Volz, 1913; Tobler, 1923; Brouwer, 1925, p. 29; Wanner, 1931, p. 597). Clearly it is possible that the whole Jurassic system exists in Sumatra in a partly metamorphosed state. According to the map by Rutten (1938), however, there are only four small patches of Jurassic beds besides the main Jambi area (see fig. 65).

The Neocomian ammonite genera *Neocomites, Kilianella* and *Olcostephanus* are also recorded from Jambi.

**Borneo**

A large part of this island is built of the Danau formation, a series of radiolarites, hornstones, siliceous shales, quartz sandstones, silicified tuffs and igneous rocks, intensely folded and compressed but not extensively overthrust (Easton, 1904; Martin, 1907; Wanner, 1931, p. 596). The radiolarites have, as always, caused differences of opinion as to date. They were at first thought to be Jurassic, but more recently almost all ages except Jurassic have been attributed to the Danau: ranging from Devonian to Paleocene. In west Borneo shallow-water Jurassic beds, which have been little disturbed but extensively denuded, and include in places Lias, transgress over the folded Danau; here the Danau is considered to be Palaeozoic to Lower Triassic, and, from the contained Radiolaria, mainly Permo-Triassic (Easton, 1904, p. 28; Umbgrove, 1938, pp. 25-7; Kobayashi & Kimura, 1944, p. 241). In north Borneo, however, where no fossiliferous Jurassic is known, intensely folded Danau rocks contain derived fragments of radiolarites and foraminifera of Cretaceous to Lower Tertiary age. It seems, therefore, that in different parts of the island the so-called Danau formation is of widely different ages, and received its tectonic deformation at widely different periods. (For full discussion see Reinhard & Wenk, 1951, pp. 91-7.)

From the Sambas district, in the extreme west of the island (see fig. 65), an ammonite from a nodule has been figured as 'Aegoceras' borneensis' Krause (1911, pl. vii); it may be a *Xipheroceras* and in that case of middle Sinemurian date. From shales at another locality in the same district have been figured Upper Toarcian Grammomoceratids, apparently for the

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most part *Dumortieriae* (Krause, 1896, pl. xi) and of about the same age as the deposit at Trian in Cochin China—an horizon conspicuous also in northern Persia. Middle Jurassic is more doubtfully represented by pelecypods and gastropods, including a *Trigonia* of Bajocian-Bathonian aspect (Newton, 1903), and by *Astarte*–*Corbula* beds (Easton, 1904) which suggest the Bathonian.

Upper Jurassic certainly occurs but is even more skimpily known: reef limestones with an Upper Jurassic *Lopha* are recorded on the Sarawak River (Newton, 1897), and Spath (Cutch, 1924, p. 16; 1933, pp. 825-6) has identified a 'Subplanites of the schlosseri group' from Upper Sarawak; this indicates Upper Kimeridgian. A fragmentary Perisphinctid figured by Easton (1904, pl. xii) is not determinable. Land probably existed to the north-west (Martin, 1907).

**Eastern Indonesia**

In the eastern part of the archipelago, as mentioned above, the Jurassic system comes on in force and in the ‘Banda Arc’ there seems to have been continuous deposition from Lower Trias or Permian to Lower Cretaceous. The predominant facies in the geosyncline, from Hettangian to Tithonian, is shales with nodules, resembling the Spiti Shales. In the Sula Islands and Obi, to the north, the facies of some formations is more shallow-water, neritic; and, so far as negative evidence can be relied on, deposition did not begin until the Upper Lias or even Middle Jurassic. The deposits on Misol are intermediate in character.

The supposed limits of the trough, indicated by broken lines in fig. 66, were based largely on evidence from the Trias and from the physiography of the present sea-bed. For the Jurassic alone, the conventional picture so constructed is less satisfactory, for from Toarcian times onwards a trough at least as important continued eastwards through New Guinea; and on Buru (Wanner, 1922, p. 99) the earliest known beds are Oxfordian, although this island lies in the middle of the trough. In any case, all reconstructions are hazardous while we remain so ignorant of the stratigraphy of Sumatra and Borneo. The small relic of Upper Kimeridgian in Borneo is a warning of the vast amount of denudation that has taken place, before and since the Cretaceous.

The emphasis usually laid on facies will be disregarded in the following summary, which aims at bringing together the multitudes of scattered records of ammonites from all parts of the eastern half of the archipelago and sifting them critically. A complete but uncritical catalogue of Cephalopods down to 1930 is available (Kruizinga, 1931), and a detailed account of the stratigraphy island by island (Wanner, 1931). An attempt to classify the occurrences by means of the belemnites has been made by Stolley (1934), and the interesting *Aucellae* [*Buchia*] and *Inocerami* have been studied respectively by Krumbeck (1934) and Wandel (1936). Other mollusca are catalogued by Krijnen (1931) and other groups by various authors in the same Festschrift. Of special interest is the pelecypod

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assemblage of the Liassic ‘Grey Limestones’ of south Tyrol, found in black limestone on Timor (Wanner, 1910). Liassic brachiopods from Ceram are described by Wanner & Knipscheer (1951).

Excellent general accounts of the geology, including useful summaries of the Mesozoic formations, will be found especially in Brouwer (1926), Umbgrove (1938) and Van Bemmelen (1949). The geological map, (Rutten, 1938) does not differentiate Jurassic from other Mesozoic rocks.

Volcanic activity during the Jurassic is proved by the Upper Oxfordian Sasifu Beds of Buru, which are composed largely of water-laid tuff with lapillae. Thick volcanic breccias and eruptive igneous rocks in the same island are believed to date from the same period (Wanner, 1922, p. 101). Tuffs assigned to the Oxfordian also occur on Misol (Wanner, 1931, p. 592).

TITHONIAN AND LOWER CRETACEOUS

At least in Misol there is a continuous conformable succession from Jurassic to Cretaceous. The Valanginian and Hauterivian are represented by limestones with *Hibolites subfusiformis*. The same is probably true of Rotti, Timor, Ceram, Buru and eastern Celebes (Umbgrove, 1938, pp. 19-21). In Buru there is red limestone with aptychi, reminiscent of the Alpine Tithonian (Martin, 1900). The most interesting finds, however, have come from the Sula Islands, Taliabu and Mangoli (Boehm, 1904). From streambeds on the south side of the islands have been

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**Fig. 66.—Locality map for the eastern Indonesian archipelago.** The broken lines indicate the conventional concept of the Timor-East Celebes and Papuan geosynclines, as suggested by present-day distribution of facies, which must, however, have been subsequently distorted to an unknown degree.
collected some of the typical fauna of the Lochambel Beds of the Spiti Shales: *Haplophylloceras strigile* (Blanford), *Blanfordiceras wallichi* (Gray) (in quantity), and local species of the Himalayan genera *Uhligites*, *Himalayites* and *Bochianites* (Boehm, 1904, pls. i-vii). From the Sula Islands have since been figured also two new species of *Kossmatia* (Kruizinga, 1926, pp. 64-9, pls. xi, xii). These are more evolute than typical *Kossmatia* and differently ribbed, but more nearly resemble some Mexican species (*K. zacatecana* Burck.). A ‘*Lithacoceras*’ from East Celebes (Wandel, 1936, pl. xvi, 1) is also a Tithonian form, perhaps identical with Schlüter’s *Kossmatia* from New Guinea.

**Kimmeridgian**

From the Sula Islands have been figured two *Idoceras* (Boehm, 1912, pl. xlv; Kruizinga, 1926, pl. x, figs. 1, 2).

**Upper Oxfordian**

From Wai Galo streambed on the south coast of Taliabu, Sula Islands, Boehm in 1900 collected some 250 well-preserved ammonites associated with crowds of belemnites and large coarse-ribbed *Inocerami* like those from the Spiti Shales. Taking shelter from the sun in a native hut, he noticed on the ground the holotype of *Mayaites palmarum* Boehm, which had been a toy belonging to the local children. This find led him to search the streambed and discover the classic Upper Oxfordian fauna of Wai Galo. The ammonites occur in cementstone nodules weathering out of shales, as in the Himalayan Spiti Shales (Boehm, 1907). As in the Dhosa Oolite of Cutch, the fauna comprises mainly Perisphinctids associated with Mayaitids, but the species are different. There are also *Peltoceratoides* and Phylloceratids: *Psychoxyphyllloceras galoi* (Boehm), *Calliphylloceras malayanum* (Boehm), *Holcophylloceras passati* (Boehm), *H. insulindae* (Boehm) and *? Partschiceras monsunii* (Boehm).

The Perisphinctids, as has been pointed out (Arkell, 1939, Mon. Am. Engl. Corallian Beds, p. lx), all or nearly all belong to the subgenus *Kranaosphinctes*, which in England is early-Plicatilis Zone. The Wai Galo forms are all new, and the fact that neither they nor the Mayaitids are the same as those found in Cutch can be explained by supposing them to be slightly earlier. If, as Boehm believed, they occur on the same horizon as the large *Peltoceratoides* spp., a late-Cordatum Zone age is suggested. The assemblage may perhaps be nearest in date to that from Kwa Dikwaso in Tanganyika (p. 328), in which there are fragments of a *Perisphinctes* indistinguishable from *P. burui* Boehm and similar Phylloceratids. Similar *Prograyiceras* and *Epimayaites* occur near Mombasa.

The belemnites include *Belemnopsis* of the group of *B. gerardi* of the Spiti Shales; Boehm (1907, p. 113) considered that these and the *Inocerami* occurred slightly below the ammonites.

On the island of Buru, about 100 miles to the south-east, Upper Oxfordian ammonites occur at many places. Near Mefa village they are

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in a red-weathering whitish limestone rich in microfossils, and occasionally shale, and at Bara Bay in water-laid volcanic tuff with small lapillae (Sasifu Beds). From the Mefa Beds Boehm (1908) obtained Calliphylloceras malayanum (Boehm) and a suite of Perisphinctids of which he named and figured only one species, *P. (Kranaosphinctes) burui* Boehm, remarking that the species were different from those at Wai Galo. From these and the absence of Mayaitids he inferred that the beds were not quite the same age as those at Wai Galo and probably somewhat younger (Boehm, 1908, p. 298). Later collections made by Deninger in the same and a number of new localities in Buru were described by Hummel (1923), who unfortunately was inexperienced in ammonites (and the Rules of Nomenclature). His lengthy discussions and graphs are shown by his photographs to be worthless, for they make it evident that he considered conspecific forms which would now be placed in different subgenera (different genera by Buckman and Spath). His pl. ix, fig. 5, shows a small form with lappets, probably more closely related to *Dichotomosphinctes rotoides* than to *Kranaosphinctes burui*; and his fig. 7 is a distinctly late *Dichotomosphinctes* or *Discosphinctes*. This and the *Taramelliceras* cf. *flexuosum* (Münster) (Hummel, pl. xi, fig. 8) bear out Boehm's inference of a somewhat later date than the Wai Galo assemblage—though still in the Plicatilis Zone. Hummel also figures some typical European pelecypods which might have come from the Upper Corallian Beds of England: the *Inocerami* are absent. He also records most of the Wai Galo Phylloceratids and some others, *Ptychophylloceras insulare* (Waagen), *Holcophylloceras mediterraneum* (Neum.) and a *Euaspidoceras*.

Upper Oxfordian Perisphinctids occur also on Timor (Boehm, 1908, p. 332), and a *Taramelliceras* of this age has been figured from a mud-volcano on Rotti (Krumbeck, 1922, p. 204, pl. xviii, fig. 7).

**Upper Callovian**

As previously pointed out (Arkell, 1951, Mon. Engl. Bathonian Am., p. 59), some of the specimens from the Sula Islands figured by Boehm (1912) under *Oppelia fusca* represent Upper Callovian Hecticoceratinæ: pl. xxxiv, fig. 2, is a *Putealiceras*, and figs. 3, 4 are *Sublunuloceras*, probably of about Athleta Zone date.

**Middle and Lower Callovian**

At Keeuw and several other localities on Taliabu, Sula Islands, stream-beds have yielded a wonderful assemblage of Macrocephalitids of sub-genera (or genera) familiar in Cutch and in Europe. A wide selection was figured by Boehm (1912) under the same specific name *Macrocephalites keeuwensis* Boehm, of which Spath (1928, Cutch, p. 205) selected Boehm's pl. xxxvi, fig. 3 as lectotype. This is a *Dolikephalites* very close to the English Upper Cornbrash species *M. (D.) typicus* Blake (synonym *M. (D.) dolius* Buckman) which has also been figured from the Caucasus (see p. 361). The following other new names and

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attributions for Boehm’s Taliabu Macrocephalitids (Boehm, 1912, plates xxxv-xliv) are scattered through nearly 100 pages of specific descriptions and lengthy discussions of Indian ammonites in Spath’s Cutch revision (1928, pp. 163-252):—

*Dolikephalites subcompressus*? (Waagen), Spath 1928, p. 201, for Boehm’s pl. xxxviii, fig. 2.

*Kamptokephalites beta-gamma* (Boehm), Spath, p. 198, for Boehm’s pl. xli, fig. 5.

*Kamptokephalites subkamptus* Spath, p. 174, for Boehm’s pl. xli, figs. 1a, b only.

*Indocephalites apretus* Spath, 1928, p. 190, for Boehm’s pl. xxxix, fig. 3.

*Idiocycloceras bifurcatum* (Boehm), Spath, p. 206, for Boehm’s pl. xxxix, fig. 1 (= Kruizinga, 1926, pl. viii, figs. 1-3).

*Eucycloceras intermedium* Spath, p. 210, for Boehm’s pl. xxxviii, fig. 3.

*Kamptokephalites etheridgei* Spath, 1928, pl. xxxii, fig. 3 (New Guinea), covering *Macrocephalites waageni* Kruizinga, 1926, pl. ix, figs. 1, 2, non Uhlig, from the Sula Islands.

From these determinations it emerges that both Macrocephalus and Rehmanni Zones of the Cutch Callovian are represented in the Sula Islands. *Macrocephalites* s.s. as now understood seems to be represented by Boehm’s pl. xxxvi, fig. 1 and perhaps pl. xliv, fig. 1.

The presence of Lower Callovian on Rotti is attested by a *Dolikephalites* figured by Boehm, 1908, pl. xii, fig. 2.

**Bathonian**

The occurrence of both Lower and Upper or Middle Bathonian (or all three) at Keeuw in the Sula Islands is shown by three ammonites figured by Boehm (1912) amongst his Lower Callovian Macrocephalitids. *Sphaeroceras sofanum* Boehm (p. 150, pl. xxxv, fig. 2) is a typical *Bullatimorphites*, like the three species with which he compared it, all of which are Bathonian. *Sphaeroceras godohense* Boehm (p. 151, pl. xxxv, fig. 1) appears to be a *Rugiferites* like those from the Subcontractus Zone of England; but the apertural region is missing, and if the complete ammonite identified with Boehm’s species by Kruizinga (1926, pl. xiv, figs. 2, 3) is the same, appearances are deceptive and *S. godohense* is nearer to the Bajocian *Chondroceras*. Lastly, at least one of the ammonites figured by Boehm as *Oppelia fusca* (pl. xxxiii, fig. 3) is the true *O. fallax* (Guéranger), of the Lower Bathonian. I have no hesitation in confirming this identification since receiving a collection of this species (in 1951) from Persia (see p. 371). *Lissoceras* occurs on Babar (Wanner, 1931, p. 588).

**Bajocian**

Some other Keeuw ammonites figured by Boehm (1912) indicate the presence of the Bajocian. The fine *Cadomites* (pl. xxxiv, fig. 5), it can hardly be doubted, was correctly identified as an Upper Bajocian species by Boehm, although *Cadomites* ranges up into at least the Middle Bathonian.
and (according to some authors) the Lower Callovian in Europe. An allied species was figured from the Sula Islands by Kruizinga (1926, pl. xiii, fig. 1) as ‘Stepheoceras’ indicum Kruizinga. As just mentioned, Kruizinga’s version of Sphaeroceras godohense Boehm (Kruizinga, 1926, pl. xiv, figs. 2, 3) appears to be a Sphaeroceratid at least closely related to Chondroceras of the Middle Bajocian, a genus that occurs in New Guinea (Boehm, 1913, pl. ii, 3, 4). Coeloceras indicum Kruizinga (1926, pl. xiv, fig. 1) is too worn to interpret with confidence, but seems to be a Teloceras comparable with Canadian species such as T. stelki Warren and the English T. banksi (Sowerby), in which primary ribs become obsolete. ‘Stephanoceras aff. braikenridgii’ Boehm (1908, pl. xii, fig. 3), from Babar, strongly suggests a Normannites close to N. orbignyi Buckman, but according to Jaworski (1933, p. 323) it is a Toarcian Catacoeloceras. A link with Australia is Pseudolotites (Kruizinga, 1926, pl. vi, 1, 2, pl. xiii, 3). Bajocian pelecypods from Taliabu are figured by Jaworski (1920).

TOARCIAN

Species of Dactylioceras and ‘Coeloceras’ have been figured from Rotti (Krumbeck, 1922, pls. xvii, xviii) and Timor (Krumbeck, 1923, pl. clxxvii) and revised by Jaworski (1933). Toarcian Harpoceratids, which require further attention, seem to be commoner, having been recorded or figured from Borneo (Krause, 1896, pl. xi), from Jefbie and Fialpopo in the Misol Archipelago (Soergel, 1913, 1915), where they indicate levels up to the Aalense Subzone, and from Babar (Wanner, 1931, p. 588). More accurate determination is possible for Grammoceras timorense Krumbeck (1923, p. 115, pl. clxxvii, fig. 8) from Timor, which is an Esericeras and indicates about Striatulum Subzone of the Jurense Zone, and Harpoceras arietiforme Kruizinga (1926, pl. i, figs. 3-5) from the Sula Islands, which is a large Fuciniceras probably of Lower Toarcian date, like some from Baluchistan and Italy. Grammoceras kiliani Kruizinga (1926, pl. i, fig. 2), also from the Sula Islands, indicates once more the Jurense Zone; while a Lytoceras of the jurense group is known from Rotti (Krumbeck, 1922, pl. xvii, fig. 6).

Hammatoceras molukkanum Cloos (1916; and see Kruizinga, 1926, pl. ii) is more difficult to date accurately but is certainly Upper Toarcian.

LOWER LIAS

All parts of the Lower Lias are strongly represented in the islands, especially in Rotti, Babar and Timor, but there are no sections. Almost without exception the ammonites have been collected loose from stream-beds or from the ejectamenta of mud-volcanoes. Details of the occurrences, island by island, will be found in Wanner (1931), and figures chiefly in Krumbeck (1922; 1923), Wanner & Jaworski (1931) and, with a revision of most of the families, in Jaworski (1933). The following is a list of important species that have been figured or authoritatively recorded, arranged to show the probable representation of the stages and zones.

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Lower Pliensbachian

Lytoceras cf. fimbriatum (Sow.). Rotti
Phylloceras rotticum Krumbeck. Rotti
Calliphyloceras subcapitanea (Krumbeck). Rotti
Juraphyllites rotticensis (Krumbeck). Rotti

Ibex and Davoei Zones
Liparoceras aff. kilbiense Spath (Krumbeck, 1922, pl. xviii, 3). Rotti
Liparoceras rotticum Krumbeck. Rotti

Jamesoni Zone
Phricodoceras subtaylori (Krumbeck). Rotti
Tropidoceras masseanum (Quenst. non d'Orb.) (Krumbeck, 1922, pl. xviii, 4). Rotti
Uptonia sp. (Krumbeck, 1923, pl. clxxvii, 4). Timor
Coeloderoceras ? moermanni (Kruizinga). Sula Is.

Sinemurian

Raricostatum and Oxynotum Zones
Echioceras wichmanni (Rothpl.). Rotti, Jamdena
Echioceras rotticum (Rothpl.). Rotti
Echioceras cf. radiatum Trueman & Williams. Rotti, Timor
Eoderoceras sp. (Krumbeck, 1922). Rotti
Oxynoticeras spp. (Krumbeck, 1922). Rotti

Obtusum and Turneri Zones
Microderoceras landaui (Boehm). Rotti
Asteroceras sparsicostatum Wanner. Jamdena

Semicostatum and Bucklandi Zones
Arnioceras cf. semilaeve (Hauer). Celebes
Arnioceras cf. fortunatum Buckman. Rotti
Arnioceras mendax Fucini. Rotti
Arnioceras subgeometricum Jaworski. Rotti, Timor
Arnioceras ceratitoides (Quenst.). Rotti
Arietites aff. lyra Hyatt. Rotti
Arietites cf. rotiformis (Sow.). Rotti

Hettangian (some perhaps Sinemurian)
Psiloceras spp. (Wanner, 1931, p. 587). Babar
Paracaloceras cf. coregonense (Sow.) Waehner. Timor
Ectocentrites aff. italicus (Canavari) Waehner. Timor
Pleuroacanthitidae, 2 spp. Timor
Juraphyllites ? (Calaiaceras ?) aff. stella (Sow.). Timor
? Phylloceras cylindroides Krumbeck. Timor

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Shales in the south-east of the Isle of Mindoro have yielded Jurassic ammonites recorded as of the genera *Arietites*, *Oppelia*, *Macrocephalites*, *Peltoceras*, *Perisphinctes* and *Streblites*, and *Trigonia mindoroensis* occurs. Some radiolarites in the island are probably also Jurassic, since similar Radiolaria occur in the matrix of some of the ammonites. (Hayasaki, 1943.)
PART V
AUSTRALASIA
CHAPTER 18

NEW GUINEA, NEW CALEDONIA, NEW ZEALAND AND AUSTRALIA

NEW GUINEA, NEW CALEDONIA, NEW ZEALAND

It is not altogether imagination to link these three distant countries geologically as relics of an orogenic belt, most of which has foundered beneath the sea. The trend-lines of the great central range of New Guinea, called in its south-eastern part the Owen Stanley Range, are continued by the elongated island of New Caledonia, although separated by 1200 miles of ocean; and after another gap of 1000 miles the same trend is picked up again at North Cape, New Zealand, and continued, after a virgation in North Island with the Kermadec-Samoa ridge, through the Southern Alps of the South Island. This reconstruction forms an arc 5000 miles long, which Suess called the ‘3N arc’ (New Guinea, New Caledonia, New Zealand). The south-easterly turn taken by the trend-lines at the south end of the South Island, New Zealand, suggests that the orogen links up under the sea with the fold-ranges of West Antarctica and the Andes, to complete the circum-Pacific orogenic ring.

Geological exploration of New Guinea and New Caledonia is still in infancy, but enough is known to indicate essential parallelism in the Jurassic system in all three countries. In fundamental contrast with Australia, a continental area in the Jurassic, the ‘3N arc’ was a region of geosynclinal marine deposition. New Zealand has about 4500 m. of Jurassic, most of it greywackes and mudstones, interspersed with grits and conglomerates, such as are more usually associated with the Lower Palaeozoic systems in Europe. The Upper Jurassic of both New Zealand and New Guinea show strong resemblances, lithologically and palaeontologically, to the Spiti Shales of Indonesia and the Himalayas. In both New Zealand and New Caledonia there are indications of a land area to the west, which supplied the sediments to the trough. This land must have lain on the site of the Tasman and Coral Seas. Geophysical and geological lines of evidence converge to the conclusion that these seas are a foundered land area, quite different from the Pacific Ocean.

It is therefore a hypothesis less shaky than many in geology, that the ‘3N arc’ coincides with a Jurassic sinking mobile belt, the Papuan Geosyncline, which was folded and upraised in the manner of an active orogen during the Cretaceous and Tertiary orogenies; furthermore, that this orogen separated greater-Australia (inclusive of the Tasman and Coral Seas) on the west from the Pacific Ocean on the east; and that between the geosyncline and the ocean to the east there may have risen a chain or

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chains of island arcs over the site of the present edge of the continental shelf, from the Solomons to Samoa. As will be seen below (Chapter 30), this picture resembles in essentials that deduced independently for the Andes of South America.

Upon the continental area of greater-Australia there were other troughs, but broad and shallow and of stable-shelf type, occupied during the Jurassic by freshwater lakes (see p. 461). These may have connected with the sea southwards off the present coast of eastern Australia by a gulf surviving from the Tasman geosyncline of Palaeozoic times (David & Browne, 1950, pp. 695-6).

![Map of New Guinea and Indonesian islands showing Jurassic outcrops](http://jurassic.ru/)

**NEW GUINEA**

The largest known areas of Jurassic in New Guinea are in the northwestern peninsula, between Geelvink Bay and McCluer Gulf. Thence outcrops are known intermittently along both sides of the Central Range which forms the backbone of the island, as far as the Fly and Strickland Rivers, longitude 142°E. The Jurassic and Cretaceous rocks consist mainly of shales poor in fossils, with mudstones in nodules and bands, and subordinate sandstones. On the headwaters of the Fly River the shale series is estimated to be 2250 m. thick. It there crops out from the foot of a massive escarpment of Tertiary limestones (Osborne, 1945). Inside this barrier the mountains rise abruptly from densely forested lowlands up to heights culminating in 16,400 ft. in the Carstensz Peaks. From the Central Range numerous rivers, 200-300 miles long, cross the plains to the sea, bringing with them products of denudation far in the interior. It is from boulders in these rivers that most of the fossils have been collected, and they have caused outcrops of Jurassic rocks to be
shown on maps in regions which have later proved to be entirely Tertiary (Osborne, 1945, p. 132).

Bajocian and Bathonian are present in the north-west of the island, and of the Lias at least Pliensbachian is represented, but in the south-east, in the headwaters of the Fly River, nothing earlier is known than presumed Callovian, which rests on granitic basement rocks, as if overlapping on to the south-west edge of the geosyncline. There is another gap above the Oxfordian. Nothing representative of the Kimeridgian has been found, and locally the Tithonian may be absent also, so that Albian and Oxfordian shales are in contact.

With these reservations, the succession closely resembles that in the Indonesian archipelago.

A general account of the geology is given by Stanley (1923), and discussions of Mesozoic and later stratigraphy will be found in Klein (1937) and Glaessner (1943). Localities in Dutch New Guinea are listed by Gerth (1927, p. 228) and Wanner (1931, p. 595). Significant ammonites and some other fossils are listed below, by stages.

**Upper and Middle Tithonian**

The following ammonites of the Lochambel Beds of the Upper Spiti Shales have been figured, mainly from the north-west:

- *Haplophylloceras strigile* (Blanford) (Boehm, 1904, p. 25)
- *Blanfordiceras wallichi* (Gray) (Boehm, 1904, p. 34)
- *Paraboliceras cf. polysphinctum* Uhlig (Schlüter, 1929, pl. xi, fig. 4)
- *Kossmatia desmidoptycha* Uhlig (Schlüter, 1929, pl. x, fig. 3)
- *? Kossmatia* sp. (Etheridge, 1890, pl. xxix, fig. 4)

On the upper Fly River the Tithonian may be locally absent, cut out by overstep of the Albian on to Oxfordian, but in other places it is represented by shales with Perisphinctids (Osborne, 1945).

**Oxfordian**

- *Perispininctes burui* Boehm (Schlüter, 1929; Upper Sepik)
- *Perispininctes taliabuticus* Boehm (Schlüter, 1929; Upper Sepik)
- *Perispininctes cf. moluccanum* Boehm (Schlüter, 1929; Upper Sepik)
- *Peltoceratoides* sp. (Gerth, 1927, p. 277)
- *Belemnopsis gerardi* (Oppel) (Gerth, 1927, p. 228)
- *Inoceramus galoi* Boehm (Gerth, 1927, p. 228)

The beds with *Belemnopsis gerardi*, *Buchia malayomaorica* and large *Inoceramus* also occur in the headwaters of the Fly River (Osborne, 1945; Glaessner, 1945). They correlate with the Moluccas and with Broome in NW. Australia.

A *Quenstedtoceras* has been recorded from New Guinea (Martin, 1911), but it may be suspected of being a *Kossmatia*, like *[Oppelia] lingulata* Quenstedt sp. misidentified by Woodward (in Etheridge, 1890, pl. xxix, http://jurassic.ru/
fig. 4), which several authors have remarked looks like a *Cardioceras*. There is, however, a plaster cast in the British Museum (No. C2239) and it has no keel and belongs to *Kossmatia* or some allied genus (Tithonian).

**Callovian**

Many Macrocephalitids were figured by Boehm (1913) and have been recorded from various outcrops hundreds of miles apart (Martin, 1911; Schlüter, 1929, from the upper Sepik River; Gerth, 1927, p. 226, etc.). Spath (1928, Cutch, p. 212 and pl. xxxii, figs. 3, 4) has provided some new names:

- *Subkossmatia beta-gamma* (Boehm) for Boehm, 1913, pl. v, fig. 2
- *Kamptokephalites etheridgei* Spath, for Etheridge, 1890, pl. xxix, fig. 1, from the Strickland River
- *Dolikephalites flexuosus* Spath, for Etheridge, pl. xxix, fig. 5

The first indicates the Anceps Zone, the last two the Macrocephalus Zone, the species being hardly distinguishable from some in the English Upper Cornbrash.

Beds with pelecypods believed to be of Callovian date transgress on to granite basement in the headwaters of the Fly River (Osborne, 1945, p. 146).

**Bathonian**

- *Bullatimorphites cf. bullatus* (d'Orb.) (Gerth, 1927, p. 226)
- *? Rugiferites godohensis* (Boehm) (Boehm, 1913)

**Bajocian**

Both Upper and Middle Bajocian ammonites have been figured. Upper Bajocian is attested by *Cadomites daubenyi* (Gemmellaro), matching Sula Islands specimens, which Boehm (1912, p. 148, pl. xxxiv, fig. 5; 1913, pl. iii, fig. 1) considered identical with the types borrowed from Sicily. The Humphriesianum Zone is represented by the following:

- *Stephanoceras aff. humphriesi crassicosta* (Quenst.) Boehm (1913, pl. iii, fig. 2). This looks possibly related closely to some Canadian forms; e.g. Warren, 1947, pl. iii, and McLear, 1930, pl. ii.
- *Stephanoceras of humphriesianum* group; inner whorls figured (Boehm, 1913, pl. v, fig. 4) of a large specimen said to be indistinguishable from Bayeux specimens.
- *Chondroceras cf. submicrostoma* (Gottsche) (Boehm, 1913, pl. ii, figs. 3, 4).
- *Normannites etheridgei* (Gerth) (1927, p. 226, pl. xxxvi, fig. 1, holotype).

**Pliensbachian**

- *Coeloderoceras aff. moermanni* (Kruizinga). Gerth, 1927, pl. xxxvi, fig. 2, and Jaworski, 1933, p. 323, pl. xi, fig. 8.

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NEW CALEDONIA

The island of New Caledonia, midway between New Guinea and New Zealand, is 250 miles long by about 40 miles wide. The backbone of the island is a mountain range which runs longitudinally from end to end, with many peaks up to about 5000 ft. The range consists mainly of serpentine and, towards the north and on the north-east side, a mass of metamorphic rocks, formerly lavas, tuffs and sediments, all believed to be Mesozoic. On the west side is a coastal belt formed, with adjacent islets, of strongly folded but unmetamorphosed Mesozoic sediments and volcanic rocks. The sediments are largely in sublittoral facies and were presumably formed close to the shore of the Australian continent that lay to the west. They have been folded and thrust westward during and after intrusion of the serpentine, which is thought to have arrived as an immense ultrabasic sill intruded between Middle Eocene and Miocene times. The metamorphic suite is believed to represent deeper-water equivalents of the Jurassic and Cretaceous rocks, highly metamorphosed because they lay above the magma, and were presumably carried westwards on its back. (Piroutet, 1903, 1917; Benson, 1926a; Jensen, 1936; also Uhlig, 1911, p. 412, whose brilliant predictions have been confirmed by recent work by Jensen and Avias.)

The presence of all the stages of the Lower Lias is now established, chiefly through the work of Avias (1950, 1951, 1954).* Above the Lias greywackes is a thick carbonaceous formation, consisting predominantly of black clay-shales, with some lenses of sandstone or arkose, sometimes containing thin coal seams, and numerous calcareous and siliceous nodules (Routhier, 1953, p. 49). This formation contains few fossils but is for the most part Upper Cretaceous, as shown by the presence of Kossmaticeras spp., which indicate the Senonian. However, in addition three different Upper Jurassic faunas have been discovered. Flows of andesite and rhyolite have been reported about the Jurassic-Cretaceous boundary, and much of the greywacke series contains tuff, as in New Zealand. The evidence of the faunas may be summarized as follows:—

[BERRIASIAN ?

Sandstones, conglomerates, mudstones and lavas, with gastropods, especially Dicroloma (Avias, 1954, p. 171, fig. 110), and pelecypods which include Trigoniae close to species in the Umia Beds of Cutch (Piroutet); but the determinations require confirmation (Routhier, 1953, p. 58). These beds have also yielded Duvalia and two fragmentary impressions of Berriasella perhaps comparable with B. novoseelandica (Hochstetter) (Avias, 1954, pp. 172-3, pl. xx, figs. 13, 14).]

* I am indebted to M. Avias for most kindly sending me advance proofs of his important monograph (1954), and for supplying the map (fig. 68).

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FIG. 68.—Map of the Jurassic outcrops of New Caledonia, specially drawn by Monsieur J. Avias, 1954.

Key: A, dated Jurassic outcrops; B, undated Permian-Triassic-Jurassic, mainly greywackes, probably including some Jurassic; C, Jurassic fossil-localities, 1-13, listed below.

Fossil-localities 1-13:—1, Mount Katepouenda, pre-Toarcian Lias (after Routhier); 2, Upper Nounin, Upper Jurassic black shales with *Inoceramus*; 3, Goipin, same as 2 (after Routhier); 4, Ba, pre-Toarcian Lias, greywackes; 5, Aymes Creek basin, Me Chamara and Quele region, pre-Toarcian Lias, greywackes and sandstones; 6, Kondaou, Upper Jurassic, perhaps with Tithonian; black shales and sandstones with *Belemnopsis*; 7, Teremba Islet, Hettangian, greywacke-like sandstones; 8, Gally-Passeboe Monument, Tithonian? or Berriasian?, sandstones and conglomerates with gastropods and Berriasellids; 9, Middle Ouamenie, same as 8; 10, Puen Island, Upper Jurassic green greywackes with *Belemnopsis*; 11, Lower Ouamenie, Upper Jurassic, same as 10; 12, Ducos Island (Fly Bay), Sinemurian felspathic greywackes with *Arnioceras*; 13, Inaccessible Bay, Hettangian with ammonites.

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KIMERICDIAN-OXFORDIAN?

Sublittoral sandstones and green greywackes at Puen Island and Saint Vincent Bay, with abundant fossil wood, and containing abundant belemnites compared to *Belemnopsis aucklandica* (Hochst.). These beds also yielded *Holocyliloceras aff. polyolcum* (Ben.) and a Lytoceratid (Avias, 1954, pp. 161-8).

Black shales near the centre of the island, on the upper Noumin and upper Poya Rivers, yield forms of *Inoceramus* comparable with species figured from the Oxfordian of Indonesia (Routhier, 1953, pp. 55-8; Avias, 1954, pp. 168-70). A very poorly preserved Perisphinctid figured by Routhier (1953, p. 57, pl. iii, fig. 1) from a limestone fossil-bed in the shales was misidentified as *Perisphinctes (Arisphinctes) schilli* Oppel sp. (holotype refigured Schneid, 1944, Palaeontographica, vol. xcvi A, p. 27), which is an involute, *Discosphinctes*-like offshoot of *Arisphinctes*. Though too poorly preserved for determination, the New Caledonian ammonite (kindly sent me on loan) appears most likely to be a Kimeridgian *Idoceras*.

PLIENSBACHIAN?

Beds with abundant *Pseudoucella marshalli* (Trechmann) as in New Zealand, where they are pre-Toarcian and post-Hettangian and believed to be Pliensbachian.

SINEMURIAN

The presence of Lower Sinemurian is indicated by an *Arnioceras* found on Ducos Islet (Avias, 1954, p. 153, pl. xx, fig. 12).

HETTANGIAN

At Inaccessible Bay, close to Ducos Islet, have been found a number of Psiloceratidae and Schlotheimiidae, including the genera *Discamphiceras*, *Laqueoceras*, *Waehneroceras* (including 'Storthoceras' and 'Megastomoceras'), *Saxoceras* and *Schlotheimia*; also a *Paradasyceras*. With the Schlotheimiids occurs the pelecypod *Otapiria marshalli* (Trechmann), described from the Hokonui Hills in New Zealand. This fauna has been monographed by Avias (1954).

NEW ZEALAND

Although much still remains to be done in New Zealand geology, the picture already built up is incomparably fuller and clearer than we can yet obtain of any other part of the Papuan geosyncline.

Of the geosynclinal nature of the Jurassic sediments there can be no doubt. The predominant rock-types are greywackes and mudstones, with subordinate sandstones and conglomerates at several levels. The total thickness near Kawhia Harbour, south of Auckland, on the North Island, is about 4500 m. In the South Island the thickness diminishes, being about 2200 m. at the south end. These measurements are hardly comparable, however, owing to uncertainty about the upper boundary.
The structure is complex and has not yet been fully elucidated. The Southern Alps and neighbouring ranges consist largely of folded sedimentary and metamorphic rocks, schists of undetermined age in the west grading eastwards into less metamorphosed Upper Triassic beds (Wellman & others, 1952). From the lie of the proved Jurassic, however, it seems that the sediments were derived from lost land in the west and laid down in a subsiding trough which ran longitudinally through both islands and bent round to the south-east just before emerging at the SE. corner of the South Island.

Strong folding and compression of the geosyncline with all its contents, up to Neocomian inclusive, took place during the Lower Cretaceous. In the South Island, after folding, uplift and faulting, there was deep erosion before initiation of a new cycle with deposition of transgressive Albian and Upper Cretaceous. The new cycle of sedimentation continued through most of the Tertiary, until brought to an end by the most recent (late Tertiary) orogenic movements, characterised by folding, uplift,
faulting and volcanicity. These movements raised the present mountains and determined the existence and approximate shape of the country. In the North Island tectonic events were more complex and there are Aptian greywackes with considerable volcanic material.

Despite its great thickness, there is no reason to suppose that the Jurassic system in New Zealand is complete. Numerous changes of lithology, from greywackes and claystones to coarse conglomerates, and even 'fossil forests', indicate repeated movements in the trough and its surroundings. The faunas, though including Hettangian and Tithonian, are far from complete. As yet no ammonites definitely assignable to the Sinemurian, Bajocian, Bathonian or Oxfordian have been found. Disconformities certainly and unconformities possibly occur, but their detection will be difficult owing to complexity of structure, rarity of fossil-horizons, and discontinuity of exposures. No red beds or salt deposits occur in the Jurassic or any other system in New Zealand; which suggests that the country has never formed part of a major continental landmass (Fleming, 1949, p. 74).

As the most southerly and most remote in the old world, the Jurassic rocks of New Zealand are of great palaeontological interest. Despite their remoteness they have less endemic fossils than most isolated areas. The ammonites, whether Hettangian, Toarcian, or Tithonian, nearly all belong to ordinary cosmopolitan genera, with special affinity with species found in Indonesia and New Guinea, but also Mexico and Japan. Some pelecypods are astonishingly European. For instance, there occur Oxytoma cf. cygnipes (Young & Bird), Meleagrinella cf. echinata (William Smith) and Camptonectes cf. lens (Sowerby), all first described from the Lias and Oolites of England. In the Lower Jurassic, as in the Trias, the common pelecypods tend to be endemic. There is a striking abundance of Pteriidae, Myalinidae and Buchiidae. The Upper Jurassic pelecypods are largely identical with those of the Spiti Shales and are dominated by the genus Buchia (= Aucella) (at one time believed to be boreal), which ranges from Oxfordian to Tithonian and higher (Marwick, 1926, 1934, 1935). One notable endemic Buchiid genus, Pseudaucella, is a rock-former on a large scale in New Zealand as in New Caledonia.

The Jurassic rocks of the two islands are grouped as follows, with their approximate thicknesses (Willett, 1948, p. 14; Marwick, 1950, 1953, and subsequent information):

<table>
<thead>
<tr>
<th>Kawhia, North Island</th>
<th>South Island</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upper Jurassic</strong></td>
<td></td>
</tr>
<tr>
<td>Heterian series</td>
<td>Metaura series</td>
</tr>
<tr>
<td>2400 m. (+?)</td>
<td>1050 m.</td>
</tr>
<tr>
<td>Temaikan series</td>
<td>Middle Jurassic</td>
</tr>
<tr>
<td>600 m.?</td>
<td></td>
</tr>
<tr>
<td><strong>Lower Jurassic</strong></td>
<td>Putataka and Flag Hill series</td>
</tr>
<tr>
<td>Ururoan series</td>
<td>Bastion series</td>
</tr>
<tr>
<td>1500 m.</td>
<td>660 m.</td>
</tr>
<tr>
<td>Aratauran series</td>
<td>Total</td>
</tr>
<tr>
<td>4500 m.</td>
<td>2210 m.</td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Contemporaneous igneous activity was not extensive, but that it occurred in both islands is proved by the presence of tuffs and rewashed volcanic materials (Wellman, 1952, p. 23; Wood, 1953). There are also frequent occurrences of pebbles of igneous rocks, notably spilites and keratophyres, in Jurassic as well as Triassic conglomerates. Examples of this are seen in the coast sections of Nugget Point in the south and Kawhia Harbour in the north. Andesites, basalts and rhyolites occur in places in both islands in rocks which according to present knowledge might be either late Jurassic or early Cretaceous. Lavas and ash-beds are also widespread in the Triassic greywackes. (Reed, in Willet, 1948, p. 43).

The following tabulation of the faunas is based chiefly on the sections at Kawhia Harbour, on the west coast of the North Island, south of Auckland, which are the most complete in New Zealand. The Jurassic system crops out in the west limb of a large syncline, some 20 miles wide. The district has been mapped in detail and described in an authoritative memoir by Henderson & Grange (1926; and see Trechmann, 1923). A similar memoir is available for the area immediately to the south (Marwick, 1946). The coast-sections near Nugget Point, at the south-east end of South Island, are described by Mackie (1935) and their continuation inland by Ongley (1939; see also Ongley, 1940).

**[NEOCOMIAN]**

The highest Mesozoic strata in the Kawhia Harbour sections are coarse sandstones and conglomerates with plant-remains and rare marine fossils near the base, in all about 600 m. thick: the Puaroan series (Marwick, 1953, p. 30). Ammonites so far known (K. J. McNaught Coll., kindly sent me on loan) are an assemblage of Berriasellids of predominantly Berriasian appearance.

**TITHONIAN AND KIMERIDGIAN**

Under the Puaroan at Kawhia Harbour is a great thickness (2400 or 3000 m.) of marine mudstones with numerous *Belemnopsis aucklandicus* (Hochst.), also *Inoceramus haasti* Hochst., *Buchia malayomaorica* Krum., *Indogrammatodon* cf. *egertonianus* (Stol.), etc. From concretions in these mudstones on the north shore of the harbour come *Aulacosphinctoides brownii* (Marshall), *A. sisyphi* (Hector) (= *marshalli* Spath ?), *Uhligites motutaranus* (Boehm) and *U. hectori* Spath (Boehm, 1911; Spath, 1923). This assemblage is reminiscent of the Middle Spiti Shales (Lower Tithonian). It has not been located on the south shore of the harbour, where various *Aulacosphinctoides*, *Kossmatia*, *Aspidoceras*, *Idoceras* and indeterminable Perisphinctids have been found; also the types but no subsequent specimens of *Berriasella novoseelandica* (Hochst.), which was recorded from Kowhai Point, well down in the Ohauan (Marwick, 1953, p. 28). Much work is still required to sort out the stratigraphical order of these ammonites. *Aulacosphinctoides* or *Torquatisphinctes* and *Idoceras*
PLATE 22a.—Urawitiki Point, at entrance to Kawhia Harbour, New Zealand. The tidal platform consists of Temaikan rocks.

PLATE 22b.—Entrance to Kawhia Harbour, looking south to the Jurassic outcrops. Kawhia in foreground. (See Fig. 70.)
PLATE 23a.—Weathered Middle Bajocian limestone with *Trigonia moorei* Lycett, Moonyoonooka, near Geraldton.

PLATE 23b.—Bringo cutting, 19½ miles east of Geraldton, Western Australia. Marine Bajocian unconformably overlying continental sandstone, which unconformably overlies gneiss.

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of strongly Mexican affinities occur. Near the base of the Heterian at Captain King’s, south of Totara Point, have been collected Idoceras cf. *humboldti* Burckhardt, Epicephalites cf. *epigonus* (Burckhardt) and squashed *Subneumayria*, all of the Mexican Lower Kimeridgian. The Mexican *Idoceras* beds also occur in the South Island, as demonstrated by an isolated find of *Idoceras speighti* Marshall sp. (Arkell, 1953).

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**U** **P** **E** **R** **A** **N** **D** **M** **I** **D** **D** **L** **E** **L** **E** **J** **U** **R** **A** **S** **I** **C**, **U** **N** **D** **E** **T** **A** **D**

Most of the 3000 m. of the Upper and Middle Jurassic at Kawhia Harbour is unfossiliferous. It consists mainly of grey, slightly calcareous mudstones, with concretions at many horizons and scattered plant remains throughout. About the middle of the series there is a band of coarse sandstones, grits and conglomerates, in all 60 m. thick, and similar beds also occur near the base. Below the Ohauan and Heterian faunas just mentioned only one horizon with ammonites is so far known, in the upper Tamaikan or the base of the Heterian at Totara Point: this yielded *Lytoceras* sp. and *Holcophyllloceras* sp. Pelecypods are more numerous but inconclusive (Spath, 1923, pp. 294-7; Henderson & Grange, 1926, p. 38; Marwick, 1953, p. 27). The same *Holcophyllloceras* has been
collected by Mr A. P. Mason at Onewhero, about midway between Kawhia and Auckland; it is much more coarsely ribbed than *H. mediterraneum* and in this respect agrees best with *H. passati* (Boehm), from the Oxfordian of Indonesia. Some 540 m. below this Mr Mason found a new genus which cannot be placed at present.

Callovian is indicated in the South Island by a *Macrocephalites* from near Nugget Point (Marwick, 1935).

The South Island has also produced a distinctively Bathonian faunule of pelecypods on the East Otago coast: *Meleagrinella* cf. *echinata*, with *Tancredia*, *Pleuromya*, etc. (Ongley, 1939, p. 43). This is regarded as Temaikan. At about the same horizon on Totara peninsula 'a faunule that is Himalayan and European Bajocian-Bathonian in its affinities' includes *Kutchirhynchia* and *Cryptorhynchia* (Marwick, 1953, pp. 25-6). The shallow-water sandstones and conglomerates, with granitic pebbles, are undated. In some of the sandstone layers are stumps and trunks of trees in position of growth. They may well be Bajocian or Upper Toarcian.

**TOARCIAN**

On the ocean coast south of the entrance of Kawhia Harbour, near Ururoa Point, a 2 to 4 inch band of calcareous mudstone contains numerous small fossils, including ammonites, brachiopods and corals. The ammonites are species of *Dactylioceras* comparable with some figured from Rotti and Japan (Spath, 1923, p. 301). Below this band are 120 m. of greenish sandstones without fossils.

**PLIENSBACKIAN**

At 120 m. below the *Dactylioceras* bed is the top of a block of strata 180 m. thick, consisting of greywackes crowded with shells of *Pseudaucella marshalli* (Trechmann). There is no intrinsic evidence of the age of these beds, except that they are pre-Toarcian and post-Hettangian, but they are regarded as probably Pliensbachian. They stretch for 30 miles southwards and are also found 120 miles to the east, and again in the South Island, on both sides of the syncline of the Hokonui Hills. Several Pliensbachian (probably Domerian) ammonites are also known from New Zealand, but all unfortunately from unrecorded localities: *Partschiceras partschi* (Stur), *Juraphyllites* aff. *diopsis* (Gem.) and *Lytoceras* cf. *cornucopia* (Y. & B.) (Spath, 1923, pp. 290-3).

**HETTANGIAN**

The lower part of the Lias consists mainly of fine-grained greywackes, argillites and hard claystones, in which no fossils have been obtained from the Kawhia Harbour sections. In the Hokonui Hills, South Island, however, are fossiliferous Hettangian strata overlying sandstone with cannon-ball concretions; they yield *Psiloceras*, ? *Euphylites* (Spath, 1923) and *Ectocentrites* cf. *petersi* Hauer sp. (Arkell, 1953). Above come beds with *Otapiria marshalli* (Trechmann), considered 'Callovian?' by
Trechmann, but from the small vertical distance above the Hettangian ammonites these beds are unlikely to be later than Sinemurian, and they may be Hettangian as in New Caledonia (see p. 451).

**Western Australia**

The Indian Ocean transgressed only a short distance on to the pre-Cambrian shield of Western Australia in the Jurassic, leaving a narrow fringe of shallow-water deposits which has been reduced by denudation and faulting to small isolated patches. Some connecting links may still await discovery, especially beneath Cretaceous and later sediments. One area underlies Broome at depth and crops out near the neck of the promontory of Dampier Land, between Broome and Derby; the deposits here are mainly sandstones, shales and marls, ranging in age from Oxfordian to Tithonian and up into the Cretaceous. The other outcrop forms a narrow strip along the middle part of the west coast, behind Geraldton and Champion Bay; the only marine formations here are limestone and shale of Middle Bajocian age.

Though small, these outcrops are palaeontologically important on account of their isolation. The Oxfordian and Tithonian fossils—ammonites, belemnites and pelecypods—of the northern area show

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close affinity with the faunas of Indonesia and the Himalayas. The Bajocian of the west coast is more peculiar, showing signs of isolation in its pelecypods, ammonites and nautiloids; but its special ammonite genus, *Pseudotoites*, is found also in the Sula Islands, Canada, Alaska and Argentina.

It has been postulated that the marine Jurassic of Western Australia represents the edge of a 'Westralian' geosyncline, joining the Indonesian geosyncline with a southern sea. The evidence for such a geosyncline, however, is derived from the Palaeozoic systems. The Jurassic and later rocks do not give any indication of the nature of the sea that laid them down on its eastern shores: whether it was a narrow geosyncline or gulf as shown on palaeogeographical maps (e.g. in David & Browne, 1950, pp. 474, 696), or a more open sea something like the present one. Geophysical investigations may throw some light on this question. (But see p. 461).

**Dampier Land and the fringe of the Desert Basin**

The blunt peninsula of Dampier Land, which juts into the Indian Ocean between Broome and Derby, consists of horizontal sediments, chiefly sandstones, of Cretaceous and later dates, largely covered with bush-grown sand. Owing to a gentle doming, the valleys of the Frazer and Logue River systems have cut through into Tithonian beds; and borings for water at Broome and south of Derby have proved *Buchia* sandstones of Oxfordian date below sea-level. The succession is as follows (Teichert, 1940, 1942; Brunnschweiler, 1951, 1951a, 1954):

**NEOCOMETAN**

Cross-bedded, ripple-marked, ferruginous sandstone with belemnites and pelecypods, and a Criocraterid indet., at least 60 m. (Overlain by a quartzite of probably Aptian age).

**TITHONIAN**

Pale greenish glauconitic and siliceous marls like the 'Aucellen Kieselmergel' of Misol, with *Kossmatia aff. tenuistriata* Uhlig. *Blemnopsis* cf. *tanganensis* (Futterer), *B. cf. gerardi* (Oppel), *Buchia* cf. *malayomaorica* (Krumbeck) and other pelecypods, also brachiopods and abundant *Calpionella* sp. This is probably Upper Tithonian (Brunnschweiler, 1951, 1951a).

In the Edgar Range, inland, in the Canning Desert, Brunnschweiler (1954) reports a Lower Tithonian fauna of badly-preserved ammonites including *Virgatosphinctes* cf. *communis* Spath.

**? KIMERIDGIAN**

This stage is believed by Dr Brunnschweiler (*in lit.*) to be probably present in the Edgar Range, but near Derby and about the Lower Fitzroy River the marine Tithonian and Oxfordian are separated by brackish-water sandstones and shales (Brunnschweiler, 1951).
OXFORDIAN

The artesian borings at Broome proved about 150 m. of Jurassic sandstones and shales with Buchia subspitiensis (Krumbeck), B. sub-pallasi (Kr.), Belemnopsis cf. alfurica (Boehm) and B. cf. incisa Stolley. These fossils correlate with Oxfordian beds in the East Indies, especially Misol (Teichert, 1940). Similar fossils were found at shallower depth in borings 95 miles to the east, 20 miles south of Derby (Teichert, 1942).

Geraldton and the coastal plain north of Perth

Lacustrine sandstones with Jurassic (probably Lower Jurassic) plants in the southern part underlie the coastal plain for about 300 miles north of Perth. They reach thicknesses of 300-600 m. or more, but diminish on approaching Geraldton. At Mount Hill, 25 miles south-east of Geraldton, similar beds but without fossils are overlain by the highly fossiliferous marine Newmarracarra Limestone, of Middle Bajocian age, which covers considerable areas in the hinterland of Geraldton and Champion Bay. Farther north in places this limestone overlaps the lacustrine sandstones and comes to rest on the crystalline pre-Cambrian basement (Teichert, 1947).

The Newmarracarra Limestone forms flat-topped hills at the back of

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the coastal plain and appears to be faulted down against the ancient rocks to the east; it has a general dip of about half a degree towards the sea. The thickness is observed to vary from about 3.3 m. to 11.4 m. (11 ft. to 38 ft.). A superficial layer of variable thickness is generally converted by lateritic weathering to haematite, and in this the fossils are generally dissolved away, leaving external moulds. Overlying the limestone are up to 13.5 m. of clay with sandstone bands (Playford, in Arkell & Playford, 1954).

The Newmarracarra Limestone in the Bringo district rests on up to 37 m. of yellow and grey shales with lenses of ferruginous sandstones and subordinate conglomerate. The shales yield casts of some of the same marine pelecypods and gastropods, including Trigonia moorei, Ctenostreon pectiniforme, etc. as in the overlying limestone, but no ammonites. Under this are up to 35 m. of unfossiliferous multicoloured sandstones, conglomerates and mudstones, which probably represent a continuation of the lacustrine beds more thickly developed farther south. The basement of pre-Cambrian gneiss has a deeply weathered surface.

The Newmarracarra Limestone is rich in ammonites and other fossils, above all pelecypods, and in some places the fossils are very well preserved. Squeezes taken from moulds in the surface layer in some places suggest Stephanoceratids of the age of the Humphriesianum Zone, but the bulk of the ammonites from the limestone, Sonninids and Stephanoceratids, indicate the Sowerbyi Zone, without definite elements of the Sauzei Zone. The commonest Sonninids are species now assigned to Fontannesia (formerly to Dorsetensia) which bear an extraordinary resemblance in every character, including sutures, to Grammoceras spp. of the Upper Toarcian (Variabilis and Striatulum Subzones); but their age here is put beyond doubt by their association with typical Middle Bajocian Sonninia and Witchellia. The predominant Stephanoceratids belong to the genus Pseudotoites. It is accompanied in the Newmarracarra Limestone by Zemistephanus and Otites, some of which are transitional, in style of ribbing, to Pseudotoites.

Owing to poverty of exposures and hardness of the rock, it has not yet been possible to determine distinct horizons in the Newmarracarra Limestone in the field. The collections made by Mr P. E. Playford in 1952-3, however, have revolutionized our knowledge of the ammonites and for the first time made it possible to interpret the species figured from inadequate material by Moore, Neumayr, Crick, Etheridge, Whitehouse and Spath. (Arkell & Playford, 1954.)

Minilya River

A tiny outcrop of sandstone containing algae and marine pelecypods (Ostrea, Meleagrinella) occurs south of the Minilya River, a short distance south of the Tropic of Capricorn. It is exposed along a fault which throws Cretaceous against Permian (Teichert, 1940a). The occurrence bears witness to marine transgression of the continental margin some 350 miles

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to the north of the Geraldton outcrops. The beds are considered to be Upper Jurassic (Teichert, 1952, p. 131).

**North-West Cape**

A massive development of marine Upper Jurassic and Callovian has been proved to underlie the later surface rocks near North-West Cape. Deep borings made in 1954 in the Cape Range by the West Australian Petroleum Co. proved over 1300 m. of dark grey micaceous siltstone.

Remains of ammonites and belemnites in core samples sent me in 1955 indicate the presence of Berriasian or Tithonian, ? Oxfordian and Lower Callovian assemblages from 4293 to 6536 ft. below surface. (See fig. 72).

**Jurassic freshwater beds of Australia**

Except for these fringes in the west and north-west, Australia was continental during the Jurassic. Almost half the total area of the present continent, however, was covered by a vast system of freshwater lakes ('Lake Walloon'), having a total surface area of perhaps 300,000 square miles. The areas submerged are shown approximately in fig. 71. In

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Queensland the total thickness of freshwater beds assigned to the Jurassic exceeds 2500 m. In Victoria the thickness is about 1200 m.

The chief fossils are plants, belonging to an abundant cosmopolitan flora, of which most of the elements have a range from Lias to Kimeridgian. Some closely resemble Middle Jurassic plants of Yorkshire. In certain places there are remains of fish and, much more rarely, saurian reptiles and shells of *Unio*. (For details see David & Browne, 1950, ch. X, especially palaontology, pp. 465-9.)

A doubtful record of a *Coroniceras*, often mentioned in the literature, has been kindly investigated by Professor F. W. Whitehouse and Dr R. O. Brunnschweiler, who allow me to state that they are fully convinced that it is based on an error. The specimen is in the Queensland Museum. Its matrix and type of preservation are unlike anything known from Australia, and the reports of the Hann expedition (on which the label alleges it to have been found) make no reference to such a find, although all fossil localities are carefully noted. ‘All their collecting grounds for marine fossils have been visited and have yielded only the familiar forms’. (R. O. Brunnschweiler in lit., 1953, quoting Professor Whitehouse, who believes the specimen came from Europe and, judging by the preservation, probably from South Germany.)

The lake beds are assumed to span the whole of the Jurassic system, but correlation is by lithology from place to place, aided by plant-beds, and the only pointer to general correlation is the fact that at Mount Hill, south-east of Geraldton, as mentioned above, the local freshwater beds are overlain by the Middle Bajocian marine Newmarracarra Limestone. Elsewhere, in the east, they pass up conformably into the Cretaceous.

Volcanic activity in Australia is proved by the occurrence of rhyolitic lavas, tuffs and agglomerates, with trachytes, dacites, andesites and andesitic tuffs, interbedded near the bottom of the lake beds in Queensland, and by olivine basalts in the upper part of the series in New South Wales. In Victoria there are felspathic sandstones which are regarded as tuffaceous. (David & Browne, 1950, p. 473.)
PART VI

NORTH-EASTERN EUROPE AND NORTHERN ASIA
CHAPTER 19

THE BALTIC REGION AND POLAND

THE SOUTHERN BALTIC REGION

Since the Caledonian orogeny the depression partly occupied now by the southern Baltic Sea has undergone relatively little geological change. It has remained essentially a broad, shallow depression fringing the southern part of the ancient Baltic or Fenno-Scandian shield and collecting sediments (and, in the Pleistocene, glacial debris) resulting from almost continuous erosion of the crystalline rocks of the shield. At times of high sea-level, during Jurassic and Cretaceous transgressions, the sea flooded in from the west. At its periods of maximum extension sea covered all the stable shelf of north Poland and the Russian platform and connected NW. Europe with the central Tethys by way of the Caspian basin. At times of relative elevation of the shield the marginal depression became a collecting ground of river debris. Deltaic sandstones and shales with plant-remains and even coal seams were laid down at these times. The deltaic deposits resemble those which in the Middle Jurassic covered Yorkshire, but in the Baltic area they have a much greater stratigraphical range, reflecting the greater proximity of the shield.

The only place where Mesozoic rocks are seen at the surface in direct contact with the shield is Scania, the southern peninsula of Sweden (Nathorst, 1910; Troedsson, 1951). Here the Trias with Rhaetic Beds is followed by Lower Lias, both containing coal measures and marine intercalations. Most of the coal is Rhaetic, but there are also *Pteria contorta* beds. The Hettangian is of mixed marine, brackish and freshwater facies. During the Lower Sinemurian and Lower Pliensbachian there were major marine periods with ammonite faunas, but the Upper Sinemurian is missing. A similar succession occurs on the Island of Bornholm, but here both the Rhaetic and the marine Lower Sinemurian are absent. The Pliensbachian marine phase is well developed, however, and ends with ammonites of the Spinatum Zone. The Lias of Bornholm contains coal seams and insects. In both Scania and Bornholm it is overlain by sandstones believed by some to be Wealden.

In Pomerania the earliest marine Lias is Lower Pliensbachian (Ibex Zone), but borings indicate a south-easterly and easterly extension of the non-marine sandstone and shale facies with plants under most of the basin of the Vistula, through northern and central Poland, to the borders of the Carpathians near Cracow (fig. 74). At Jastrow these beds, underlying marine Middle Jurassic, are 402 m. thick, and as far east as Heilsberg the thickness is still 94 m. (Brinkmann, 1927; Höhne, 1933, p. 73). The facies ('Baltic') is reminiscent of the Gresten facies of the Alps and

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is of the general type characteristic of the Lower Lias over immense areas in the Caucasus and Elburz Mountains.

Middle and Upper Jurassic rocks are seen south of the Baltic in scattered inliers in Pomerania (near the mouth of the Oder) and in Lithuania and Latvia, but for the most part the area is covered by a thick mantle of glacial drifts. The Pleistocene ice-sheet in its southerly advance crossed and ploughed deep into the Mesozoic sediments fringing the shield, carrying erratics south from Bornholm and the Baltic sea bed (with the

Kattegat and Skagerak) and leaving them, mingled with crystalline debris from the shield, strewn over the Cretaceous and Tertiary outcrops of Jutland, the Danish islands and the north-European plain. Some displaced masses, even of soft clays, are so large that they have been mistaken for outcrops in situ; for instance at Lukow, SE. of Warsaw, a brickworks has been sustained for many years by a cake of Callovian clays about 4 m. thick and covering at least a square kilometre, which until recently was taken to be a normal outcrop, but which is now known from a boring to rest on a succession of Pleistocene and Tertiary beds 120 m. thick, which repose normally on the Cretaceous (Makowski, 1952).

Much information about the distribution of destroyed or buried Jurassic

Fig. 74.—Sketch-map showing Jurassic outcrops and some important borings in the Baltic region and Polish plain. Some buried boundary lines have been added.

http://jurassic.ru/
rocks has been obtained from the smaller erratics. The principal studies are those of Fiebelkorn (1893), Frebold (1928) and Richter (1931a) for north Germany, and Skeat & Madsen (1898) for Denmark. The fauna of the Middle Jurassic erratics has been monographed by Fräulein Stoll (1934). From these and other studies, tied in with information from a boring at Kammin at the mouth of the Oder and exiguous occurrences near by, it is deduced that no fossiliferous marine Middle Bajocian or Lower Bajocian except the lowest (Hudlestonia, of the basal Opalinum Zone) occurs in the Baltic area. Any beds of this age that may be present are developed in deltaic or 'estuarine' facies as in Yorkshire; but even the Scarborough Limestone with its Stephanoceras marine episode is unrepresented by fossils. The Upper Bajocian is well represented by Subfurcatum, Garantiana and Parkinsoni Zone ammonites; the Bathonian is condensed and equivocal as in so many other places. The Callovian and Oxfordian are condensed but more or less complete in outcrops in the banks of the River Windau at Popilani and near the coast at Memel (both in Lithuania). Uppermost Oxfordian, Kimeridgian and Lower Volgian all crop out and are well exposed in large quarries at Zarnglaff in Pomerania (fig. 74). Lower Kimeridgian shales yielded Amoeboceras, Enosphinctes and Aulacostephanus, and Callovian beds Grossovuria, Peltoceras and Kosmoceras, in the Heilsberg boring in East Prussia (Krause, 1909, pls.).

Deep borings in Denmark (Gregersen & Sorgenfrei, 1951) have shown that Jurassic rocks are absent under the islands of Zealand and Funen and the 'neck' of the Danish peninsula. In this region and in a boring (Höllviken) at the extreme south-western tip of Sweden, ? Wealden Beds, or in Funen Cenomanian, rest directly on the Trias (Rhaetic or Keuper). Thus there is here a transverse swell crossing the Baltic trough and joining up with the 'high' previously known to exist under the coastal region of Lower Saxony and northern Holland ('Cimbria'), which in turn is prolonged south-eastwards as 'Pompeckj’s Swell'. Towards the north, under central and northern Jutland, a more or less complete Jurassic succession comes in underground. At Gassum boring 315 m. of dark grey mudstones and shales yielded ammonites from Psiloceras and Schlotheimia at the base to Amaltheus and Pleuroceras at the top, followed by Upper Jurassic. At Haldagar boring, farther north, the Lias is succeeded by 313 m. of sandstones and shale with lignite, resembling the Deltaic ('Estuarine') Series of Yorkshire and Scotland, and above this follow clays in which Upper Oxfordian was recognized, and finally more sandstones and shales with plant remains, from the top of which were obtained Pavlovia and Buchia fischeri (Upper Kimeridgian or Lower Portlandian).

These Jutland Jurassics seem to be a direct continuation of those of northern Britain and make it unlikely that the two basins were separated at the time of deposition by a land barrier joining 'Cimbria' to southern Norway, as has been shown on palaeogeographical maps. Cimbria seems to
have been a small island or else was joined to southern Sweden. The Jurassic erratics of Jutland presumably came out of the Skagerak and northern Kattegat.

**Undated**

The highest beds exposed, in the large Schwanteshagen quarry, near Zarnglaff, consist of 7 or 8 m. of limestones and marls with a partly brackish fauna of small pelecypods. They have still to be worked out, but are recorded as ‘Avicula, Corbula, Corbicella, Leda and Cyrena’. At the top is a 0.6 m. band of bluish-green sandstone full of ‘Cyrena’

![Sketch-map to show positions of some important borings in Denmark and Scania (black circles) and the Lias and Rhaetic Beds in Scania and Bornholm.](http://jurassic.ru/)

(Richter, 1931, p. 16.) Below come 3.6 m. of glauconitic marls and in part sandy limestones, likewise undated.

**Lower Volgian**

The rest (17.5 m.) of the Schwanteshagen quarry is worked in a series of limestones and marls, in part glauconitic, containing oysters, serpulids, *Buchia pallasi* (Keyserling) and many other shells. The highest bed is full of *Trigonia hauchecornei* Schmidt (1905, pls. 7, 8). In these beds occur *Zaraiskites (= ‘Provirgatites’) pommerania* (Arkell) (1926, Proc. Geol. Assoc., vol. xlvi, p. 340, pl. 26, fig. 1; and Schmidt, 1905, pl. x, fig. 14) and *Z. quenstedti* auct. (Dohm, 1925, pl. iii, fig. 3), which are
closely allied to 'varieties' of the Russian Z. scythicus (Visch.) (e.g. Michalski, 1890, pl. xiii, fig. 10). (Description of the beds and fauna in Richter, 1931, pp. 15-16 and Profil B; many figures in Schmidt, 1905.)

UPPER AND MIDDLE KIMERIDGIAN

No Pavlovids are known from Pomerania, either in situ or as erratics. Between the Schwanteshagen and Zarnglaff quarries, however, there is a gap, occupied by unexposed strata believed to be 20-30 m. thick. That the middle zones of the Kimeridge Clay are there represented is probable from the occurrence of Subplanites in the drift (e.g. Fiebelkorn, 1893, pp. 425, 427, pl. xix). Some fragments figured from the drift of Denmark (Skeat & Madsen, 1898, pl. v, figs. 2, 3) moreover, appear to be Pectinatites (cf. Buckman, Type Ammonites, pls. ccclxxxi, dclxiv). In the Danish borings (Haldager), sandstones and shales with carbonaceous seams are believed to represent the Kimeridgian and are followed by shale and clay with Pavlovia and Buchia fischeri (Gregersen & Sorgenfrei, 1951).

LOWER KIMERIDGIAN

Zarnglaff quarry gives a section from the Pseudomutabilis Zone down into the Upper Oxfordian. The Pseudomutabilis Zone is about 7 m. thick and consists of marls, with at the top a bed full of crushed Perisphinctes compresso-dorsatus Fiebelkorn (1893, pl. xxi, fig. 2), associated with Exogyra virgula, though the main virgula level is lower down in the zone. This ammonite has nothing to do with 'Provirgatites' (with which it has been confused), but belongs to some much earlier stock such as Progeronia: probably it is closely related to P. digitatus Schneid (1914, pl. iii, fig. 1) from the Pseudomutabilis Zone of Franconia. At the base of the zone at Zarnglaff is a bed of dolomitic and glauconitic sandstone, which rests with a basal pebble bed on an eroded and bored surface of the zone below (Richter, 1931, p. 13, and Profil A). The ammonites are Physodoceras liparum (Oppel), Aulacostephanus pseudomutabilis (de Loriol) (Schmidt, 1905, pl. x, fig. 11) and other species of the eudoxus-subundorae group (Schmidt, 1905, pl. x, figs. 10, 12), and Progeronia or Ataxioceras sp. (Dohm, 1925, pl. i, fig. 2).

The Aulacostephanus beds rest on a bored, eroded surface of a 1 to 1.5 m. coral and Nerinea limestone containing Aspidoceras iphicerum and large Rasenids (Involuticeras involutum Quenst. sp., Dohm, 1925, p. 35, pl. i, figs. 1, 3, 4, 6). This rests on 1.5 m. of oolitic limestone with other similar large Rasenids (R. trimera Oppel sp. Dohm, 1925, p. 30 and many figures; and R. electra Dohm, p. 29, pl. ii, figs. 1-2). These species belong to a group abundant in the middle and upper parts of the Tenuilobatus Zone of Franconia, whence many species have been figured by Schneid (1939, Palaeontographica lxxxix A, pp. 137 ff.), the more coarsely-ribbed as Rasenia, the smoother species as Ringsteadia. They are, however, not contemporary with the true Ringsteadiae of Zarnglaff and southern.
England. (They should for the most part be assigned to the genus *Involuticeras*: see p. 115).

The lowest Kimeridgian bed at Zarnglaff unfortunately yields no ammonites. It is a 2-3 m. marl band full of gastropods and many other fossils, including the large ‘*Pterocera* oceani’ of the French Lower Kimeridgian. Elsewhere in the Baltic region, however, characteristic ammonites of the English basal Kimeridgian zones (*Cymodoce* & *Baylei*) occur at widely separated places. At Memel in Lithuania *Amoeboceras cricki* (Salfeld) was found in a micaceous sandstone underlying drift (Frebold, 1926), and in Denmark a large *Rasenia* cf. *cymodoce* (d’Orb.), with smooth outer whorl, was found in an erratic (Skeat & Madsen, 1898, pl. vii, misidentified).

**UPPER OXFORDIAN (Bimammatum Zone)**

The top bed of the Oxfordian, under the ‘*Pterocera*’ marl, consists of 2·5-3·5 m. of limestone yielding *Ringsteadia pseudocordata* Dohm non Blake & Hudleston, *R. frequens* Salfeld, *R. aff. marstonensis* Salfeld, *R. (Balticeras) pommerania* Dohm, *R. (B.) ramlowi* Dohm, and large evolute Perisphinctids with coarse-ribbed outer whorls: *Pomerania robusta* (Dohm), *P. schmidti* (Dohm), *P. latecosta* (Dohm) and *P. dohmi* Arkell (see Arkell, Mon. Am. Engl. Corallian Beds, p. lxiv). The inner whorls of *Pomerania* being unknown, it seems advisable to keep them separate from *Decipia*, but in any case the genus is very close to *Decipia* and has nothing in common with *Pictonia*. (Cf. *P. westburyensis* Arkell, loc. cit., Monogr., p. 368-9, fig. 131). This is the true Pseudocordata Zone of England. Underneath come another 4 m. of limestones yielding *Ringsteadia (Vineta) jaekeli* (Dohm), which is closely allied to *R. (V.) evoluta* Salfeld, also from the English Pseudocordata Zone. At the base of this zone in the Zarnglaff quarry there is a conglomeratic bed.

The lowest 5·4 m. of varied beds at Zarnglaff contain *Amoeboceras alternans* auct. which, to judge by the figure in Schmidt, 1905 (pl. x, fig. 8), is one of the *Amoeboceras* of the drift in East Anglia (*recte A. ovale* (Quenst.—Salfeld)), here, at Zarnglaff, placed in situ beneath the Pseudocordata Zone, as inferred for England in the absence of sections.

This condensed ammonite succession in the two quarries at Zarnglaff and Schwanteshagen is so important for European correlation that it is summarized in the following table. The revised identifications are based largely on my own examination of the ammonites in 1935 in the University of Greifswald, through the kindness of Dr Konrad Richter. (See Richter, 1931, p. 24, pl. ii, for general photo of the collection.)

**UPPER OXFORDIAN (Transversarium Zone)**

Lower beds down to Callovian at Heilsberg, south of Königsberg, and to Lower Bathonian at Hohensalza near Posen, have been proved in borings (Brinkmann, 1927, pp. 71, 74, with refs.). For exposed profiles of the rest of the Oxfordian and the Callovian, however, the scene shifts to

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Popilani (Papile) in Lithuania, where sections are provided by steep banks of the River Windau. These are to some extent duplicated by inferior sections at Niegranden in Latvia, also on the Windau.

The highest beds exposed at Popilani consist of 3·25 m. of dark grey, brown-weathering sandstone, ironshot sandstone, and clay-ironstone, interbedded with dark micaceous clays (Brinkmann, 1927, pp. 57-8).

Table 20.—The Upper Jurassic Sequence in Pomerania

<table>
<thead>
<tr>
<th>Thicknesses in metres</th>
<th>Strata and Ammonites</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-8</td>
<td>Brackish beds</td>
<td>? Purbeckian</td>
</tr>
<tr>
<td></td>
<td></td>
<td>? Upper Portlandian</td>
</tr>
<tr>
<td>17·5</td>
<td>Limestones and marls with Zaraiskites pomerania (Arkell) and Z. spp., also Buchia pallata</td>
<td>Lower Volgian</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(= ? Lower Portlandian)</td>
</tr>
<tr>
<td>20-30</td>
<td>Unexposed beds. From erratics Pectinatites spp. and Subplanites spp.</td>
<td>Pectinatus Zone</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Subplanites Zones</td>
</tr>
<tr>
<td>7</td>
<td>Marls with basal sandstone and conglomerate. Aulacostephanus spp. etc.</td>
<td>Pseudomutabilis Zone</td>
</tr>
<tr>
<td>2-2·5</td>
<td>Coralline, Nerinean and oolitic limestones with large, coarse-ribbed Raseniae of the trimera group 'Pterocera' marl</td>
<td>Tenuilobatus Zone</td>
</tr>
<tr>
<td>2·3</td>
<td>Rosteadia and Pomerania beds (the so-called ‘Pictonia baylei Zone’) ‘Jaekeli Zone’: Rosteadia jaekeli Dohm</td>
<td></td>
</tr>
<tr>
<td>2·5-3·5</td>
<td>‘Alternans Zone’: beds with Amoeboceras (Prionodoceras) marchense Spath</td>
<td>Pseudocordata Zone</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Decipsiens Zone</td>
</tr>
<tr>
<td>5·4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The splendidly preserved ammonites have been monographed by Boden (1911) under the title ‘Lower Oxfordian’, but his admirable plates show a fauna of Cardioceratids and Perisphinctids of the basal Upper Oxfordian with much in common with the Elsworth Rock of Cambridgeshire. Cardioceras (Subvertebriceras) densilicatum Boden (pl. i, fig. 14), C. (S.) cf. zenaidae Ilovaisky (pl. i, fig. 13), C. (Maltoniceras) schellwieni Boden (pl. ii, fig. 3), C. (M.) bodeni Maire (pl. i, figs. 6, 7) are characteristic of the Elsworth Rock and the lower part of the Plicatilis Zone of the English south-Midland counties. The Perisphinctids also agree with this dating: the large fragment of an Arispinctes or Kranaothoriptes aff. indogermanus (pl. iii, fig. 1), Kranaothoriptes windauensis (Boden) (pl. iv, figs. 2, 3, 4, 5),

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Dichotomosphinctes spp. (pl. iv, fig. 1, pl. iii, fig. 2) and an Arispinctes nucleus (pl. iii, fig. 8) all indicate the Plicatilis Zone.

On the other hand a minority of Boden's figures show forms which, by themselves, would indicate an earlier date (Cordatum Zone): the Pro-perisphinctes (pl. iii, figs. 4, 5), Prososphinctes (pl. iii, figs. 6, 7) and a single fragment of Cardioceras costicardia Buckman (pl. i, fig. 16). Possibly the explanation is that the material was derived from museums, not collected in situ. This should not at this stage be assumed, however.

Beneath these irony ammonite beds are 7 m. of black, sandy, micaceous clay with some of the same ammonites in the upper half (Brinkmann, 1927, p. 57) and, in the middle, two layers of septaria which contain nests of iron-shot oolite with abundant Cardioceras (Plasmatoceras) tenuicostatum Nik. and C. (P.) popilaniense Boden. These small, very finely ribbed Cardioceratids occur in similar concentration at the base of the Plicatilis Zone at Heersum near Hanover and in the Arngrove Stone near Oxford. Extreme difficulty of specific determination, however, detracts from their value for wide correlation (Arkell, 1941, Mon. Am. Engl. Corallian Beds, p. 230). With them at Popilani occurs Euaspidoceras perarnatum Sow. sp. (Pakuckas, 1933, p. 478). Haldager boring in Denmark yielded Trigonia hudlestoni Lycett, of the early-Upper Oxfordian, in a series of clays and claystones.

LOWER OXFORDIAN

Some ammonites which seem to belong to the upper part of the Lower Oxfordian are figured by Boden with the Plicatilis Zone assemblage, as mentioned above. According to Brinkmann's profile (1927, p. 57) there is no other likely bed for these to have come from; for the 3 m. of sandy black micaceous clay under the Cardioceras tenuicostatum nodules rests directly on the Lamberti Bed, with Kosmoceras. Similarly Krenkel (1915) figured a few ammonites which could belong to the lower part of the Lower Oxfordian among the Callovian fauna: namely Pavloviceras sp. (pl. xxii, figs. 21-24) and a Cardioceras (Scarburgiceras) sp. (pl. xxii, fig. 14). Peltoceras arduennense (d'Orb.) is recorded from borings at Hohensalza and Heilsberg, and from the Pomeranian drift.

UPPER AND MIDDLE CALLOVIAN

In the banks of the Windau at Popilani the Middle and Upper Callovian, comprising the Coronatum, Athleta and Lamberti Zones, is condensed into 7·65 m. of strata, consisting mainly of sandstones and sand. Well-preserved ammonites occur at a number of horizons and have been monographed by Siemiradzki (1890, 1890a), Krenkel (1915) and Pakuckas (1932, 1933). The stratigraphy and the Kosmoceratids have been revised by Brinkmann (1927, 1929).

At the top is the Lamberti Zone, a bed 0·15 m. thick, containing abundant Quenstedtoceras henrici Douville (Krenkel, 1915, pl. xxii, figs. 16-20) (but not, apparently, Q. lamberti) and rare Kosmoceras cf. spinosum.
BALTIC REGION AND POLAND

Although the Lower Callovian sea did not reach the eastern Baltic, its presence in the western Baltic is attested by typical Macrocephalitids in the drift of Pomerania (Stoll, 1934, p. 33, pi. iii, figs. 10, 19, 20) and Jutland (Skeat & Madsen, 1898, pi. i, fig. 10). Proplanulites teisseyrei and Kepplerites also occur in the Pomeranian drift (Brinkmann, 1924, p. 491; Stoll, 1934, p. 33).

The earliest Kosmoceratids figured are Gulielmites (Jason group) and Gulielmiceras (gulielmi group) (Krenkel, 1915, pls. xix, xx), which are not older than the Jason Zone (i.e. lower Anceps Zone). Beneath are exposed a few metres of sands, containing only Meleagrinella cf. echinata; but as this species also occurs nearly to the top of the ammonite-bearing beds, there is no reason for suspecting any beds older than Middle Callovian. Borings indicate that similar sands go down for some 9 m. and rest on the Palaeozoic (Zechstein) conformably. The profiles at Niegranden and Memel are similar.

LOWER CALLOVIAN

Although the Lower Callovian sea did not reach the eastern Baltic, its presence in the western Baltic is attested by typical Macrocephalitids in the drift of Pomerania (Stoll, 1934, p. 33, pi. iii, figs. 10, 19, 20) and Jutland (Skeat & Madsen, 1898, pi. i, fig. 10). Proplanulites teisseyrei Tornquist and Kepplerites also occur in the Pomeranian drift (Brinkmann, 1924, p. 491; Stoll, 1934, p. 33).

BATHONIAN

In the Hohensalza boring (Brinkmann, 1927, p. 74) there is a great thickness (147 m.) of dark clay with beds of dolomite, clay-ironstone, limestone and sandstone, assigned to the Bathonian from the occurrence of Parkinsonia ‘ferruginea’; but it seems likely that the Bajocian is represented also. Lower Bathonian is certainly represented in the Pomeranian drift, as shown by the occurrence of Parkinsonia wurttembergica (Oppel) and forms of Oxycerites and Oecotraustes (Stoll, 1934, p. 32, pl. iii, figs. 7, 8). As in Yorkshire, probably the Bathonian is represented by part of the thick deltaic sandstones and shales which exceed 300 m. thickness in the Haldager boring, Denmark.

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BALTIC REGION AND POLAND

UPPER BAJOCIAN

The Pomeranian drift yields a full suite of *Strenoceras*, *Garantiana*, *Spiroceras*, *Parkinsonia* and *Bigotites* (Stoll, 1934), indicating an extension to the western Baltic of the full sequence in the Hanover-Brunswick area. (Palaeogeographical treatment in Brinkmann, 1924.)

LOWER AND MIDDLE BAJOCIAN

Two small indeterminable Stephanoceratids are known from drift at Rostock and near Berlin (Brinkmann, 1924, p. 486), but now that Bentz has established that some Stephanoceratids range up into the Subfurcatus Zone in NW. Germany, these cannot be regarded as proof of the extension of the Middle Bajocian sea. The only other zone represented among the erratics is the basal Opalinum Zone with *Hudlestonia affinis* (Seebach) in an ironstone oolite. This rock is found only west of the Oder. A *Leioceras* of about Opalinum Zone date has been figured from the drift of Jutland (Skeat & Madsen, 1898, pi. i, fig. 8). Under Denmark the 313 m. of deltaic series presumably represents largely Bajocian sedimentation.

TOARCIAN

In the west, in Jutland, Schleswig-Holstein and Mecklenburg, glacial drift has yielded *Dactylioceras*, *Peronoceras* (Skeat & Madsen, 1898, pl. i, fig. 7) and *Hildoceras*, in addition to later zonal forms some of which are found farther east. In the Danish borings, however, no Toarcian ammonites appeared. In Pomerania only Upper Toarcian is found, and of that only the zones of *Harpoceras elegans* and *Grammoceras striatum* are represented (Frebold, 1928, p. 122).

PLIENSCHACHIAN

The Spinatum Zone is the latest Jurassic zone preserved in situ on the isle of Bornholm. Fragments of *Pleuroceras* have been figured from there (Höhne, 1933, pl. xiv) and both *Pleuroceras* spp. and the contemporary *Pseudoamaltheus* are widespread in the drift of Denmark, Mecklenburg and Pomerania (Frebold, 1928, p. 120). The latter has been misidentified as *Amaltheus margaritatus*. *A. margaritatus* and *Pleuroceras spinatum* and also Lower Pliensbachian ammonites were recognised in the Gassum boring in Denmark by Frebold (in Gregersen & Sorgenfrei, 1951). The Lower Pliensbachian was a time of marine transgression. Ammonites of the Jamesoni and Ibex Zones occur in situ in Bornholm and Scania, as shown by *Phricodoceras bornholmiense* (Höhne) and various *Acanthopleuroceras* (valdani-maugenesti group) of the Ibex Zone, and *Tragophylloceras numismale* (Quenst.) figured from Bornholm (Höhne, 1933, pls. xii-xiv). Ammonites of the Ibex Zone and in addition *Androgynoceras capricornus* of the Davoei Zone are widespread in the drifts of Pomerania and Mecklenburg; and *Polymorphites polymorphus* (Quenst.) of the Jamesoni Zone occurs in Denmark. In Scania the Lower
Pliensbachian is 115 m. thick, comprising marine clays with beds of ironshot oolite, the Katsløsa formation (Upper Höganas Series).

**Sinemurian**

Both in Scania and in Bornholm there is a hiatus where the Upper Sinemurian should be (Troedsson, 1951), and no ammonites representing this interval have been found in the drifts to the south or south-west. It is therefore inferred that the sea retreated before the Lower Pliensbachian transgression.

The Lower Sinemurian is represented in Scania by the Döshult formation (Middle Höganas Series). It comprises 70-170 m. of marine sandstones, clays and marls, containing an ammonite bed with Arietitidae (some figured by Lundgren, 1881, pls. ii, iii—Euagassiceras sp.—and by Troedsson, 1951, p. 241, pl. xxiv, fig. 11). These beds and the immediately overlying Lower Pliensbachian contain a rich fauna of other mollusca and brachiopoda, also monographed by Troedsson (1951). Marine beds are not known on this horizon in Bornholm, where they seem to be represented by the estuarine or lacustrine facies, but the characteristic Arietitids and other fossils occur in the drift of Denmark and Schleswig-Holstein, to the west and south-west.

**Hettangian**

In Scania the Hettangian is represented by the Helsingborg formation (Lower Höganas Series), consisting of 200 m. of rhythmically deposited sandstones, clays and coal seams, with some calcareous and ferruginous beds. It is dated by its position between Lower Sinemurian ammonite beds and fossiliferous, partly marine, Rhaetic beds and by containing in the lower part a marine phase with Cardinia beds (Troedsson, 1951). The flora is characterized by Thaumatopteris. The same flora and the Cardinia beds also occur in Bornholm. In the Gassum boring in Denmark Schlotheimia and Psiloceras were recognized by Frebold (in Gregersen & Sorgenfrei, 1951) in the bottom of the 315 m. of dark grey marine mudstones and shales that represent the Lower and Middle Lias.

**Poland**

Towards the southern edge of the Vistula basin, between Warsaw and the western Carpathians, the buried Jurassic rocks gradually come to the surface. The first to appear are the Portlandian-Volgian beds, which are exposed in the valley of the Vistula at Wroclawek and farther south in the tributary valley of the River Pilica at Tomaszow (respectively 80 miles WNW. and 65 miles SW. of Warsaw). Farther south these higher stages are overstepped by the Cretaceous, but the remaining Upper and Middle Jurassic rocks, from the Kimeridgian downwards, make extensive outcrops in a broad syncline between the ancient massif of the Sudetes Mountains on the west and the Lysa Gora on the east: that is, between the valleys of the Oder and the Vistula. On the south the
basin is bounded by the abrupt front of the Carpathian ranges south of Cracow.

The principal outcrop forms the Jasna Gora cuesta running from Cracow north-westwards past Czestochowa (Czenstochau) to Wielun and beyond, with the last outcrops at Kalisz. The Jurassic limestone escarpment faces south-west towards the Oder valley and the Sudetes massif, against which and its easterly extension at depth the formations were no doubt deposited. This is shown, despite the erosion of the Oder, by the fact that in the cuesta the Bajocian, Bathonian and Callovian stages when traced southwards in turn pass laterally from clays and marls into sands and sandstones with conglomerates and successively wedge out, until a condensed Lamberti Zone comes to rest on the Palaeozoics in places near Cracow. The cuesta is dissected by the River Warthe, in the steep valleys of which occur the classic exposures.

On the opposite side of the basin there are extensive outcrops on the SW. flank of the Lysa Gora hills. Here the lowest Jurassic stage present at the surface is the Callovian (Swidzinski, 1931). Beyond the Lysa Gora and the upper Vistula the Jurassic extends, mainly buried beneath Cretaceous and later rocks, approximately to the heavy broken line shown in fig. 74 (after Sujkowski, 1946). It feathers out underground against Devonian and Carboniferous rocks, which in the south surround a levelled Archaean massif under the Podolian platform. Some attempt to reconstruct the successive overlaps along this buried line, between the Pripet and the Niemen, has been made by Halicki (1935) from the distribution of erratics in the drift.

In the deep valley of the River Dneister, at Nizniov, at the point where the Jurassic wedges out against the Podolian platform on the east and the Carpathian front on the south, is a remarkable deposit, the Nizniov Limestone, about 20 m. thick, sandwiched between Devonian below and Cenomanian above. The only cephalopod known is a Nautilid of Tithonian or Berriasian type, but on the strength of an extensive fauna of gastropods and pelecypods the limestone is dated to the Upper Kimeridgian or the Portlandian-Purbeckian or both (Alth, 1882).

The main outcrops of the Jasna Gora cuesta and around Cracow and SW. of the Lysa Gora are formed by an immense development of Upper Oxfordian and Lower Kimeridgian limestones, together about 700 m. thick. The facies, both lithological and palaeontological, is the same as in the Swabian Alb. The chief landscape-former is some 400 m. of limestone, almost devoid of ammonites but zoned by brachiopods (Wisniewska, 1932; Rozycki, 1948). The upper half is largely coralline and belongs to the Tenuilobatus Zone. The lower half, belonging to the Bimammatum Zone, is on the horizon of the Swabian-Franconian Werkkalk but resembles the later (Kimeridgian) Schwammkalk, Felsenkalk, and Plattenkalk. Huge lenticular masses of unbedded Felsenkalk, composed largely of sponge remains, have resisted compaction and weathering more successfully than the surrounding flaggy limestones (Plattenkalk)
and stand up in the landscape as hills and crags. The bedded limestones bend over and under these masses, an effect of compaction (Dzulynski, 1952).

A striking contrast is provided by the Bathonian and Upper Bajocian, which are developed as clays altogether at least 110 m. thick, and the underlying Middle and Lower Bajocian sandstones, all of which correspond closely with NW. Germany. The intervening Callovian is more cosmopolitan in fauna and facies, but its palaeontological links are also mainly with the west and north. The Lower Volgian element (Scythicus Zone) has no parallel in the west or south-west but shows open sea connexion with Pomerania on the one hand and Russia on the other, while the final Jurassic beds, above the Scythicus Zone, and the overlying ? Wealden, revert to NW. Germany, providing an almost exact repetition of the Einbeckhausen Plattenkalk and Serpulite of the Hanover district.

[Marine Neocomian. Hils Clays and Hils Conglomerate.]

[? Wealden]


PURBEKIAN

'Niveau IV, Couche L' (Lewinski, 1923). 2 m. Yellowish flaggy serpulitic limestone, crowded with Serpula coacervata Blum. and numerous Corbulae; also Cypris purbeckensis. Correlates with the Serpulite of NW. Germany, which is Middle Purbeck.

PURBEKIAN-UPPER PORTLANDIAN?

'Niveau III, Couches I, J, K'. More than 28 m. Flaggy limestones, slightly marly or chalky in upper part, which contains only Cypris purbeckensis and Cypridea. In the lower part a few small marine shells: Anomia, Ostrea, Nucula, Cucullaea, Anisocardia, Corbula (3 spp.), with Turritella minuta Roem. and 'Natica'. Suggests the Münder Marls and Plattenkalk of Einbeckhausen.

LOWER VOLGIAN (LOWER PORTLANDIAN)

'Niveau II, Couches G, H'. Zone of Zaraiskites alexandrae Lewinski. Z. alexandrae, Z. zaraiskensis (Mich.) and 7 pelecypod species common to the Scythicus Zone, but 30 other special species, also Glaucolithites aff. gorei (Salfeld) (= Perisphinctes aff. pellati Lewinski, 1923, pl. vii, fig. 9, which name is an objective synonym), and other Perisphinctids of doubtful generic position: P. quadriscissus Lewinski (pl. ix, figs. 1, 2), Lydistratites? sp. (pl. viii, fig. 1), and Ataxioceres-like fragments (pl. vii, fig. 8) compared by Lewinski to A. lothari (Oppel), but more likely some much later stock, perhaps derived from some such form as P. dubius Schneid of the Ciliata Zone at the top of the highest Neuburg Beds (1914, 1916).
A noteworthy fossil in this zone is *Trigonia hauchecornei* Schmidt, which is characteristic of the top of the Lower Volgian of Pomerania.

‘Niveau I, Couches A-F’. Zone of *Zaraiskites scythicus*. 20-25 m. Grey micaceous clays, shales and marls, with some thin sandy beds. Chiefly at two levels near base and at top are 55 species of fossils including lumachelles of *Oxytoma*, also the vertebrates *Ophthalmosaurus* and *Cimoliosaurus*, with *Buchia pallasii* Keys. and other spp., *Zaraiskites scythicus*, *Z. aff. quenstedti*, *Z. aff. pilicensis*, *Z. cf. tschernyschovi* of Russian authors, plus *Z. sauvegei* Lewinski. Clearly these beds correlate with the Lower Volgian of both Pomerania and the Ural and Ilek Rivers, from which latter similar ammonites are figured (see p. 494). Further, a fragment of *Z. scythicus* figured by Lewinski (1923, pl. ix, fig. 4) is almost identical with one figured from the Gorei Zone of Dorset by Buckman (1926, Type Am. pl. DCLXXV); and Lewinski (pl. vii, fig. 9) figured from the Alexandrae Subzone a fragment which he rightly likened to the zonal index fossil, *G. gorei* (Salfeld).

The Scythicus Subzone has also been described about 20 km. south of Tomaszow, with *Buchia* and some of the same ammonites (Passendorfer 1928).

**KIMERIDGIAN** (up to 370 m.)

In the neighbourhood of Tomaszow the junction of the Lower Volgian with the underlying Kimeridgian is not exposed, and information from borings is insufficient to establish the extent of the hiatus between the two stages. *No Hybonoticeras* seems to have been recorded from Poland, but Premik (1926, p. 374) believes on the evidence of some other ammonites (not figured) that the Beckeri Zone is present in limestone facies at Biala.

The Pseudomutabilis Zone is probably represented by marls and clays with lumachelles of *Exogyra virgula* and *Gereillia* which immediately underlie transgressive Cretaceous sandstones in outcrops SW. of the Lysa Gora and elsewhere; from them the only ammonite identified seems to be *Aspidoceras uhlandi* (Oppel) (Siemiradzki, 1889, p. 53; Swidzinski, 1931, p. 860).

It is to the Tenuilobatus Zone, however, that the bulk of the Polish Kimeridgian belongs. Separation from the Upper Oxfordian is difficult, owing to the great thickness and the paucity of ammonites. In the outcrops SW. of the Lysa Gora *Involuticeras* sp., *Aspidoceras cf. inflatum* (Quenst.) and *Prorasenia stephanoides* (Oppel) are recorded from the highest 150 m., but below this there are a further 200 m. of limestones without ammonites, assigned to the 'Astartien' (Swidzinski, 1931, p. 854) on their gastropod fauna and on the occurrence of *Septaliphoria pinguis* (Roemer) (Rozycki, 1948, p. 26). These beds are largely in coralline facies or contain *Diceras*, but they comprise a wide variety of limestones. The formation is thinner and the facies more favourable to ammonites farther north. In marly limestones near Kalisz is an extensive ammonite
fauna of the Tenuilobatus Zone of the Swabian and Franconian Jura, characterized above all by a wealth of Ataxioceratids and Aspidoceratids, with Prorasenia, Nebrodites? and other genera (Premik, 1926).

**UPPER OXFORDIAN**

**Bimammatum Zone**, c. 200 m. To this zone apparently belong the 200 m. of bedded (Plattenkalk) limestones with large and small lenticles of unbedded sponge-reef (Felsenkalk) limestones which Polish geologists classify as 'Rauracien'. *Epipeltoceras bimammatum* and Perisphinctids have been recorded (Siemiradzki, 1889, p. 53) but as a rule ammonites are wanting. Instead the abundant brachiopods are used for correlation; 5 subzones are recognized (Rozycki, 1948).

**Transversarium Zone**, c. 110-150 m. Zawodzie Beds. A further series of thick, white, bedded and in part chalky limestones, quarried for lime especially about Czestochowa and rightly correlated with the Argovian, yield many large Perisphinctids and other ammonites (monographed by Bukowski, 1887; Siemiradzki, 1891, 1892; Klebelsberg, 1912). *Pelto­ceras (Gregoryceras) transversarium* occurs in the higher part (Upper Zawodzie Beds) (Rozycki, 1948, p. 18). The thickness of 110-150 m. is developed in the hills SW. of the Lysa Gora (Swidzinski, 1931). In the Czestochowa quarries it seems to be much less, and according to Bukowski (1887, p. 92) all the other ammonites occur in the lowest 30 m.; nevertheless he twice states (pp. 93, 94) that *Perisphinctes wartae* is found only at a higher level than the others. The fauna comprises *P. promiscuus* Buk., *P. chloroolithicus* Gümbel, *P. biblex* de Lor. non Sow., *P. cotovui* Simionescu (= *P. cristatus* Klebelsberg, 1912, pl. xviii, fig. 3) and a great variety of other Perisphinctids figured chiefly by Siemiradzki (1891), with Euaspidoceratids cf. *perarmatum* (Sow.), Goliathiceras, Vertebriceras, etc. (Bukowski, 1887, p. 93). Specimens of large *Perisphinctes cotovui* and *P. maximus* (Y. & B.) seen by me in Berlin came from Weilun and also from far in the south-east, at Busk.

**LOWER OXFORDIAN**

**Jasna Gora Beds.** Below some undated limestones which form passage­beds to the Zawodzie Beds and are of unstated thickness, is a 2 m. band of white marl with interbedded thin marly limestones in layers and nodules, often containing sponge­remains. From this bed Bukowski (1887, p. 87) listed nearly 50 species of ammonites. They include *Holcophylloceras mediterraneum*, but consist for the most part of Oppeliids (*Ochetoceras, Campylites, Trimarginites, Proscaphites, Creniceras*, etc.), Cardioceratids, Perisphinctids, Euaspidoceratids, and Peltoceratids. From Cardioceratids such as *C. (Scarburgiceras) bukowski* Maire (Bukowski, pl. ii, figs. 21, 22) and *C. (Subvertebriceras)* aff. *sowerbyi* Arkell (pl. ii, fig. 23), and Perisphinctids such as *P. (Prososphinctes) mazuricus* Buk., *P. (P.) consociatus* Buk., *P. (P.) claromontanus* Buk., *P. (Mirospinctes) mirus* Buk. and *P. (M.) marsyus* Buk., a late Lower Oxfordian age is evident (Cordatum
Zone). The Creniceras spp. and Proscaphites spp. are likewise not those of the Mariae Zone, which seems to be unrepresented. *Q. mariae* is sometimes recorded from the Lamberti Zone below (e.g. Wojcik, 1910, p. 767) but this requires verification.

**Callovian**

Characteristic ammonites of all the zones of the Callovian occur in one or more thin beds, in places crowded with cephalopods, in the escarpments that run from Cracow past Czestochowa towards Wielun. The facies of the Middle and Upper Callovian is generally glauconitic marl, and in this form the whole bed is less than 1 ft. thick in the Jasna Gora, although it yields at least 22 species of ammonites, including Kosmoceratids, Hectico-
ceratids, Reineckeids, Macrocephalitids and Perisphinctids (Bukowski, 1887, p. 85 and plates). The Lower Callovian is a condensed ironshot oolite, the celebrated Balin Oolite, 1 metre thick. Locally the Jason Zone becomes differentiated as an ironshot oolite similar to the Balin Oolite on which it rests, and in this form it yields many well-preserved Kosmo-
ceras jason, *K. fuchsi* Neumayr sp. (1871, pl. xv, figs. 3, 4), small Macro-
cephalitids and a great variety of Grossoveria, Binatissphinctes and Choffatia (Siemiradzki, 1894, with 3 plates; pl. xlii Choffatia). In other places an upper bed with numerous Quenstedtoceras and Peltioceras becomes separable as the condensed Athleta and Lamberti Zones. Although still highly condensed, the zones become rather better differentiated at Raclawice, where the profile is as follows (Wojcik, 1910, pp. 766-8):

<table>
<thead>
<tr>
<th>Metres</th>
<th>Beds</th>
</tr>
</thead>
<tbody>
<tr>
<td>11, 10</td>
<td>Cordatum Zone. Light, flaggy, marly limestone and marl with Peltioceratoides constantii (d'Orb.), <em>Parasvedekindia arduennense</em> (d'Orb.), Euaspidoceras cf. <em>peratum</em> (Sow.), <em>E. edwardsi</em> (d'Orb.), Cardioceras sp. ('cordatum' auct.), Vertebria sp., Taramelliceras flexuosum (Münst.), Creniceras crenatum (Brug.), Campylites delmontanum (Oppel)</td>
</tr>
<tr>
<td>9, 8, 7</td>
<td>Red marl divided by yellow marl: Some ammonites of the Cordatum Zone as above, plus others of the Lamberti and Athleta Zones. Quenstedtoceras lamberti auct., <em>Q. sutherlandiae</em> auct., <em>Q. mariae</em> auct., Hecticoceras rossiense Teiss., <em>H. brighti</em> (Pratt), Peltioceras athleta (Phil.), Kosmoceras spinosum (Sow.) (ornatum auct.), Grossoveria subtilis (Neum.), Subgrossoveria orion (Oppel)</td>
</tr>
</tbody>
</table>
| 6 | Reddish oolitic and glauconitic marl with ammonites of Athleta Zone: Kosmoceras duncani (Sow.), *K. spinosum* (Sow.), Hecticoceras brighti (Pratt), and of the Anceps Zone: Erymnoceras coronatum (Brug.), Kosmo-
ceras castor (Rein.), *K. pollux* (Rein.), *K. jason* (Rein.), Reineckeia anceps (Rein.), *R. fraasi* (Oppel), *R. greppini* (Oppel) |
| 0.25 | Yellow oolitic limestone with Reineckeia stübeli Steinmann of the Anceps Zone, but chiefly Lower Callovian: Keplerites torricellii (Oppel), *K. gesserium* (Sow.), Sigaloceras calloviense (Sow.), Macrocephalitids spp., Oppelia subcostaria (Oppel), Grossoveria curvicastra (Oppel), Choffatia funesta (Neum.) |
| 0.15 | Fine quartz conglomerate in calcareous matrix, locally oolitic, with lignite: Wagnericeras wagneri (Oppel), *Oppelia aspidoides* (Oppel); therefore Upper Bathonian |
| 0.3 | Sandstones, sand and conglomerate without fossils, to |
| 6.9 | Beds 4 and 5 of this profile are both developed in the same facies near Cracow and unite to form the Balin Oolite. This condensed deposit, 1 m. thick, spans the Upper Bathonian and Lower Callovian, which are indistinguishable by the matrix, and in consequence the combined fauna,
monographed by Neumayr (1871), has a 'mixed' aspect. Teisseyre (1887), who first described the genus *Proplanulites* from the Balin Oolite, handled over 10,000 ammonites from it, but saw only two specimens of *Lytoceras* and none of *Phylloceras*. The following is a list of the ammonites figured in Neumayr's classic monograph, embodying numerous subsequent changes of nomenclature.

- *Hecticoceras laubei* (Neum.), pl. ix, fig. 4
- *Hecticoceras krakoviensis* (Neum.), fig. 5
- *Hecticoceras balinense* Bonarelli, fig. 6
- *Hecticoceras taeniolatum* Bonarelli, fig. 7
- *Hecticoceras metomphalum* Bonarelli, fig. 8
- *Torricellites uhligi* (Parona & Bonarelli), fig. 9
- *Procerites* sp., pl. x, fig. 1, pl. xi, fig. 1
  - *? Orionoides* sp., pl. x, figs. 2, 3
- *Proplanulites majesticus* Buckman, pl. xi, fig. 2
- *Proplanulites* sp., fig. 3
- *Proplanulites cf. spirorbis* (Neum.), fig. 4
- *Subgrossouvria euryptycha* (Neum.), pl. xii, fig. 1
- *Grossouvria anomala* Loczy, fig. 2
- *Siemiradzkia de mariae* (Parona & Bonarelli), fig. 4
- *Wagnericeras* sp., fig. 6
- *Indosphinctes* sp., pl. xiii, fig. 1
- *Indosphinctes pseudopatina* (Parona & Bonarelli), fig. 2
- *Choffatia funata* (Oppel), pl. xiv, fig. 1
- *Choffatia evoluta* (Neum.), fig. 2
- *Grossouvria subtilis* (Neum.), fig. 3
- *Choffatia furcula* (Neum.), pl. xv, fig. 1
- *Choffatia balinensis* (Neum.), fig. 2
- *Parapatoceras calloviense* (Morris), p. 46

In the Cracow area conglomerates in the Callovian contain pebbles derived from Palaeozoic rocks and in at least one locality a 0.4 m. marl belonging to the Lamberti Zone rests directly on Upper Carboniferous porphyry (Dzulynski, 1952, p. 168). In the hills SW. of the Lysa Gora, however, the Callovian reaches a thickness of about 33 m. It consists of sandy marls with subordinate bands of limestone, partly silicified, and chert, and yields *Macrocephalites, Reineckeia* and *Erymnoceras* (Swidzinski, 1931, p. 851).

Very different is the facies to the north-east, where at Lukow, 65 miles ESE. of Warsaw, a brickfield is worked in an erratic mass of unstratified clay 4 m. thick, containing nodules with splendidly preserved ammonites mainly of the Upper Callovian (Makowski, 1952). A few nodules found in a separate part of the workings yield only *Cadoceras tscheffkini* (d'Orb.), gen. nov. (aff. *Longaeviceras*) sp. nov. (Makowski, pl. vi, figs. 1-3), and *schumarovi* (Nik.) (pl. v, 10); the age of these is probably Athleta Zone or Middle Callovian. All the other ammonites

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are forms of the Lamberti Zone. Since some of the names used by Makowski are misleading as to age, the following corrections need to be made:

Quenstedtoceras (Quenstedtoceras) aff. leachi (Sow.), pl. iii, 2
Quenstedtoceras (Quenstedtoceras) aff. damoni (Nik.), pl. vii, 1, 2
Quenstedtoceras (Eboraciceras) carinatum (Eich.), pl. vii, 3
Quenstedtoceras (Eboraciceras) rybinskianum (Nik.), pl. vi, 4
Quenstedtoceras (Eboraciceras) henrici (R. Douv.), pl. viii, 1
Kosmoceras (Kosmoceras) spinosum (Sow.), pl. iii, 6 only
Kosmoceras (Kosmoceras) aff. spinosum (Sow.), pl. iv, 13
Kosmoceras (Kosmoceras) tidmoorense (Ark.), pl. iii, 5
Kosmoceras (Spinikosmoceras) arkelli Mak., pl. iv, 10-12
Kosmoceras (Spinikosmoceras) annulatum (Quenst.), pl. iv, 1-9
Grossouvria aff. variabilis (Lah.), pl. viii, 4
Choffatia cf. recupereri (Gem.), pl. ix, 3

**Bathonian**

In the Cracow area the Balin Oolite rests on sands, sandstones and conglomerates with locally interbedded limestones, in which *Oecotraustes serrigerus* Waagen and *Clydoniceras discus* (Sow.) are recorded (Wojcik, 1910, p. 757). Towards the north these beds pass into clays and are augmented by older beds coming in below, until in the Czestochowa part of the escarpment the Bathonian consists of 80 m. of clays with bands and nodules of fossiliferous clay-ironstone. In these beds Rehbinder (1914) recognized four ammonite zones (first published in Russian with French abstract, 1912):

Zone of *Oecotraustes serrigerus* Waagen sensu lato, accompanied by *Oppelia (Oxycerites) latilobata* Waagen [possibly the *Clydoniceras discus* of Wojcik?], *Oppelia biflexuosa* (d'Orb.) and *Siemiradzkia aff. de mariae* (P. & B.).

Zone of *Morrisiceras morrisi* (Oppel), with *Tulites subcontractus* (M. & L.), *Siemiradzkia aurigera* (Oppel) and abundant *Oppelia fusca* auct., which last reaches its maximum here.

Zone of *Perisphinctes tenuiplicatus* (Brauns). The zonal ammonite, which is said to be abundant and restricted to this level, is of doubtful generic position. One is reminded of the abundant fine-ribbed Perisphinctids of the Progracilis Zone in England, also immediately under the Subcontractus and Morrisi Zone. *Meleagrinella echinata* and *Ostrea knorri* abundant; *Oppelia fusca* auct.

Zone of *Parkinsonia württembergica* (Oppel) (= *compressa* Quenst.). *Oppelia fusca* auct. begins here. [= Zigzag Zone.]

The correspondence with the Bathonian sequence in NW. Europe is remarkable. Careful collecting of the *Oxycerites* recorded as *Oppelia fusca* from the three lowest zones would probably lead to solution of the problem of the ranges of *O. fallax*, *O. aspidoides* and their allies, which have so much confused Bathonian stratigraphy in the west.

http://jurassic.ru/
UPPER BAJOCIAN

This is also developed as clays with bands and nodules of fossiliferous clay-ironstone in the northern part of the escarpment, but wedges out towards the south. The total thickness is 30 m., in which two ammonite zones are recognized (Rehbinder, 1914):—

Zone of Parkinsonia parkinsoni (Sow.), c. 25 m. Abundant *P. parkinsoni*, *P. rarecostata* (Buckman) and *P. neuffensis* auct.; also *Lissoceras oolithicum* (d’ Orb.).

Zone of Garantiana garantiana (d’ Orb.), 5 m. *Garantiana* spp. abundant, but even more so *Parkinsoniae* of the group of *P. arietis* Wetzel and *P. rarecostata* Buckman. No *Strenoceras* recorded, but *Teloceras blagdeni* (Sow.) occurs exclusively in the Garantiana Zone and is not rare (Rehbinder, 1914, p. 221).

MIDDLE AND LOWER BAJOCIAN

Below the Garantiana Zone there is a lithological change to sands, sandstones and conglomerates. In the top part a condensed bed represents the Humphriesianum Zone, with large *Stephanoceras*, *Stemmatoceras* and *Teloceras* (Rehbinder, 1914, p. 217; Langer, 1942, p. 90). Despite some earlier records, the underlying sands are undated but are generally supposed to represent the Murchisonae Zone, or at least the Lower Bajocian.

LIAS?

The southerly extension of the supposed ‘continental’ facies of the Lias, shown in fig. 74 (p. 466) is copied from Höhne’s map (1933), which is admittedly hypothetical in respect of details. About 200 m. or more of sandstones and shales on the north side of the Lysa Gora, however, have yielded a rich flora comparable with that of the Scanian Lower Lias (Samsonovicz, 1929). These beds are said to extend underground as far as Cracow, and to the north they have been encountered in borings at Poznan, Jastrow and other places.

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CHAPTER 20

RUSSIA AND THE EUROPEAN ARCTIC

During the Lower and Middle Jurassic the Russian platform separated the Tethys and Boreal seas. The first marine fauna is the Toarcian, which appears in the Donetz basin and in Spitsbergen. Bajocian transgressions narrowed the divide slightly, extending the sea perhaps to Franz Joseph Land and the lower Petchora basin in north Russia, and in the south up the lower Volga perhaps as far as Saratov, near which Parkinsonia has been recorded (Haug, 1910, Traité, p. 1002) as in the Donetz and Mangyshlak in Trans-Caspia. To the east thick continental-lacustrine deposits of presumed Middle Jurassic age flank the Ural Mountains and continue in thickness (up to 500 m.) southward into the Emba basin NE. of the Caspian Sea. This facies thins rapidly westward, but representatives of it (Bathonian?) form the base of the Jurassic on the lower Ural and lower Volga and as far west as Kiev and Smolensk (fig. 76).

In the Upper Jurassic a continuous broad seaway was opened meridionally across European Russia, linking the Tethys and the Arctic Ocean. The transgression began in the latter part of the Lower Callovian, but parts of the central region, as around Moscow, were not submerged until the Lower Oxfordian. Westward marine connexions were opened across Poland to the Baltic, and eastwards probably across the northern Urals into the basin of the lower Ob. This transgression is one of the greatest that occurred during the Jurassic anywhere in the world.

THE DONETZ BASIN

The Donetz River runs NW.-SE. through the northern Ukraine and flows into the Don shortly before reaching the head of the Sea of Azov. Near Izyum, 70 miles SE. of Kharkov, it crosses Jurassic outcrops of much interest for their contrast with the development in the rest of Russia and their affinity with Poland and central Europe. Here, as just mentioned, Toarcian and Bajocian faunas are developed, and the Upper Oxfordian and Lower Kimeridgian are in limestone facies. As in southern Poland, there is no Upper Kimeridgian and no Volgian.

Already in the Upper Palaeozoic the Donetz basin was a geosyncline lying between the pre-Cambrian crystalline horsts of Podolia and Ukraine on the south and Voronezh on the north. During the Variscan orogeny and again in the Trias the structure was folded and upraised, and the resulting folds had been deeply eroded and almost levelled by the end of the Trias. The Jurassic overlaps the Trias (with Rhaetian), but without angular unconformity. It begins with sands and clays of Lower or Middle Toarcian date. The total thickness of the Jurassic is 350 m.
The highest limestones, being without ammonites, are only vaguely dated but are probably Lower Kimeridgian. There follow some variegated clays and there is then a big gap in the succession, the next deposits being Cenomanian sands, which form a continuous ring round the older rocks and overstep them all transgressively. Between the Kimeridgian and Cenomanian there occurred a minor phase of folding which, unfortunately, cannot be accurately dated (Stepanov & others, 1937, pp. 25, 30).

The Donetz Jurassic resembles that in the rest of Russia in lacking characteristic Tethyan ammonites. No Phylloceratid or Lytoceratid has been recorded. The following citations of ammonites refer to the monograph by Borissjak (1908) except where stated otherwise.

**Undated**

Variegated clays with plant-remains.

**Lower Kimeridgian**

Thick shelly limestones with *Nerinea, Nerinella* and other gastropods (Borissjak, 1917, p. 13, figs. 10, 11), in places coralline.

**Upper Oxfordian**

Bimammatum Zone. Limestones with *Amoeboceras bauhini* (Oppel) and brachiopods, and below that beds with *Decipia? aff. achilles* (d'Orb.) and echinoids, including *Paracaidaris florigemna, Nucleolites scutatus* and *N. dimidiatus* (Makridin, 1951).

Transversarium Zone (Plicatilis Zone). To this zone belong beds at Mount Kremenez with large *Arisphinctes* (Borissjak, 1908, pl. vi) and *Perisphinctes* s.s. (pl. ii, fig. 14). The supposed fragment of *Peltoceras* (Gregoryceras) cf. *transversarium* (p. 77, pl. iii, fig. 3) comes from an Upper Callovian locality and could equally well belong to a *Rursiceras* sp. nov.; but Makridin (1951) records *G. cf. transversarium* from beds with Upper Oxfordian *Perisphinctes* (not figured).

**Lower Oxfordian**

Cordatum Zone. To this zone is to be assigned *Euaspidoceras nikitini* (Borissjak) (pl. ix, fig. 1), which occurs in England in the Cordatum Subzone s.s.; also probably *E. indorossicum* (pl. vii, fig. 4) and the assemblage of small Cardioceratids of the subgenera *Plasmatoceras* and *Subvertebriceras* from Mogilni Ravine (pl. i, figs. 7, 9-13), though at least some of them might be a little later, being reminiscent of the Arngrove Stone faunas.

Mariae Zone. To the Praecordatum Subzone belong *Scarburgiceras subexcavatum* Maire (pl. i, fig. 6) and *Pavloviceras naliokini* (Borissjak) (pl. i, figs. 4, 5), both from Uski Ravine. To the Mariae Zone are also to be assigned the large *Scarburgiceras* sp. (pl. i, fig. 8), *Euaspidoceras ivesense* Spath (pl. iii, fig. 7), and *Q. cf. mariae* (p. 63), all from Chutor Sawodski.

FIG. 76.—Jurassic outcrops of Russia, based on the Geological Survey map.

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UPPER CALLOVIAN

Lamberti Zone. Records of *Q. lamberti* and *Q. leachi* (= *vertumnum*) (p. 63) indicate that this zone is represented at Chutor Sawodski, as does the figure of *Kosmoceras aff. spinosum* (Sow.) (pl. iii, fig. 16).

Athleta Zone. Presumably of this date are the *Peltoceras* beds of Beryesowi Ravine, with *Peltoceras s.s. aff. athleta* (pl. iii, fig. 4), inner whorls of *Peltoceratoides* or *Parawedekindia* (pl. iii, fig. 5), and *?Rursiceras* (pl. iii, fig. 3).

MIDDLE CALLOVIAN

Both *Erymnoceras cf. coronatum* and *Kosmoceras jason* are recorded (Borissjak, 1908, p. 74; Makridin, 1951).

LOWER CALLOVIAN

The foregoing Callovian and Oxfordian beds record an advance of the limestone facies and retreat of sandstones towards the east and southeast as the Palaeozoic shoreline retreated in that direction (Borissjak, 1908, p. 91). The first truly marine beds were thought by Makridin (1951) to begin with the Calloviense Zone. Below this come thick coarse sandstones which pass up diachronically, as just stated, into the Callovian clays; they are supposed to represent the Lower Callovian.

BATHONIAN

Underlying the sandstones are clays with plant-remains. In some places equivalents of these beds contain *Pseudocosmoceras michalskii* Borissjak sp. and other Parkinsonidae, some belonging to the *württembergica* group (Mourachkine, 1930). Clays assigned to the Bathonian and Callovian also occur as far west as Kiev (Chirvinsky, 1937, p. 87).

UPPER BAJOCIAN

The lower part of the same clay formation contains iron concretions from which have been obtained *Parkinsonia, Spiroceras, Garantiana* and *Strenoceras* (Borissjak, 1908, p. 88 and figs.). The lithological, stratigraphical and palaeontological similarities to Algeria (Ghar Rouban mountains) are most striking.

MIDDLE AND LOWER BAJOCIAN

This is represented by a bed of conglomerate with belemnites and *Dorsetensia rossica, isjumica, and kamenka* (pl. ii, figs. 5-12), which Borissjak was inclined to correlate with the Humphriesianum Zone, overlying beds with *Leioceras*.

TOARCIAN

*Hammatoceras cf. insigne* (pl. i, fig. 14) indicates the Jurense Zone. The earliest marine fauna in the Donetz is typical of the Falcifer and Commune Zones, with *Hildoceras* and *Dactylioceras* (Borissjak, 1908, p. 88, and pls. i, ii, iii).

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In the depression between the lower Ural and Emba Rivers, NE. of the Caspian Sea, Jurassic clays come to the surface in many small anticlinal and domal inliers in the steppes. In the eastern part, near the southern end of the Urals, the continental-lacustrine facies is strongly developed and seems to extend high into the Upper Jurassic, the thickness totalling 500 m. In the Indersk Hills, on the left bank of the lower River Ural, it has thinned to 105 m. (map and sections in Bubnoff, 1926, pp. 123, 127). Here marine Lower Kimeridgian with Ostrea delta and Aulacostephanus crops out (Khudyaev, 1932, p. 652), and Virgatus Beds are reported (Pavlow, 1884, p. 696), but in view of the earlier virgatotome ammonites since made known in the Orenburg area (see below), this latter record requires confirmation.

In the Kirghiz Steppes, 100 miles east of the great bend of the Volga at Stalingrad, lies the salt Lake Elton. The country is flat and lacks natural exposures, but from wells, ditches and other excavations are dug clays with small pyritized ammonites of the Upper Callovian. The figured specimens (Kamysheva, 1938, pls. i, ii) being all nuclei or small fragments, and the figures being available to me only as enlargements from a microfilm, specific determination is hazardous, but Kosmoceras jason seems to have been misidentified and nothing earlier than the Coronatum Zone, and more likely the Athleta Zone, is represented. The fauna is a typical assemblage of the Lamberti Zone, comprising Quenstedtoceras (Lamberticeras), Kosmoceras of the spinosum and duncani groups, Properisphinctes, Peltoceratidae, and Hecticoceras (Lunuloceras and Brightia), with a nucleus of Erymnoceras cf. doliforme (Roman) (pl. i, fig. 6).

Kamysheva considers the assemblage is dwarfed and transitional between faunas of the Tethyan and boreal provinces; but the ‘dwarfing’ is due to preservation, and the figures show a collection typical of the Oxford Clay facies of the Upper Callovian, which might have come from anywhere from Oxford to the Rhone valley and from Normandy to the Moscow basin.

The thickness of the Callovian is 220 m. and the Lamberti Zone is followed by reduced Lower Oxfordian marls with Cardioceras (13 m.) and that in turn by Kimeridgian and Lower Volgian (Bojarinova & Ilyin, 1951).

BASIN OF THE UPPER URAL AND ILEK RIVERS

The Ural River rises in the southern end of the Ural Mountains and, after gathering its tributary the Ilek, flows west as far as Uralsk, within 170 miles of the Volga, where it turns south to the Caspian Sea. On the Ural, soon after it has left the mountains, stands Orenburg (Chkalov), ancient provincial capital, surrounded by a large area of Upper Jurassic rocks. Although once continuous with those on the Volga, these outcrops are now isolated, and being the most easterly in Russia they deserve

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separate treatment. Farther north and only a little farther east, in the
southern Urals near Orsk, and on the western flanks of the mountains,
the Jurassic is exclusively represented by its continental facies.

The Orenburg Upper Jurassic is remarkable for a development of
Middle and Upper Kimeridgian ammonite faunas of the Beckeri, Sub-
planites and Pectinatus Zones, corresponding as closely with equivalents
in western Europe and England as do the better-known and almost
ubiquitous Lower Kimeridgian Acanthicus Beds. It is evident that from
the middle of the Lower Callovian to the Upper Kimeridgian there
stretched an uninterrupted seaway from Dorset to the southern end of the
Ural Mountains.

LOWER VOLGIAN

Zone of Epivirgatites nikitini. This zone (named by Haug, 1898) occurs
at the top of the Lower Volgian in the Orenburg and Simbirsk districts
and occupies the position of the Blakei Zone of the Moscow district.
The zonal index and its allies (Epivirgatites Spath, 1923, = Nikitinella
Ilovaisky & Florensky, 1941) strongly resemble ammonites in the Gorei
Zone in England, ascribed to Glaucolithites or Crendonites. The zone was
equated by Pavlow with his Blakei Zone, but if the comparison with
England is any guide, it should be slightly earlier, and the Blakei Zone
be missing in the east.

Zone of Virgatites virgatus. Better developed in the Moscow Basin
(see p. 494).

Zones of Zaraiskites scythicus and Dorsoplanites dorsoplanus (= Zones of
Z. quenstedti and D. panderi). These zones are reduced and not separate,
being partly or wholly represented by a phosphatic nodule bed. The
following ammonites are figured from this horizon (under wrong names)
by Ilovaisky & Florensky (1941): Zaraiskites diprosopa (I. & F.) (pl. xxiii,
fig. 43) (cf. scythicus Visch.), Z. cf. sauvagei (Lewinski) (pl. xxiv), Z.
scythicus (Visch.) (pl. xxv, fig. 46), Z. quenstedti (Mich.) (pl. xxv, fig. 47),
Acucostites sp., Dorsoplanites primitivus (pl. xxvii).

UPPER AND MIDDLE KIMERIDGIAN

The Lower Volgian rests upon the Vetlianka Sandstone (10 m.),
characterized by a rich fauna of Perisphinctids. Some were figured
(poorly and reduced) by Semenow (1896) who identified them all with
western European species of the Lower Kimeridgian, and for the most
part with species from Crussol, Ardèche. The matter was not clarified
by subsequent discussions by Sokolov (1903-4) and Steiger (1914, p.
499 ff.), but Ilovaisky & Florensky (1941) have now published 15 plates
of natural-size photographs. From these it is clear that the commonest
forms are species of the genus Subplanites Spath (1925) (= Sokolovia
Ilovaisky 1934 non Boehm, = Ilovaiskya Vialov, 1940). They include the
English species S. pseudoscruposus Spath (I. & F. 1941, pl. xxii) and the
closely allied S. klimovi (pl. xxi) with more distant ribs, S. aff. wheatleyensis

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(Neaverson) (pl. xvi), and Allovirgatites ianschini (pls. xviii, xix). In addition there are fragments of Pectinatites (pls. ix, x, fig. 23, xiii, fig. 27, the last aff. pectinatus Phil. sp.?) and the coarse-ribbed Wheatleyites (pl. xiv, x o-8). The Vetlianka Sandstone therefore represents the Subplanites and Pectinatus Zones of Dorset. To raise it to the rank of ‘Wetlian Stage’ (I. & F., 1941, p. 188) is unnecessary.

In the basins of the upper Ural and Ilek Rivers the Vetlianka Sandstone rests on beds with Virgataxioceras fallax (Ilovaisky & Florensky, 1941, pls. ii, iii, and Semenov, 1896, pl. iv, fig. 14), a collective species, some forms of which are almost identical with V. setatus (Schneid), of the Beckeri Zone of Franconia. Ilovaisky & Florensky rightly correlated these beds with the Beckeri Zone.

LOWER KIMERIDGIAN

Next below are the Gorodistché Clays of the Pseudomutabilis Zone, crowded with Exogyra virgula and ammonites of the genera Aulacostephanus and Aspidoceras, as in England and western Europe (Pavlow, 1886) (Zone of Aulacostephanus kirghisensis d'Orb., sp., the type of which came from Saragula, Orenburg). Besides a remarkable series of species of these two genera, there are several species of Amoeboceras (Pavlow, pl. viii, figs. 4, 5), Prionodoceras (pl. v, fig. 4), Streblites (pl. viii, figs. 6, 7) and Torquatisphinctes (pl. viii, fig. 3, ? pl. vii, fig. 3). (Pl. vii, fig. 4, seems to be a Virgataxioceras cf. fallax I. & F. sp., presumably from the overlying zone). These ‘Acanthicus Beds’ include also the Tenuilobatus Zone, as is shown by a number of the ammonites figured by Pavlow.

UPPER OXFORDIAN

Beds on the Oxfordian-Kimeridgian boundary, equivalent to the Pseudocordata Zone, are represented by Ringsteadia kurmani (I. & F.) (1941, pl. i, fig. i, = R. aff. marstonensis Salfeld) and Dichotomoceras sublacertosus (I. & F.) (pl. i, fig. 2). These beds form the top of Nikitin's comprehensive ‘Alternans Zone’, and it may be suspected that farther west they yielded Prionodoceras jaskowi Pavlow sp. (1886, pl. v, fig. 4).

The rest of the Upper Oxfordian is much more fully known in the Moscow basin (see p. 496).

LOWER OXFORDIAN

Ammonites of this age cited by Sinzow (1899) include Goliathiceras goliathum, Cardioceras cordatum, 'vertebrale', rouillieri, quadratoides, Peltoceras arduennense, subconstanti, Aspidoceras perispinctoides, Grossouria miranda, also Scarburgiceras praecordatum and Q. mariae (Sinzow, 1899, as interpreted by R. Douville, 1912, p. 258).

UPPER CALLOVIAN

The Lamberti Zone is conspicuous, with numerous Quenstedtoceras of the subgenera Lamberticeras, Eboraciceras, and Quenstedtoceras s.s.,
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including *Q. problematicum* Sinzow and *Q. subflexicostatum* Sinzow. Inseparable from these stratigraphically, according to Sinzow, are a number of *Peltoceras, Kosmoceras, Hectoceras, Grossouvria*, etc. This is the horizon of the Lake Elton beds (see p. 488).

**MIDDLE AND LOWER CALLOVIAN**

Middle Callovian is represented by *Erymnoceras coronatum, Kosmoceras jason, K. gulielmii, K. castor*, and *K. subobductum* and *K. aenigmaticum* Ilovaisky & Florensky (1941, pl. xxviii, figs. 55, 56); Lower Callovian by *Cadoceras* sp.? and *Keplerites* spp. (*gowerianus, galilaei, and fortinodus* I. & F.).

**BATHONIAN, UPPER BAJOCIAN**

As in Trans-Caspia, the Orenburg Jurassic is said to begin with *Parkinsonia parkinsoni* of the Upper Bajocian (not figured, but this was accepted by Uhlig, 1911, p. 380).

**THE VOLGA BASIN**

Across the endless monotony of the Russian plains the Volga winds from within 150 miles of the Gulf of Finland to Astrakhan on the Caspian, a straight-line distance of over 1000 miles. In its long journey it crosses the so-called Moscow basin, a structure so flat that it is only perceptible by a roughly concentric arrangement of outcrops on a small-scale geological map. Dips in the Jurassic and Cretaceous rocks are generally nil or too small to measure. The surface is encumbered over wide areas with Quaternary deposits—loess and loessic loams, alluvium, solifluxion products and till, and by tchernozem. The best sections are afforded by the banks of the Volga, which flows in places at the foot of cliffs comparable with those on a sea coast.

The widespread scatter of outcrops (fig. 76) shows that almost the whole of the central Russian plain is or was covered by Upper Jurassic clays. A remarkable feature in view of this enormous extent of outcrop is their small thickness and uniform lithology. The whole Volgian stage consists of only some 6-8 m. of beds, often less, and the underlying Upper Jurassic is generally thinner, only rarely a little thicker, until the Lower Volga is reached. The differentiation of the stages and substages rests almost entirely on palaeontology, with little or no lithological guidance.

The Russian platform is, in fact, the type example of a stable shelf, and the Jurassic sediments are developed accordingly. Except for some low anticlines, gently folded and eroded during the Palaeozoic, there has been no tectonic disturbance or igneous action since the beginning of the Cambrian, and diagenesis has been at a minimum. Even the Cambrian (near Leningrad) is developed as blue clay with perfectly-preserved fossils, and bituminous shales in the Silurian contain fossils comparable in perfection with those of most Tertiary formations. The Carboniferous Limestone is more like chalk. It is not surprising, therefore, that

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the Jurassic fossils, and particularly the ammonites, are often in a superb state of preservation, with their opalescent pearly test intact. This condition is rivalled, however, by the Lower Kimeridgian ammonites of Market Rasen in Lincolnshire. It would be normal for the Jurassic clays of England but for crushing due to compaction into shales.

As is to be expected from the great areal extent and small thickness of the deposits, there are non-sequences in the Jurassic, which vary the succession from place to place. For instance, the Lower Callovian is missing in most places in the centre of the Moscow basin, the sequence beginning with the Coronatum Zone; but in places this also is missing, and in others the Lamberti Zone, so that first the Lamberti Zone (at Novosselki in the province of Ryazan), and then the Mariae Zone of the Lower Oxfordian (at Miatchkovo near Moscow) come to rest unconformably on the Carboniferous Limestone. The zones represented in the Oxfordian and Kimeridgian likewise vary from place to place, and it is only at Kashpur on the middle Volga that shales with Subplanites like those in the Ural and Ilek basin have been found. The Volgian is more constant but it also is by no means complete everywhere. For instance on the middle Volga the Virgatus Zone in places is represented by a band of phosphatic nodules, and north of Simbirsk the Subditus Zone is directly succeeded by relatively late Neocomian; while near Nijni Novgorod the Upper Oxfordian is succeeded directly by Neocomian clays with a band of phosphatic nodules at the base containing derived ammonites of the Virgatus Zone (Pavlow, 1889, p. 89).

The thickness of the Jurassic below the Volgian increases greatly at and south of the Samara bend, rising to more than 100 m. (Murchison, 1845, p. 246; Boutrov, 1937, pp. 38-9).

[BERRIASIAN

Ryazan Beds (upper part). Zone of Paracrassedites spasskensis. The Ryazan Beds are developed only in the southern part of the Moscow basin and are thickest in the valley of the Oka, where they consist of glauconitic sands, 0.5 to 2 m. In the classic exposures, whence the ammonites were monographed by Bogoslovsky (1897), two zones are condensed and only one horizon can be recognized (Bogoslovsky, 1897, pp. 148-50), but in other places the Spasskensis Zone is distinct from and overlies the Rjasanensis Zone, as was early recognized by Pavlow (Zonov, 1937, p. 41). At least one species of the later zone, Subcrassedites subpressulus (Bog.), occurs in the Spilsby Sandstone in Lincolnshire (Swinnerton, 1935, p. 37), and other species figured by Bogoslovsky have been claimed as probably close to Spilsby Sandstone forms (Spath, 1936, pp. 81, 170).

UPPER VOLGIAN

Ryazan Beds (lower part). Zone of Riasanites rjasanensis. R. rjasanensis (Nikitin, 1888, pl. i) was believed by Kilian to occur in the Upper Tithonian
(Transitorius Zone) in the south-east of France, but according to Mazenot (1939, p. 262) this was based on a misidentification. Nevertheless, two species of *Riasanites* are still admitted by Leanza in the Upper Tithonian of Argentina (see p. 582). Accordingly it seems indicated that the lower zone of the Ryazan Beds be considered Upper Jurassic, and this view has been adumbrated by Spath (1947, pp. 54-5, 66), on these and general grounds. It is therefore here transferred to the Upper Volgian.

Zonov (1937, p. 41) states that in some places near Moscow the Rjasanensis Zone is separated from the underlying Nodiger Zone by 4-6 m. of unfossiliferous sands. Whether these are the same as the Vorobiewo Sands of Pavlow (1889, pp. 91, 97) is not clear. In other places, however, the condensed Ryazan Beds overlap all the Jurassic stages down to Middle Callovian inclusive and in several places come to rest on Carboniferous rocks (fig. 77). This behaviour is consistent with an Upper Tithonian age for the Rjasanensis Zone, the Upper Tithonian being notably transgressive in many parts of the world, though it is unlikely that the transgressions were everywhere exactly contemporaneous.

The remainder, and principal part, of the Upper Volgian consists of up to 4 m. of grey marly clay, but it may become (as near Moscow) mainly a glauconitic and micaceous loam or sandstone with phosphatic nodules. It is characterized by species of *Craspedites* and numerous *Buchia* (= *Aucella*). The number of zones that can be recognized differs from place to place and there is doubtless a subjective element, due partly to the chances of collecting. The following succession was established by Nikitin (1884, p. 73):

Zone of *Craspedites nodiger*, with *C. tripychus, okensis, unshensis, kachpuricus, Garniericeras catenulatum, G. subclypeiforme*, and *Stschurovska stschurowskii*.

Zone of *Craspedites subditus*, with *C. okensis* and *G. catenulatum*.

Zone of *Craspedites (Kachpurites) fulgens*, with *C. subfulgens, okensis, subditus, fragilis*.

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**Fig. 77.**—Section at Ryazan, showing the transgressive relation of the Ryazan Beds to the underlying Upper Jurassic and Callovian. After Bogoslowsky. The section is:

1, Unfossiliferous sandstone; 2, Polyptychites Beds: sand with phosphatic concretions containing at least 4 species of *Polyptychites*, also belemnites (*lateralis*), etc.; 3, Ryazan Beds. Glauconitic loams with many *Buchia*, etc.; 4, Upper and Lower Volgian. Glauconitic sandy beds with many *Buchia*, etc. *Craspedites* spp. in upper half, *Virgatites* in lower half; 5, 6, Oxfordian clays; 7, Callovian.
Pavlow (1889, pp. 85, 91-2, etc.) used alternative indices and recognized only two zones; but although he averred that he could not separate the Fulgens Zone from that next above, he recorded *C. fulgens* only from a separate bed at the base of the Upper Volgian at Mnionviki, near Moscow, thus supporting Nikitin’s conclusions at Yaroslavl (1881, p. 23). Zonov (1937, p. 40) considers still further subdivision possible. The Nodiger Zone is best known at Kostroma, NE. of Moscow (Nikitin, 1884a).

**LOWER VOLGIAN**

In the Moscow district this substage consists of as little as 1·5 m. of thinly-bedded glauconitic sand and micaceous clay, with two beds of phosphatic nodules, one at the base (Pavlow, 1889, p. 91). At Kashpur it may be about 2 m. thick, but it passes down without visible break into bituminous shales which have proved to be pre-Volgian (see below). On the Mologa and Kostroma Rivers also it is very thin. The full sequence of zones, according to Nikitin, Pavlow, and Rosanov, is as follows:—

*Zone of Lomonossovella [Titanites?] blakei* (Pavlow), with *Titanites (Kerberites) portlandicus* (Cox) and giants, *cf. 'gigas' Blake.*

*Zone of Epivirgatites nikitini.* This occurs in the Simbirsk and Orenburg districts and is probably somewhat older than the Blakei Zone of the Moscow district. Pavlow thought them equivalent, and is supported by Zonov (1937, p. 40), who states that this is the horizon of *Lomonossovella lomonossovi* (Michalski).

*Zone of Virgatites virgatus,* with *V. pilicensis* and other species, and *Acuticostites acuticostatus.* These extraordinary genera, with their ‘machine-made’ ultra-virgatotome ribbing have yet to be found outside Russia. (For good figures see Vischniakoff, 1882, and Michalski, 1890.)

*Zone of Zaraiskites scythicus* with *Z. zaraiskensis* and *Z. quenstedti.* This zone, which also occurs in Poland and the Baltic region and probably in Dorset (see p. 20), was first separated and named by Rosanov in 1906. It was also recognized by Pavlow (1907, table facing p. 84) as the Quenstedti Zone. It is probably impossible in most places in the Volga basin to separate it from the Dorsoplanus Zone, and Rosanov and also Sokolov & Bodylevsky (1931, p. 25) equated the two; but the facts in Poland and also in England confirm Pavlow’s contention that there are two zones, though much condensed. (The generic name *Zaraiskites,* after Zaraisk near Ryazan, is due to Semenow, 1898; = *Provirgatites* Lewinski, 1923.)

*Zone of Dorsoplanites dorsoplanus,* with *D. panderi,* and probably also *Pavlovia pallasi* (d’Orb.). Named by Pavlow (1907, pp. 43, 74). This zone probably corresponds with the *Pavlovia pallasioides* Zone at the top of the Kimeridge Clay, which at Hartwell, near Aylesbury, contains a possible *Dorsoplanites, ‘Pallasiceras’ ultimum* Neaverson.

**MIDDLE KIMERIDGIAN**

In the river cliff and ravine at Kashpur the clays with *Virgatites* (and *Zaraiskites?*) pass down into bituminous shales not separated by Nikitin

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(1897, p. 16) or Pavlow (1897, p. 26) from the Virgatus Zone. J. F. Blake, however, who took part in the Congress excursion of 1897, collected and brought home from this locality ammonites which Spath (1923, p. 307) was able to identify as *Subplanites*. The occurrence of *Subplanites* in SE.

N. Neocomian.

N.SMB. Black clay with *Simbirskites versicolor*.

N.SQ. Friable greenish-grey sandstone with *Belemnites subquadratus* (1 m.) and shaly grey clay, more or less sandy and poorly fossiliferous (2-3 m.).

N.PL. Phosphatic conglomerate (0·2 m.) and yellow sand (0·25 m.) with *Polyptychites keyserlingi*, *P. gravesiformis*, *P. beani*, *Belemnites lateralis*, *B. subquadratus*, *Buchia* spp.

N.VG. Friable sandstone and conglomerate of fossils (0·9 m.) with *Subcraspedites spasskensis*, *Buchia* spp. and belemnites as in N.PL.

AQ. Aquilonian (= Upper Volgian). Undated green sand (0·25 m.).

AQ.K. Marl passing into sand and into a dense mass of fossils (1 m.): *Crasspedites kaschpuricus*, *Garniericeras subclypeiforme*, *Belemnites lateralis*, *B. russiensis*, *Buchia fischeri*, etc.

AQ.S. Grey glauconitic and sandy marl (3 m.). *Crasspedites subditus*, *C. okensis*, *C. catenulatus*, same belemnites and *Buchia fischeri*, etc.

PT. Portlandian (= Lower Volgian).

PT.G. Sandy marl and green sandstone with phosphatic nodules (0·7 m.). ‘Ammonites of the group of *A. giganteus*, *A. triplicatus*’ (= Blakei Zone).

PT.V. Phosphatic conglomerate, bituminous shales, and grey clays with *Virgatites virgatus*, *Belemnites absolutus*, etc. (3 m.).

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**Fig. 78.**—Section at Kashpur on the Volga, after Pavlow, 1897.
Russia has since been confirmed by the figuring of numerous specimens by Ilovasky & Florensky from the basin of the Ural and Ilek (see p. 489). In some places a thin zone of *Glochiceras cf. fialar* (Oppel) occurs above the Pseudomutabilis Zone (Zonov, 1937, p. 36).

**LOWER KIMERIDGIAN**

The Gorodistche Clays, or Acanthicus Beds, of the Middle Volga begin at Saratov and are almost ubiquitous in the Volga basin. The type section is in the Volga bank NNW. of Simbirsk (Murchison, 1845, p. 246). With their rich fauna of *Aulacostephanus* spp., *Aspidoceras* spp. and *Physodoceras* spp. (monographed by Pavlov, 1886) and beds crowded with *Exogyra virgula*, they belong mainly to the Pseudomutabilis Zone, but the Tenuilobatus Zone is also represented by *Streblites, Amoeboceras* spp., *Rasenia fraasiforme*, *Prorasenia mniovnikensis* and *P. cf. stephanoides*, most of which were included by Russian authors in the old 'Alternans Zone'. It is possible that there is a non-sequence representing the Mutabilis Zone, for no forms like *R. mutabilis* have yet been figured from Russia: this was already noticed by Salfeld in 1914 (p. 238).

In the sections on the upper Volga around Rybinsk, Mologa and Myshkin (about 170 miles north of Moscow) the Volgian seems to rest on the basal Kimeridgian, with *Amoeboceras cf. subcordatum* (d'Orb.) and *Prorasenia cf. stephanoides* (Oppel) (Nikitin, 1881, bed 4).

**UPPER OXFORDIAN**

An exact and highly important paper by Ilovasky (1904) gives the sequence of Upper and Lower Oxfordian clays at the villages of Miatchkovo near Moscow and Novosselki and Nikitino in the province of Ryazan. The whole Oxfordian series is about 10 m. thick at Miatchkovo and 15 m. at Novosselki, where it is overlain by the Volgian (*Virgatites* beds). The succession may be classified as follows:

- **Bimammatum Zone.** Beds D and C. At the top (bed D4) are *Amoeboceras leucum* Spath and *A. ilovaiskyi* Arkell (Ilovasky, 1904, pl. xi, figs. 2, 7), which correlate with the Pseudocordata Zone in England. At a lower level (beds D1 and C) is *Amoeboceras pseudocaelatum* Spath (Ilovasky, pl. xi, fig. 6, pl. x, fig. 30). *C. zietenii* is also recorded (as rare) in bed C. *Amoeboceras alternoides* (Nikitin), by comparison with the English succession, should come from about this level (see Arkell, 1948, p. 395; for discussion of the European correlations of these Cardioceratids see Arkell, 1947, pp. 353-6).

- **Plicatilis Zone.** To this zone clearly belong the clays of beds B and A2, with large *Perisphinctes* s.s. (pl. xii, fig. 2, and pp. 277-8, sub *P. martelli*), *Kranaoasphinctes bolohanowi* (Nik.) (pl. xii, fig. 1), *Euaspidoceras cf. puictuberculatum* Arkell (pl. xii, fig. 3), *Cardioceras zenaidae* Ilov. (pl. x, figs. 33, 35), *C. densiplicatum* Buckman sp. (pl. xi, fig. 5) and *Ochetoceras canaliculatum.*

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LOWER OXFORDIAN

Cordatum Zone. Bed A1, with Cardioceras ilovaiksiy Maire (Ilov., pl. x, fig. 28) and other forms of the cordatum group (pl. x, fig. 31), Goliathiceras sp. (pl. x, fig. 27), Pachycardioceras rouilleri (p. 268) and Perisphinctids. Other ammonites of the Cordatum Zone were figured by Lahusen (1883): C. cordatum (Sow.) (pl. v, fig. 5), C. costicardia (Buck.) (pl. v, fig. 3), Aspidoceras aff. catena (Sow.) (pl. x, fig. 14), Pelto ceratoides sp. (pl. x, fig. 12).

Mariae Zone. Bed K contains Quenstedtoceras (Pavloviceras) pavlovi Douvillé, of which the type came from Ryazan, and allied species (Ilovaisky, pl. x, figs. 22-25; Lahusen, 1883, pl. iv, figs. 6-17). To the same zone belongs Cardioceras (Scarburgiceras) lahuseni Maire (Lahusen, 1883, pi. v, fig. 1). At Miatchikovo near Moscow, this zone rests on Carboniferous Limestone, which is quarried on both banks of the Volga.

UPPER CALLOVIAN

The Lamberti Zone is strongly represented on the Upper Volga and in the Ryazan province by the Leachi Zone of Nikitin, with a range of Quenstedtoceratids comparable with those in the Hackness Rock and the Lamberti Limestone at Woodham pit in England. The clay of this zone similarly passes into a band of argillaceous limestone in places on the upper Volga; and at Novosselki in Ryazan province it oversteps on to Carboniferous Limestone. A notable link with England is the presence of conspicuous large Eboraciceras, to which belong Q. rybinskianum Nik. (1881, pi. i, fig. 8) and Q. problematicum Sinzow, 1899 (type, Nikitin, 1881, pi. i, fig. 6), together with Lamberticeras (pl. i, fig. 1, and Lahusen, 1883, pl. iv, figs. 1-3, and perhaps fig. 4, the type of Q. pseudolamberti Sinzow, 1899), Prorsiceras (Nikitin, 1881, pi. i, fig. 5), Pachyceras mologae Nikitin sp. (pl. i, fig. 12), and the ubiquitous Kosmoceras spinosum Sow. sp. (pl. iv, fig. 34) and K. proniae and its allies (Teisseyre, 1884). The last and K. transitionis Nik. and various Pelto ceratids (Lahusen, 1883, pl. x, figs. 5-9) indicate that the Athleta Zone is represented. Various well-preserved Hecticoceratids come from the Upper and Middle Callovian (Lahusen, pl. xi).

MIDDLE CALLOVIAN

The Coronatum and Jason Zones are widespread and are represented by Lahusen's beds b, c. They yield Erymnoceras coronatum and E. doliforme Roman (Neumayr, 1876, pl. xxv, figs. 1-3; Lahusen, 1883, pl. vi, figs. 1-4) and numerous appropriate Kosmoceras, Hecticoceras, etc. (Lahusen, pls. vii-xi). Presumably from this level also comes Erymnoceras renardi Nikitin sp. (1882, pl. xi, fig. 24). At Sergatch the Coronatum Zone with Erymnoceras is developed as a band of oolite (Milachewitch, 1880). Classic works, chiefly based on ammonites from this substage in Ryazan province, were published by Neumayr (1876) and Teisseyre (1884). According to Zonov (1937, p. 35) Erymnoceras spp. occur in the lower part
of the Middle Callovian, with Kosmoceras jason, not in the overlying beds with K. castor and K. pollux as in western Europe.

**LOWER CALLOVIAN**

Nikitin (1884a) divided the Middle and Lower Callovian between two zones of Cadoceras milaschevici and C. elatmae. It is difficult to determine at what level the division falls in terms of west European zones, but probably it is somewhere in the Koenigi-Callovien Zone. The Russian Callovian is famous for its variety of forms of Cadoceras (e.g. Nikitin, 1882, pl. xi, figs. 20, 21, pl. xii, figs. 26-29; 1881, pl. iii) and there are also many forms of Macrolepites (1882, pl. x, figs. 15-18), Kepplerites such as K. lahuseni Parona & Bonarelli, 1897 (type Lahusen, 1883, pi. vi, fig. 8) and Gowericeras (figs. 5, 6, 7), Proplanulites, Chamoussetia, Grossouvria, etc. When a detailed stratigraphical succession comes to be worked out, interesting comparisons with NW. Europe and especially England are to be expected.

On the middle Volga, in places, Lower Callovian ammonites are only found rolled in a conglomeratic bed of the Coronatum Zone, which rests directly on the Permian; in other places there are sands similar to the underlying Permian (Pavlow, 1884; 1885; 1897, p. 5), which may be basal Callovian or older. *Arcticoceras* is recorded near Kuibyshev (Zonov, 1937, p. 33).

**? BATHONIAN**

In the Samara bend of the middle Volga the Permian and Carboniferous are transgressively overlain by 25-30 m. of white sands, with basal pebble bed and lenses up to 4-5 m. thick of laminated clays at or near the base and filling pockets in the Palaeozoic platform. These beds are attributed by Russian geologists to the Bathonian. (Boutrov, 1937, pp. 38-9; Zonov, 1937, p. 33).

**BASIN OF THE PETCHORA RIVER**

Between the northern Urals and the Timan Range lies a wide triangular basin drained by the Petchora River, which crosses the Arctic Circle and flows into the Arctic Ocean. The greater part of the basin is filled with Quaternary marine beds, but beneath much of it there is a sheet of Cretaceous and Jurassic strata, which come to the surface between the river and the flank of the Timan Range. The best exposures are on the River Pishma and at the headwaters of the River Ishma, two tributaries of the Petchora. Near the confluence of the Pishma and Petchora, Murchison (1845, p. 417) already noted ‘large masses of grey calcareous sandstone subordinate to clays and charged with ammonites and fossil wood’, passing down to thick grey clays and shales with Posidonia, resting on Devonian limestone.

Ammonites were brought back and figured by Keyserling (1846) and a number of later explorers. The assemblages all fall, in age, between

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the upper part of the Lower Callovian and the lower part of the Lower Volgian. No Upper Volgian ammonites are known, but belemnites of this date are reported (Khudyaev, 1932, p. 518). The ammonites are of interest for their close links with the rest of the Arctic region and the Volga basin on the one hand and with England, especially Yorkshire, on the other.

The earliest ammonites are post-Macrocephalus Zone: namely *Arctoceras ishmae* (Keyserling) (refigd. Spath, 1932, pl. xv, fig. 7), *Cadoceras elatmae* Nikitin, *C. tschernyschevi* Sokolov (1912, pl. i, fig. 2), which correlate with the Koenigi Zone (the Elatmae Zone of the Volga basin, Nikitin, 1884).

The overlying zone of *Cadoceras milaschevici* Nik. and *C. tscheffkini* (d'Orb.) of the Volga basin is also represented, but this goes up to the Coronatum Zone. Here belongs *Cadoceras syssolae* Khudyaev.

The Upper Callovian Cadoceratids are of special interest, for their nearest allies are found in the Hackness Rock of Yorkshire, which is Athleta-Lamberti in date: these belong to the genus *Longaeviceras* Buckman. Two Hackness Rock species, *L. longaeum* (Leckenby, 1859) and *L. placenta* (Leckenby, 1859) (Buckman, Type Am. 1919, pl. cxxi, A, and 1920, pl. cxlviii) are perhaps identical specifically with two Petchoraland species respectively, 'Cadoceras' nikitini and 'C. keyserlingi' Sokolov (1912, pl. i, fig. 3, pl. ii, fig. 2). *Quenstedtoceras* s.s. ('leachi') and *Lamberticeras* ('lamberti') also occur, and there are the usual Lower Oxfordian Cardioceratids, as in the Volga basin. The unique *Styracoceras balduri* Keyserling sp. (see Neumayr, 1885) is Upper Callovian or Lower Oxfordian (Distichoceratinæ ?).

Another assemblage of special interest is that of the Bimammatum Zone, represented by *Amoeboceras shuravskii* (Sokolov), *A. alternoides* (Nik.) and *A. quadratoïdes* Sokolov non Nik., and other species (Sokolov, 1912, pls. ii, iii), including *A. ovale* (Salfeld) (pl. iii, figs. 9, 10, = bauhini Sokolov).

The Kimeridgian is represented by the ubiquitous *Aulacostephanus* beds; various new species have been described from the region by Khudyayev (1927, 1932) as *A. pyschmae*, etc., in addition to *A. eudoxus*, *A. subeudoxus*, *A. subundorae*, etc., known from the Volga basin and western Europe.

A nodule bed at the base of the Lower Volgian contains rolled specimens of *Amoeboceras* and *Aulacostephanus syssolae* and *subsyssolae* Khudyayev (1932, p. 653). The Lower Volgian is widespread and seems to be represented by the Dorsoplanus and Scythicus Zones only.

Jurassic pebbles occur on the Kanin peninsula to the north-west of the Petchora basin (Ramsay, 1911), and there is little doubt that the Upper Jurassic sea also spread over the northern Urals into the Ob basin, where identical deposits are found in the Liapine and Soswa River districts; but these are in Asia and will be described with the other occurrences in Siberia (p. 512).

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Novaya Zemlya

No Mesozoic beds have been found *in situ* in Novaya Zemlya and it is doubtful whether any exist: the general structure is a complex Palaeozoic anticlinorium, deeply eroded after the Variscan orogeny. A number of well-preserved ammonites have been found in gravels, however, mainly in the middle part of the west coast, and have been figured by Sokolov (1913) and Salfeld & Frebold (1924); see also list in Bodylevsky (1936), and detailed treatment by Frebold (1930; 1951, p. 81). They range in age from *Cranocephalites pompeckji* (Madsen) which is probably basal Lower Callovian to *Tollia* spp. and *Polyptychites* spp. of the Valanginian.

Lower, Middle and Upper Callovian are represented by *Arctocephalites arcticus*, *Cadoceras tschefkini* and *Longaeviceras keyserlingi* respectively, and the Bimammatum Zone by *Amoeboceras regulare* Spath and *frequens* Spath; all as in Petchoraland and Spitsbergen. The supposed Upper Volgian with *Craspedites* cf. *fragilis* (Traut.) and *C*. aff. *jugensis* Prig. is probably Lower Cretaceous (*Subcraspedites* fauna). No ammonites of the Kimeridgian or Lower Volgian have been found.

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FRANZ JOSEPH LAND

The archipelago of Franz Joseph Land contains the most northerly known Jurassic in the world, on latitude 80° N. The outcrops are mainly on the south-westerly Northbrook Island and Hooker Island, but also on some of the adjoining islets. The most complete and best-known sections are at and near Cape Flora on Northbrook Island (Nansen, 1899; Pompeckj, 1899; Koettlitz, 1898; Newton & Teall, 1897). Here Jurassic shales with layers of nodules and sandstone, with up to 14 m. of carbonaceous and pebbly sands at the base, rise from sea level to a height of about 175 m. They are overlain by 25 m. of Cretaceous basalts containing and overlain by plant-bearing sandstones (whence Cape Flora takes its name). At the top is a capping of permanent ice.

The lowest 3 m. of the shale series is a marl containing pelecypods (Meleagrinella, etc.) and brachiopods (Discina, Lingula) believed to indicate a Lower Bajocian date (Pompeckj, 1899). Above this is a considerable gap without fossils. The first ammonite fauna spans a large thickness of beds and represents two Lower Callovian zones with Arctocephalites koettlitzii (Pompeckj, 1899, pl. ii, fig. 12), A. arcticus, A. ellipticus Spath (1932, pl. xiii, fig. 6), A. pilaeformis Spath (Newton, 1897, pl. xl, fig. 2) and Cadoceras frearsi (d’Orb.) (ib. p. 131) (Macrocephalus and Koenigi Zones). (For further figures of this fauna see Whitfield, 1906.) After another gap follow beds with Cadoceras tsechekini (d’Orb.) and Pseudocadoceras nanseni (Pompeckj) (pl. ii, figs. 1-6, and fig. 16, p. 87). Pseudocadoceras is another genus represented in the Hackness Rock, but it abounds also in the earlier Kellaways Rock of South Cave (both in Yorkshire) and it is also abundant in Alaska. Finally, at the top, is a poorly-preserved faunule of Quenstedtoceras (Pompeckj, pl. ii, fig. 9), one of which was found embedded in the base of the basalt (Koettlitz, 1898, p. 638).

Arcticoceras, Pseudocadoceras and Quenstedtoceras are also recorded from Hooker Island (Samoilovich & Bodylevsky, 1933; Oghnev, 1933). The plant-bearing beds are believed to be Hauteurivian-Barremian (Wealden); on some of the islands Berriasian ammonites are recorded below (Spizarskij, 1937).

SPITSBERGEN AND KING CHARLES ISLANDS

Spitsbergen and its associated islands stand on the north-west edge of the Barents shelf. To the west and north the sea floor sinks rapidly. The shallow seas that now divide the islands of the Spitsbergen and Franz Joseph groups and separate them from the mainland may be regarded as a temporary transgression over the margins of the mobile shelf.

Conditions were essentially similar in the Jurassic. A narrow island probably broke the water close to the edge of the shelf immediately to the west of Spitsbergen, supplying some sediment; but in general deep water lay to the west as it does to-day, connecting the polar ocean with Britain. The first Jurassic transgression occurred in the Toarcian, bringing a typical English and NW. German ammonite fauna over Spitsbergen only.
During the Middle Jurassic some narrow and shallow seaways were opened on the shelf, bringing Bajocian pelecypods and brachiopods to Franz Joseph Land and a Bathonian faunule to King Charles Islands.

### TABLE 21.—CORRELATION TABLE FOR THE EUROPEAN ARCTIC

<table>
<thead>
<tr>
<th>Zones</th>
<th>Spitsbergen and King Charles Islands</th>
<th>Franz Joseph Land and Novaya Zemlya</th>
<th>European Russia</th>
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<tr>
<td></td>
<td>Subcraspedites beds</td>
<td>Subcraspedites beds (NZ)</td>
<td>Ryzan Beds pars</td>
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<td>VOLGIAN</td>
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<tr>
<td>Craspedites</td>
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<td>Upper Volgian complete</td>
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<td>Zones</td>
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<td>Blakei</td>
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<td>Scythicus</td>
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<td>Dorosplanus</td>
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<tr>
<td>KIMERIDGIAN</td>
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<td>Rotunda</td>
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<td>Pecinatus</td>
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<td>Subplanites spp.</td>
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<td>Beckeri</td>
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<td>Pseudomutabilis</td>
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<td>Raseniae</td>
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<td></td>
<td>Black shales 193 m.</td>
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<td>Gornostichy Clay</td>
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<td>Bimammatum</td>
<td>Horizons 4 and 5 (23 m.)</td>
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<td>Beds D, C, Moscow</td>
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<td>Transversarium</td>
<td>Not proved</td>
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<td>Beds B, A4, Moscow</td>
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<td>(20 m. no fossils)</td>
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<td>Mariae</td>
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<td>Bed K, Moscow</td>
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<td>CALLOVIAN</td>
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<td>Lamberti</td>
<td>Horizons 2 and 3 (35 m.)</td>
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<td>Quenstedtoceras beds of Cape Flora</td>
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<td>Athleta</td>
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<td>Cad. tschefkini and Pseudodococeras, Cape Flora</td>
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<td>Arctocephalites Arctocephalites</td>
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<td>Coronatum and</td>
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<td>Quenstedtoceras and Peltocecas beds</td>
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<td>Longaeviceras. Erymnoceras and Kosmoceras beds</td>
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<td>Seymourites</td>
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<td>Cad. elatmae and Kepplerites latuseni</td>
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<td>Macrobecephalus</td>
<td>Arctocephalites</td>
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<td>Macrobecephalites</td>
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<td>BATHONIAN</td>
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<td>Zigzag</td>
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<td>Pelecypod faunule</td>
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The major transgression over the whole area, however, came with the Lower Callovian. It brought *Cranocephalites* and then *Arctocephalites* as in East Greenland and Siberia, but not the European Macrocephalidts. Not until the Koenigi Zone, it appears, was direct communication with Britain reopened. This was the real beginning of the great Callovian transgression which united the North Atlantic with the Caspian, across the Barents shelf and the Russian platform as well as most of north-central Europe. With local and minor interruptions, shifting in time and place, this transgressive sea lasted into the Kimeridgian. There is, however,
a major non-sequence of varying size in the Kimeridgian, cutting out everything between the Mutabilis Zone and the Lower Volgian. This non-sequence represents the Pseudomutabilis, Beckeri, Subplanites, Pectinatus and Rotunda Zones of England, central Europe and south Russia (Orenburg). Only the lower part of the Lower Volgian is present, and the Upper Volgian has not been proved in Spitsbergen or King Charles

Fig. 80.—Sketch-map of Spitsbergen and associated islands, showing the Jurassic outcrops in black, and the Cretaceous and Tertiary rocks stippled. After Orvin, 1940. On King Charles Islands much of the Jurassic shown is covered by Cretaceous rocks and basalt.

Islands. The next transgression began as usual with the basal Neocomian, but in the middle of the Neocomian there is a continental phase (Weir, 1933, p. 695). It was perhaps during this phase that occurred the fissure-eruptions of basalt, in and over which are the plant-beds of Cape Flora.

The literature on the Jurassic of Spitsbergen is extensive. An excellent general account of the geology with a coloured geological map is given by Orvin (1940) and another good summary by Allan (1941). Summaries
of the mass of detail for the Jurassic are given by Frebold (1935 and 1951), and in greater detail, with palaeogeographical maps, by Frebold (1930). The standard section, ‘Festungsprofil’, near the southern side of the entrance to Ice Fiord, is described by Frebold (1928) and Frebold & Stoll (1937), and revised with full measurements and stratigraphical placement of each fossil-horizon by Hoel & Orvin (1937). Sections on the east coast of West Spitsbergen have been described by Frebold (1929b), Obruchev (1927) and Tyrrell (1933). (Some references are listed with Greenland, p. 743.) The Jurassic of King Charles Islands has been described by Pompeckj (1899a) and Blüthgen (1936), and summarized in the works by Frebold (1935, 1951).

The following is a summary of the succession:

[BERRIASIAN]
Shales with Subcraspedites of the subpressulus group, comparable to forms in the Ryazan Beds and the Spilsby Sandstone (Spath, 1936, p. 170; earlier recorded wrongly as Craspedites cf. nodiger of the Upper Volgian by Spath, 1921, pp. 351, 353; see also Frebold, 1930, pis. xxvii, xxviii). At the base is a Buchia bed (horizon 21) with species that occur in the Ryazan Beds (listed Sokolov & Bodylevsky, 1931, p. 115).

LOWER VOLGIAN
At least the Dorsoplanus Zone is well represented by numerous Dorso­planites spp. from various localities (Frebold, 1930, pls. x-xiv), but the ‘virgatotome’ ammonites on which the repeated records of the Scythicus Zone are based are much more doubtful when not definitely erroneous (see below). ‘P. sp. indet. aff. nikitini’ (Frebold, 1930, pi. xiv, fig. 3) is, as Frebold rightly stated, indeterminable, and is no evidence for the Nikitini Zone. From additional material, Spath (1952, p. 21) considers that indeterminable Perisphinctids figured by Sokolov & Bodylevsky (1931, pl. ix, figs. 3-5) are Dorso­planites spp.

LOWER KIMERIDGIAN
The extent of the non-sequence below the Lower Volgian may be very considerable. In the monotonous succession of black clay-shales which continues down into the Callovian, subdivision by palaeontology has no lithological props.

The highest identifiable Jurassic ammonite from the Festungsprofil that has been figured seems to be the ‘Virgatites cf. scythicus’ of Sokolov & Bodylevsky (1931, p. 113, pl. viii, fig. 6), from horizon 18, which appears to be an Ataxioceratid. This is only some 15 m. below the top of the black shales and some 31 m. below the supposed top of the Jurassic (Hoel & Orvin, 1937, pp. 24-5). The nearest comparable species, such as Ataxioceras aff. discobolum Font. and A. saxicolum Schneid (1944, Palaeontographica, vol. xcvi, A, pl. i, fig. 1; pl. v, fig. 5) are all from the

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Tenuilobatus Zone. This conclusion is consistent with the absence of the ubiquitous genus *Aulacostephanus* from Spitsbergen and King Charles Islands. The unidentifiable Perisphinctids (*Lithacoceras* ?) (cf. *roubyanum* Fontannes ?) from horizons 18 and 19 (Frebold, 1928, pl. i, figs. 3, 4) are not evidence against it. Hence, if this ammonite is not deceptive, horizons 18 and 19, in the upper part of the black shales, are not 'Upper Portland' but Lower Kimeridgian.

The highest record of *Amoeboceras kitchini* (Salf.) and its allies seems to be in horizon 9, which is 115·95 m. below horizon 18 (Hoel & Orvin, 1937), and records go down for at least 46·5 m., to horizon 6. These thicknesses are large but not unreasonable, by comparison with the Kimeridgian at Kimeridge, where the *Aulacostephanus, Rasenia* and *Pictonia* Zones are together 204 m. thick, of which at least 64 m. are pre-*Pseudomutabilis* Zone, probably more, and Milne Land, East Greenland, where the Lower Kimeridgian *Amoeboceras* shales are 75 m. thick and overlain by 86 m. of shales without identifiable ammonites.

It is to the basal Tenuilobatus Zone (Cymodoce and Baylei Zones of NW. Europe) that the other Kimeridgian fossils figured from Spitsbergen and King Charles Islands belong: for instance, *Rasenia* cf. *groenlandica* Ravn from Thumb Point (Frebold, 1930, pi. xxii, fig. 2), *Rasenia* cf. *borealis* Spath (Frebold, 1930, pi. ix, figs. 3, 4) and the large *Amoeboceras* (*Euprionoceras*) *sokolovi* (ibid., pi. viii, fig. 1). (*Pictoniae and Raseniae* recorded by Spath, 1921, p. 351, were based on *Dorsoplanites*: see Spath, 1935, p. 77).

**UPPER OXFORDIAN**

The Bimammatum Zone is represented by *Amoeboceras* (*Prionodoceras*) *nigrum* Spath (1935, p. 25; Frebold, 1930, pl. viii, fig. 2) and its allies, which include the Novaya Zemlya *Prionodoceras* identified by Frebold (1930, pl. xxiv) with *Cardioceras arcticum* Pavlow. These forms at Festungsprofil seem to span horizons 4 and 5, which are 12 m. apart, the higher 11 m. below horizon 6, and in uniform shales.

**UNDATED**

Between the Upper Oxfordian and Callovian at Festungsprofil there is a gap of 19·8 m., mostly unfossiliferous shales, partly concealed.

**UPPER (AND MIDDLE ?) CALLOVIAN**

From horizon 3 downwards at Festungsprofil are 35·3 m. of shales, including fossil horizons 2 and 3, then 40 m. of alternating shales and sandstones, without fossils, to the base of a conglomerate that rests on the Trias. The ammonites recorded from horizons 2 and 3 (only 3·3 m. apart) are Middle and Upper Callovian: *Cadoceras* (?) cf. *frearsi* Krenkel *non* d'Orb., *Longaeviceras keyserlingi* (Sokolov), *L.* cf. *maxsei* (Krenkel) and *Quenstedtoceras mariae*, which is a loose term, presumably here (as so often) misused (Sokolov & Bodylevsky, 1931, pl. v, fig. 3, which may be a...
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Fragment of *Q. holteähli* Salfeld & Frebold, 1924, pl. i, figs. 3, 4, type from Novaya Zemlya). *Q. lamberti* was collected in King Charles Islands.

**Lower Callovian and Undated**

Possibly part of the 40 m. of unfossiliferous shales and sandstones resting on the Trias at Festungsprofil is represented by shales in Ice Fiord and at South Cape which have yielded *Kepplerites (Seymourites) tychonis* Ravn, *K. (S.) svalbardensis* Bodyl. and *Cadoceras cf. crassum* Mads. (Frebold, 1929, pl. ii, 1930, pl. vii, fig. 1; Sokolov & Bodylevsky, 1931, pl. v, figs. 1, 2), correlating approximately with the Koenigi Zone. On King Charles Islands earlier Lower Callovian is represented by *Arctocephalites arcticus* (Newton) (Frebold, 1951, p. 79).

**Bathonian**

In King Charles Islands the earliest fossiliferous Jurassic, following a thick sandy series, consists of some shaly sandstones containing a pelecypod assemblage which includes such typical Great Oolite forms as *Meleagrinella echinata* (Smith), *M. braamburiensis* (Phil.), *Pteroperna emarginata* Morris & Lyceett and *Lima cf. semicircularis* Goldf. On the strength of this faunule Pompeckj (1899a) assigned the beds to the Bathonian.

No other Bathonian occurs in the Spitsbergen area nor in Franz Joseph Land. It must be emphasized that the placing of the *Arctocephalites* beds in the Bathonian by Spath did not result from 'revision of the ammonites' (Frebold, 1951, p. 79), but was simply a matter of nomenclature, Spath having unfortunately decided to classify the basal Callovian Macrocephalus Zone in the Bathonian. No Bathonian ammonites are known from the Arctic.

**Toarcian**

In several areas (not Festungsprofil) the base of the Jurassic is formed by a phosphatic conglomerate containing Upper and Middle Toarcian ammonites: *Pseudolioceras compactile* (Simpson), 'Coeloceras' polare Frebold, *Dactylioceras annuliferum* (Simpson), *Grammoceras cf. saemanni* (Dumortier), with belemnites and pelecypods (Frebold, 1929, pl. i; 1930, pl. vi; Bodylevsky, 1929). This thin bed has a wide distribution and always rests on Trias. It is a condensed and possibly a remanié bed (Weir, 1933, p. 693).

**Andoe Island, Lofoten Islands**

On the isle of Andoe in the Lofotens, off the north coast of Norway, about 10 sq. km. of the coastal flat is underlain by Jurassic and Cretaceous sediments. The beds are faulted down into the granitic basement in a way similar to the outliers in the Hebrides. They are almost completely concealed by Quaternary deposits and are known only from borings for coal. The total thickness is at least 510 m.

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The sequence begins with about 60 m. of sandstones, often rather coarse, with seams of coal and also beds of bituminous shale and fireclay. On the evidence of the plants the age is Middle Jurassic. Above follow at least 325 m. of sandstone. A dark grey micaceous sandstone not more than 150 m. above the base of the series and 90 m. above the coal beds yields *Amoeboceras alternans* auct., *Perisphinctes* sp., *Gryphaea dilatata* and other pelecypods, and is therefore Oxfordian. Above are numerous species of *Buchia* and some *Perisphinctids* (Sokolov, 1912, pl. i), and at the top 125 m. of shales from which a Neocomian 'Crioceras' is recorded (Sokolov, 1912; Vogdt, 1905; Lundgren, 1894).
CHAPTER 21

NORTHERN ASIA

THE CONTINENT OF ASIA AND THE ANGARA SERIES

During the whole of Jurassic time a continuous continent stretched from the Urals to the coast of China. Before the shallow Callovo-Oxfordian flooding of the Russian platform in eastern Europe, continental land extended also west of the Urals to join the Scandinavian shield, so that the Asian continent reached from the Pacific to the North Atlantic, as at the present day. Those who see any advantage in doing so follow Grabau and call this continent Pal-Asia.

Its boundaries, it is true, were different from those of the present day; but the shapes of all the continents have repeatedly changed throughout geological time. Much of the south of the present Asia was submerged beneath the Tethys, or detached by it (Peninsular India). The northern boundary of Tethys ran approximately along a line drawn from the Aral Lake to Hong Kong. From the north and NE. the continent was invaded by arms of the Arctic Ocean, which extended up the present valleys of the Ob and Lena to about latitude 60° N. but avoided the intervening Siberian Platform and Taimyr. Another arm extended from the east up the Amur valley into Transbaikalia. Sea also covered most of the extreme north-east of Siberia, beyond the Lena.

Unlike Africa, Asia does not, and did not in Jurassic times, consist of one immense pre-Cambrian shield, but of several smaller ones welded together. The largest is the Siberian Platform, lying roughly between the Yenesei and the Lena and between the Arctic coast and Lake Baikal. It is much more encumbered by later sediments than the Scandinavian shield. This is the Angara Land of Suess, but Suess’s concept has been enlarged and modified by subsequent discoveries. The ranges of mountains which lap like a letter U round the south and south-east of the ‘amphitheatre of Irkutsk’ have turned out to be no ‘ancient vertex’ but the front ranges of a late Jurassic or early Cretaceous orogenic belt that was of great importance in eastern Asia.

Farther south several smaller shields or ancient nuclei occur, notably under the Gobi and Tarim deserts, the Ordos and northern Tibet. They are swathed around and cemented together by fold ranges, as yet little known in detail, but at least in large part of Jurassic date. According to Vialov (1939) the nuclei and orogens have a linear arrangement that stretches right across Asia from west to east; but a less regular pattern such as was sketched by Grabau (1928, p. 292) seems more likely. In such a vast orogen these minor nuclei dwindle to the rank of median masses, analogous with those in Europe and Anatolia, and with the Iranian Plateau.
In this greatest of all orogens, involving all east Asia, the Cretaceous plays the role of unconformable transgressive cover and the Jurassic is generally involved in the folded basement. In many parts of China and eastern Siberia the Jurassic is intensely deformed and metamorphosed, whereas the Lower Cretaceous (Wealden?) is horizontal. In other places the Lower Cretaceous also is deformed and unconformably overlaid by Middle or Upper Cretaceous deposits. The movements were accompanied by widespread and intense magmatic activity. Granite batholiths were intruded as in North America, and in many places volcanoes ejected great thicknesses of lavas, tuffs and agglomerates. In Mongolia and elsewhere the volcanic series overlies the Jurassic (or supposedly Jurassic) continental formations but shares the same pre-Cretaceous folding (Berkey & Morris, 1924). The movements are known collectively as the Yenshan orogeny, of which three principal phases are recognized: late Jurassic, Lower Cretaceous, and Upper Cretaceous (Wong, 1926, 1929; T'an, 1926; Chang, 1933; Chu, 1939; Becker, 1939; Lee, 1939).

There is thus a great contrast between the western and eastern parts
of Asia. In the west the last orogeny occurred in Triassic times, when the Urals received their last and probably main folding (Vialov, 1939). With this episode the Angara and Scandinavian shields were welded together. The Ural folds—which may be traced far to the east of the present mountains, under the Ob basin—were planed down before deposition of the Jurassic rocks, and there were no further major disturbances west of the Lena. The plateau basalts and dolerites of Angara Land are also Triassic, like the Karroo lavas and dolerites, and were eroded to remnants before the Jurassic Angara Beds were deposited (Odintsov, 1937). (Some intrusive dolerites in the Kuznetsk coal basin, which intrude Middle Jurassic coal measures (Yavorsky, 1937), may be much later.)

This stable western region belongs tectonically with European Russia and, like it, was not invaded by the sea until the Upper Jurassic, and then by a tongue of the Arctic Ocean which spread south on both sides of the Ural Mountains and left relatively thin deposits. In the east, on the contrary, geosynclines were actively forming during the Jurassic around and between the horsts. The deposits laid down in these troughs, partly marine but mainly continental or brackish, reached thousands of metres in thickness while those forming farther west reached a few score or at most hundreds of metres. The greatest thickness of Jurassic recorded is about 7500 m. in Mongolia, largely conglomerates and sandstones. On the Kolyma River in extreme NE. Siberia 6000 m. is reported, and 2000 to 4000 m. is common in the Amur geosyncline and elsewhere towards the Pacific coast.

Like Australia during the Jurassic, Asia was largely covered by freshwater lakes, in which collected conglomerates, sandstones, shales and coal measures. The important coal measures of Siberia and China belong mainly to this period. The flora is not uniform all over the continent. From the Ob to Transbaikalia conifers predominate over cycads and ferns, whereas farther east and south-east ferns take first place and cycads second, indicating a warmer and damper climate towards the Pacific (Obrutschew, 1926, p. 330). Farther south red beds and lack of flora indicate aridity in the interior (Kobayashi, 1942). The Angara flora has been the subject of many studies, and the stratigraphy of the Angara Beds and their plants is a vast subject outside the scope of this book. Excellent summaries will be found for Siberia in Obrutschew (1926) and for China in Lee (1939). (See also Bexell, 1935; Nagibina, 1946; Leuchs, 1935). In the type sections along the Angara River, between Irkutsk and Lake Baikal, the Jurassic conglomerates, sandstones and coal measures are overthrust by pre-Cambrian gneiss and granite, mylonitized along the thrust-plane, which is in turn folded (Tetiaev, 1937). Near Lake Baikal the Jurassic is represented by polygenetic conglomerate with lenses of arkose, resting on Lower Cambrian; in the north it is only gently inclined, but towards the south end of the lake it becomes intensely folded and cleaved, and is finally overfolded by pre-Cambrian granite (Tetiaev, 1937a). This region, which from information then available
Suess inferred was undisturbed since the earliest geological times, is on
the boundary between the stable Siberian Platform and the belt of Yen-
shanian folds to the south and south-east.

Farther east in Transbaikalia, freshwater faunas are found in the upper
part of a succession of almost undisturbed lake-beds in the basins of the
Turga and Vitim (= Witim) Rivers, respectively south-east and north of
Chita (Reis, 1910; Egger, 1910). Besides plants there are freshwater
fish, Estheriae, ostracods, insects, pelecypods (Cyrena) and gastropods
(Limnaea, Viviparus, etc.). One peculiar minute gastropod, Cerithium
gerassimowi Reis, is closely similar to, but not identical with, Promatildia
(Teretrina) microbinaria Arkell, of the Dorset Purbeck Beds. The precise
age of these beds is, as usual, uncertain. Obrutschew (1926, pp. 315-7)
regarded them as Upper Jurassic, Grabau (1928, pp. 710-4) as Cretaceous.
Suzuki (1949), on the basis of a review of all known East Asian freshwater
and brackish molluscan faunules, classes them with a widespread suite
which he calls the Jehol fauna, and correlates this with a number of Chinese
faunules (e.g. the Mengyin, with the same Estheriae) regarded by Chinese
geologists as Cretaceous (Lee, 1939, p. 421, etc.). Suzuki (1949), building
on the more recent results obtained in Japan, regards all these as Upper
Jurassic (= Tetori formation of Japan; see p. 425). Mr P. C. Sylvester-
Bradley has kindly examined Egger's figures of the ostracods but informs
me that they do not enable him to make any suggestions as to the date of
the beds.

Great advances towards more accurate dating of the Mesozoic floras
of Asia may be expected when assemblages have been collected in situ
in the regions where marine intercalations with ammonites are now known,
as in the Pamirs and many places in Siberia. The key region for the far
east is Japan, where the subject has been put on a firm basis by Kobayashi
(1939a, 1942, 1942a).

THE MARINE JURASSIC OF SIBERIA

Basin of the River Ob

East of the Ural Mountains a broad tongue of the Arctic Ocean
extended transgressively in the Upper Jurassic up the valley of the River
Ob, over the northern part of the sunk plain of western Siberia. The plain
is now thickly covered in Quaternary and late Tertiary deposits, the
northern part under glacial drift, but older rocks show occasionally along
the rivers. The most southerly marine Jurassic is recorded beneath
drift on the Great Yugan River, a southern tributary of the middle Ob
(about latitude 60° N., longitude 74° E.) (Obrutschew, 1936, p. 907). On the basis of belemnites and pelecypods only, it has been interpreted
as Upper Volgian (Bodylevsky, 1936).

Farther south, in the Kazakh Uplands and along the central and southern
Urals, the Jurassic is represented by its plant-bearing continental facies,
and it appears certain that (as inferred by Suess) the northern Jurassic
sea never linked up with the southern ocean through the depression north of the Aral Lake, which Suess called the 'Straits of Turgay'. On the eastern slopes of the southern Urals, between Cheliabinsk and Orsk, the plant-bearing beds are 200-400 m. thick. They rest horizontally against the planed-off Palaeozoic and pre-Cambrian rocks of the Ural folds, which were elevated and peneplaned in the Trias, and westward they are overstepped by the Upper Cretaceous (Senonian) until they wedge out (Razumovskaya, 1937, p. 73). The continental Jurassics reappear on the west slopes of the Urals also, and there interfinger towards the west and south-west with the marine facies in the north Caspian depression (see p. 487).

The marine Upper Jurassic is known chiefly on the Rivers Soswa and Liapine (= Sygwa), which drain the northern Urals between latitudes 62 and 65° N. and when united continue, as the Soswa, to flow eastwards to join the Ob (Ilovaisky, 1903, 1906, 1917). The oldest Jurassic ammonites from this region are *Amoeboceras* (‘Cardioceras alternans’) which, in the absence of figures, might be Upper Oxfordian or Lower Kimeridgian. This is also the type area for *Rasenia uralensis* (d’Orbigny) (Rivers Tehol and Tolya, about latitude 64° N.). Most conspicuous, however, is the *Aulacostephanus* assemblage of the Pseudomutabilis Zone; but *Aspidoceras* has not been found. The Lower Kimeridgian shales appear to overlap westward against easterly-dipping Devonian and crystalline rocks of the Urals. *Rasenia cymodoce* and *Amoeboceras ovale* are recorded (Sirin & Shmakova, 1937).

The higher Kimeridgian is richly represented by several faunas of *Pavlovia, Dorsonplanites* and *Stschurovskya*. The succession still remains to be worked out, and differences between the Liapine and Soswa Rivers indicate that it may not be straightforward (Ilovaisky, 1906, p. 262). The Liapine River is the type area for the genus *Pavlovia* (based on *P. iatriensis* Ilovaisky, 1917). Ilovaisky’s intended monograph on these ammonites was unfortunately never completed.* At least the higher parts of these beds—largely green sandstones—represent the lower part of the Lower Volgian. Upper Volgian is also reported (Volkov & Jacjuk, 1937). The highest Jurassic beds (12 m.) are unfossiliferous. They are overlain by Berriasian green sandstones with *Paracrasedites spasskensis* of the Upper Ryazan Beds, and this is succeeded by Valanginian *Polyptychites* beds.

**Basin of the Anabar River**

According to the palaeogeographic maps of Archangelsky (1939, p. 300) the Jurassic sea in the basin of the Ob was connected north-eastward across the Yenesei estuary, by way of the valley of the Khata River and the lower Khatanga River, with the Arctic Ocean at the mouth of the Lena, cutting off the Taimyr Peninsula as an island. Obrutschew (1926, pl. 7) showed the postulated Jurassics (entirely concealed under Quaternary

* Only Part 1 appears to have been published, in 1917 (see Obrutschew, 1926, p. 204), and of this no copy is known to exist in Britain or America (Spath, 1936, Cape Leslie, p. 26, note 5; and personal enquiries in the U.S.A.). D. Ilovaisky died in 1939.
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drifts) in the connecting territory as ‘problematic’, and in the 1937 geological map of the USSR (ed. Nalivkin) they are all coloured as Cretaceous. Erratics found in the lower Yenesei valley are not earlier than Upper Cretaceous (Alexandrov, 1938).

The first authentic Jurassic east of the Yenesei seems to be that on the Anabar River (between longitude 110° and 115° E.), monographed by Pavlov (1913). So far from indicating any connexion with the basin of the Ob, the ammonites are entirely different, all belonging to older stages unrepresented in the basin of the Ob. According to available evidence, the two basins of the Ob and Anabar-Lena were not submerged simultaneously, and so the question of their connexion does not arise.

Ammonites collected for about 30 miles up the Anabar from the Arctic coast, figured by Pavlov (1913), belong to three stages: Upper Pliensbachian, represented by Amaltheus depressus (Simpson) and Phylloceras hebertinum Reynès; Lower Callovian, represented by Cadoceras elatmae Nikitin and Arctocephalites (?) sp. (pl. xviii, fig. 2); and Lower Oxfordian (Cordatum Zone), represented by a rich and extremely interesting fauna of Cardioceratids. Apart from some belemnites of supposed Volgian date, the next-higher assemblage is a magnificent fauna of Valanginian Polyptychitids.

Perhaps the highlight of these collections from the 73rd parallel is the Phylloceras, so generally supposed to be an essentially Tethyan genus (and even suborder). Its association with a Yorkshire species of Amaltheus suggests that it travelled by way of the North Atlantic and Arctic Oceans, from which direction certainly came the Callovian ammonites of Russian and Arctic affinity; but a more probable route (in view of the Lias of Japan) was from the Pacific by way of the Sea of Okhotsk and across the peninsula of east Siberia where the Verkhoyansk and other post-Jurassic mountains now stand. It was along some such route, presumably, that in the Lower Callovian Seymourites travelled from the Arctic (Spitsbergen, E. Greenland) to Japan (see p. 426).

The Cardioceratids of the Cordatum Zone in this remote and isolated region are of great interest for their affinities with and differences from their closely-related contemporaries in Britain, some 3100 miles away. The true C. cordatum (Sowerby) occurs (Pavlov, 1913, pl. xiv, fig. 5). Some of Pavlov’s other species are intermediate between English species, or differ but slightly from them, while yet others are quite different from anything known in any other part of the world. Forms of both the Cordatum and Costellatum Subzones of England are represented, and one day no doubt field-work will establish whether they are separate stratigraphically. (For discussions of this fauna see Arkell, 1946-8, Mon. Am. English Corallian Beds, pp. 318, 333-5, 381-2, etc., Palaeontogr. Soc.)

Callovian ammonites have also been found on the islands off the mouth of the Khatanga River (Sokolov, 1916, summarized in Obrutschew, 1926, p. 296). Cranocephalites is said to occur in this region (Moor, 1937).
North-Eastern Siberia and New Siberian Islands

On the New Siberian Islands *Cadoceras* cf. *elatmae* with insects and plant-beds are reported (Obrutschew, 1926, p. 299). On the mainland east of the Verkhoyansk Range there are widely distributed outliers of a variety of marine and continental Jurassic rocks, comprising shales and sandstones and in places tuffs and porphyrites, the whole forming sequences 2000 m. thick. In the Zyrianka depression (on the Kolyma River) there are sandstones with plants and shales reaching 6000 m. in thickness (Kropotkin & Kheraskov, 1939). Much still remains to be done, however, in the dating of the formations in this intensely folded region. Marine Lower Liassic with *Dactylioceras*, *Porpoceras*, etc., are briefly recorded for 'the eastern part of the Arctic region of the USSR' (Bodylevsky & Kiparisova, 1937). Possibly this refers to eastern Transbaikalia, mentioned on p. 515, but marine Toarcian overlain by Lower Callovian with *Arctocephalites* is known to exist in the Kharaulakh Mountains, at the north end of the Verkhoyansk Range, east of the lower Lena (Nikolaev, 1938). Later ammonites are not known, but some other fossils suggest that Oxfordian and Volgian exist there also.

Valley of the Lena and Basin of the Vilui River

During the Lower and Middle Jurassic, at least, a shallow gulf of the sea extended up the valley of the Lena into the heart of east-central Siberia and spread out south-west over the region now occupied by the basin of the River Vilui (= Vilyuy, Wilui, Viljuj). Before the Late Jurassic or Cretaceous orogeny, when the arc of Verkhoyansk was uplifted and thrust over the foreland that is now the Lena-Aldan valley, this Jurassic gulf or trough probably connected eastward with the as yet little-known Jurassic just mentioned, and with those of Japan by way of the Sea of Okhotsk.

In the basin of the Vilui (chief western tributary of the Lena) (latitude 62° N., longitude 116-118° E.; see map in Rzasnicki, 1918, p. 61), marine Lower Bajocian with *Ludwigia murchisonae* has long been known, inter-stratified with plant-bearing Angara Beds. According to revision by Krimholz (= Krymgolc) (1950), the marine beds, which are 100-150 m. thick and separate a lower and upper series of continental plant-beds, consist themselves of three distinct horizons. The lowest horizon is without ammonites, but on the evidence of pelecypods is assigned to the Pliensbachian; the middle horizon yields *Dactylioceras athleticum*, *D. gracile*, belemnites and pelecypods, and is clearly Toarcian; and the highest is Lower Bajocian, with *Ludwigia murchisonae*.

The lower continental series, which must be of Lower Liassic age, is 50-60 m. thick and consists largely of conglomerates, alternating with lenticular masses of sandstone. The conglomerates are polygenetic. The upper continental series may be Cretaceous, in part or in whole. A similar

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tripartite series, 400 m. thick, with a Bajocian marine term in the middle, occurs at Yakutsk on the middle Lena (Soikkonen, 1938).

**Eastern Transbaikalia**

On the same longitude as the occurrences in the Vilui basin but some 700 miles farther south (between latitude 50°-51° N. and longitude 115°-119° E.), near the Trans-Siberian railway, the following sequence of marine Lower and Middle Jurassic faunas occurs (Khudyaev, 1931). The beds are strongly folded along NE. axes and sometimes overfolded to the north-west, and have been intruded by granite and by porphyrite dykes. Plant-beds occur at several horizons. The series is at least 2400 m. thick, not counting the 1000 m. of undated conglomerate.

**Undated Conglomerate (more than 1000 m.)**

**Upper Bajocian (and Bathonian ?) (1100 m.)**

Thin sandstones with rare seams of sandy shale; often grading into arkoses, especially upwards. In the lower half Garantiana cf. bifurcata (Ziet.), G. sp., Lytoceras sp. indet. In the upper half Perisphinctes sp. indet. and a fauna of pelecypods largely identical with English Great Oolite species, including Meleagrinella echinata (Wm. Smith).

**Middle Bajocian? (300 m.)**

Shales alternating with sandstones and grading horizontally into pebbly sandstones and locally conglomerates. Pelecypod fauna, no ammonites.

**Lower Bajocian (120 m.)**

Lithologically similar, but yielding Leioceras cf. opalinum (Rein.), Pachylytoceras torulosum (Zieten), belemnites and pelecypods.

**Toarcian (340-360 m.)**

The upper 180-200 m. consists of conglomeratic sandstones grading horizontally into shales with gravel and sandstone interbeds, and contains Trachylytoceras cf. rubescens (Dum.), Pseudolioceras subconcauum (Y. & B.), Whitbyceras cf. lythense (Y. & B.), Porpoceras andraei (Simpson), Dactylioceras braunianum (d'Orb.), D. vermis (Simpson) and many pelecypods.

The lower 160 m. consists of shales with rare pyritic nodules and in its upper part yields Dactylioceras aff. athleticum (Simpson), D. cf. annulatum (Sow.) and D. aff. gracile (Simpson).

**Pliensbachian (295 m.)**

Shales with Beaniceras cf. centaurus (d'Orb.) in the upper part and Uptonia jamesoni (Sow.), Uptonia spp. and other ammonites in the lower part.

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UNDATED (LOWER LIAS)

- Shales with *Nucula* spp., 50 m.
- Shales with rare pebbles and *Crenatula* and *Hinnites*, 100 m.
- Conglomerate, believed basal, 80 m.

The Jurassic has been observed in some parts of Transbaikalia to rest unconformably on the Lower Carboniferous (Luchitsky, 1947). The upper conglomerate, which rests on the Middle Jurassic, may be Cretaceous, for in Transbaikalia the Jurassic tends to be overlapped towards the south-east by Cretaceous conglomerates and continental plant-beds of similar facies (Nagibina, 1946). The lake beds with freshwater fauna on the Turga and Vitim Rivers are referred to on p. 511.

**Basin of the Bureya River**

On the same latitude as the previous section but about 500 miles to the east, in the Amur geosyncline, marine Lower and Middle Jurassic and Lower Callovian faunas occur in a Jurassic succession nearly 4400 m. thick, underlying the coal series of the Bureya basin. The Bureya is a SW.-flowing left-hand tributary of the great Amur River, which forms the boundary between Siberia and Manchuria. The Jurassic system rests on eroded granite and consists as usual of sandstones and shales, in which five cyclic changes of grain-size have been noted. Fossils are poorly preserved. The succession (Krimholz, 1939) may be summarized as follows:

- **Coal Series**: the flora has been variously claimed as Jurassic and Cretaceous
- **Alevrite Series**: fine-grained silts, no fossils
- **Modiolus Series**: shales with *Modiolus* spp., *Meleagrinella* spp. and two Lower Callovian boreal ammonites: *Arctocephalites orientalis* Krimholz and *Cranocephalites era* (Krimholz) (pi. ii) 1759 m.
- **Shales without fossils** 909 m.
- **Inoceramus Series**: sandstones, becoming coarse towards base. Lower Bajocian ammonites: *Ludwigia brasili* (Buckman), *Hammatoceras* sp. and many pelecypods, especially *Inoceramus* 530 m.
- **Lias Sandstones**, fine-grained, becoming coarse, arkosic downwards. The upper part Toarcian, with *Pseudolioceras* cf. *whitbiense* Buck., belemnites and *Oxytoma*. The middle part Upper Pliensbachian, with *Amaltheus margaritatus* (pi. ii, fig. 4) and *Oxytoma* spp. The lower part unfossiliferous 694 m.

The resemblance of the ammonite faunas to the Vilui and Anabar River successions is striking. The contrast with European Russia (central and northern) and the Ob basin could not be greater. While the east of the continent was submerged the west was emerged, and *vice versa*: only in the Lower Callovian were both submerged together. And in the east the submergence was geosynclinal, in the west it was a neritic transgression over a stable shelf.

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Sikhota-Alin and Vladivostock Area

Along the east coast, from the south side of the Sea of Okhotsk to Vladivostock, the Jurassic is developed mainly in the Angara facies, with both plant-beds and volcanics, but in places there are vestiges of marine incursions of imprecisely determined dates, so far not known to yield identifiable ammonites. For the most part they are believed to be Bajocian, with perhaps Bathonian, but near Vladivostock there is probably also some marine Lias and Lower Bajocian belonging to the Japanese province. The records of Wittenburg (1909) were shown by M. K. Eliaschewitsch (now Professor Maxim K. Elias of Nebraska University) to be in part based on misidentifications of Palaeozoic fossils. The total thickness of beds assigned by Elias to the Jurassic amounts to 3750 m. (Summarized in Obrutschew, 1926, pp. 299-301, 321-4, 480-3.)

[Indo-China and Hong Kong are dealt with in the chapter on Indonesia, p. 433.]
PART VII
AMERICA AND ANTARCTICA
CHAPTER 22

GREENLAND AND THE AMERICAN ARCTIC

Jurassic sediments fringe the Greenland shield only in a strip of fiords and islands on the east coast, from 70° to 77° N. latitude. They are the only Jurassic sediments existing above sea-level anywhere on the east side of the American continental shields. The rocks consist of shallow-water, almost entirely clastic, sediments, characterized at most levels by abundance of mica and, as in other Arctic regions, by paucity of limestones. They rest indifferently on gneiss, Caledonian granite and Palaeozoic and Triassic rocks. They begin in some places (Scoresby Sound area) with Rhaetian-Lower Lias deltaic beds containing abundant warm-temperate fossil plants as in Scania and Germany; in other places with a basal conglomerate and unfossiliferous sandstones probably of late Middle Jurassic age. Dark ammonite shales are developed in the Lower and Upper Kimeridgian and Lower Portlandian, and part of the Lower Portlandian has much glauconite; so that lithologically as well as palaeontologically there is considerable resemblance to north Russia and England. The total thickness amounts to about 1400-1500 m. (excluding Rhaetian).

In general the Jurassic rocks of Greenland represent a series of transgressions of the 'Scandic Ocean' over the block-faulted, irregularly downsinking continental margin. They were laid down on the opposite shore of the same ocean as that which eastward overspread the Barents shelf, leaving its deposits in Spitsbergen and Andø and both sides of the Scottish Highlands. The western boundary against the Greenland gneiss was determined by an ancient fault-line, comparable with those exposed in Sutherland and Scania. The fault was active in the Caledonian and Variscan revolutions, and during the Jurassic the downthrown coastal strip sank irregularly, with differential tilting of fault blocks. The middle part remained above water, dividing the Jurassic outcrops into a northern and a southern area.

The northern area, comprising Clavering Island, Wollaston Foreland, Kuhn Island and northward to Koldeway Island (fig. 83), has Upper Jurassic and Lower Cretaceous sediments only. The Callovian 'Yellow Series' is transgressive on Permian or older rocks and there is a conformable sequence up to Upper Kimeridgian. Then occurred a phase of faulting, with westward tilting of the fault-blocks. In places the tilted Kimeridgian is directly followed by transgressive Valanginian. But in Wollaston Foreland and Clavering Island conglomerates believed to be of Lower Volgian and Portlandian date transgress unconformably over older rocks down to Caledonian gneiss (Maync, 1947). These

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movements occurred contemporaneously with the principal phase of the Nevadan orogeny that affected the western side of North America, from Alaska to California.

In the north of the southern sedimentary area, Jurassic fossils occur on Geographical Society Island (fig. 83), where a 400 m. series of sands, sandstones and conglomerates overlies beds of probably Triassic age and is believed to be Callovian from its resemblance to the ‘Yellow Series’ farther north (Donovan, 1949, 1955 or 56). Marine Jurassic fossils also occur on Traill Island (Donovan, 1953). In the south-west of the area, in Milne Land, a 200 m. unfossiliferous sandstone (Charcot Bay Sandstone) begins the Jurassic sequence, resting directly on granite; it is followed by shales of Upper Oxfordian date, and above this by the fullest sequence of Upper Jurassic faunas known in Greenland.

For the Lias and Callovian the principal centres are southern Jameson

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Land and a small area on Liverpool Land, both on the north shore of Scoresby Sound, each side of Hurry Inlet, which divides the two lands (fig. 83). By far the greater part of Jameson Land is covered by drift, but the Lower Jurassic and Rhaetian sediments crop out along the west coast of Hurry Inlet, forming Neill's Cliffs (pl. 24). These cliffs rise from about 30 ft. above sea near Cape Stewart, at the south end, to 2000 ft. farther north, then gradually sink again, but continue west of the isthmus to form the west coast of Carlsberg Fjord, a total distance of about 2 degrees of latitude. Inland the ground rises and provides scattered outcrops of higher Jurassic rocks, culminating in a bare Kimeridgian plateau. The general dip is to the SW. or west, off the crystallines of Liverpool Land. This tilt is of late- or post-Jurassic date, for the sediments appear to be all derived from the mainland on the west; Liverpool Land is an uptilted fault-block.

Milne Land is much freer of Drift and the Upper Jurassic rocks rise in a series of terraces from the east coast north of Cape Leslie to a mountain ridge, capped with a 330 m. Portlandian-Volgian-Valanginian sandstone (Hartzfjaeld Sandstone). Here the general dip is to the east.

Authoritative general accounts of the geology of Greenland have been published by Lauge Koch (1929, 1929a, 1935), based on his forty years of explorations. Most of the rest of the available information has been published by participants in his numerous expeditions, or by specialists to whom their collections were entrusted. The following summary is based on works by Frebold (1933), Rosenkrantz (1934, 1942), Aldinger (1935, 1937) and Maync (1947; also Cretaceous, 1934, 1939), using as framework monographs on the ammonites by Spath (1932, 1935, 1936, 1947, 1952), Donovan (1953) and (for the Lias) Rosenkrantz (1934). Earlier figures of ammonites will also be found in papers by Madsen (1904) and Ravn (1911). The succession down to the Oxfordian refers chiefly to Milne Land, the thicknesses being mainly after Aldinger (1935); that for the Callovian and Lias refers to Jameson Land. The Callovian ammonite beds are also well developed on Traill Island (Donovan, 1953; Muir-Wood, 1953).

[BERRIASIAN (160 m.+)]

An exceptionally interesting development occurs in the northern area, on Kuhn Island and Wollaston Foreland, on opposite shores of Linde- mans Fjord. Here the succession worked out by Maync (1947; 1949, pp. 28-32, 95-101), with revised determinations by Spath (1952), is as follows:—

**TOP**

- Level with *Tollia payeri* (Toula) 
  130 m. without ammonites
- Level with *Hectoroceras kochi* Spath (first described from Jameson Land: Spath, 1947) 
  12 m. without ammonites

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Micaceous shale with *Praetollia maynci* and *P. aberrans* Spath (1952)
9 m. + without ammonites

Basal conglomerate with *Subcraspedites* aff. *preplicomphalus* Swinnerton and *S.* (Paracraspedites) aff. *spasskensis* (Nikitin), also derived *Stschurovskya* spp. (= 'Laugeites') and other Portlandian ammonites (10 m.)
20 m. of shales and sandstones without ammonites

The *Subcraspedites* zone also occurs in Jameson Land and Milne Land. It correlates with the Ryazan Beds and the Spilsby Sandstone, which latter likewise contains derived Portlandian ammonites. In Milne Land it is the highest fauna found in the Hartzfjæld Sandstone, which is 330 m. thick and ends with 100 m. of Cretaceous plant-beds of uncertain date (Aldinger, 1935, p. 51).

**UPPER VOLGIAN (80-90 m.)**

Most of the upper part of the Hartzfjæld Sandstone probably belongs to the Upper Volgian. From it have been obtained, in Milne Land, *Craspedites leptus* Spath and *C. ferrugineus* Spath (1936, p. 85): species represented by small and poorly-preserved material, not identical with anything known from the Russian Volgian. At one locality, associated with a small fragment of a *Craspedites*, was found a fragment of a large ammonite body-chamber compared to *Titanites*; but considering the many contradictions and uncertainties revealed by study of the Milne Land collections (Spath, 1936, p. 142) and that this 'doubtful fragment' (ibid., p. 162) was 'loose' (p. 68) and that 'specific identification is, of course, out of the question' (p. 67), no reliance can be placed upon it as to the mutual stratigraphical relations of *Titanites* and *Craspedites*. No other Upper Portlandian ammonite was found in Greenland (ibid., p. 162).

**LOWER VOLGIAN AND PORTLANDIAN (125 m. +)**

The Lingula Bed near the middle of the Hartzfjæld Sandstone (70 m. above the base) has yielded the genus *Stschurovskya* Ilov. & Flor. 1941 (= 'Kochina' Spath, 1936, preocc., = 'Laugeites' Spath, 1947) belonging to a species (*S. groenlandica* Spath sp. 1936, p. 82) close to the type species of the genus, *S. stschurowskii* (Nik.), of the Russian Lower Volgian. Beneath come 70 m. of unfossiliferous Hartzfjæld Sandstone, then 20-30 m. of sandy shales with *Dorsoplanites gracilis* Spath and forms of the Gorei Zone of the upper Portland Sand, assigned variously to *Glaucolithites* Buckman and *Crendonites* Buckman (by Spath to the latter; 1936, p. 62). Some of them are described as 'almost indistinguishable' from English ammonites of the group of *G. gorei*, but all are assigned to new species. This assemblage can be dated confidently to the Gorei Zone of the Lower Portlandian.

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The lower part of the Portland Sand (Albani Zone) is probably represented by at least the upper part of the underlying Glauconitic Series (total 50-80 m.), from which come various *Pavlovia* and a large ammonite (originally 600 mm. in diameter) belonging to a many-whorled group characteristic of the English Portland Sands, for which several of Buckman's numerous generic names could be used. (Spath, 1936, p. 66, assigns it to *Behemoth*.)

Dorsoplanitinae also occur in conglomerates on Kuhn Island and Wollaston Foreland, with *Stschurovskya* (Maync, 1949, pp. 31, 98; Spath, 1947, p. 58).

**Upper Kimeridgian (126 m.?)**

The section in Milne Land (fig. 83) continues downward with 90 m. of sandy clays and sandy micaceous marls, with nodules. In the (presumed) upper part are numerous *Pavlovia* comparable with those in the Rotunda and Pallasiodes Zones, and in addition *Dorsoplanites* spp. Some of the species continue up into the Glauconitic Series. In the (presumed) lower part were collected six species of *Pectinatites* which correlate satisfactorily with the Pectinatus Zone.

**Middle Kimeridgian (86 m.?)**

Below the *Pectinatites* beds come 86 m. of shales, said to be unfossiliferous except for a thin band (50 m. up) of crushed Perisphinctids. These are unidentifiable but have been tentatively assigned to *Subplanites* and *Sphinctoceras* (Spath, 1936, pp. 13-17). An earlier record of *Aulacostephanus* requires confirmation (ibid., p. 143).

**Lower Kimeridgian (75 m.)**

Next below in Milne Land come 75 m. of *Amoebites* Shales. In these Spath (1935) recognized four successive ammonite horizons as follows:—

4. At top, oil-shales with *Amoeboceras* (*Hoplocardioceras*) *decipiens* Spath, a deceptively *Aspidoceras*-like form with two rows of lateral tubercles, figured also from Kuhn Island (Frebold, 1933, pl. i, figs. 1-4). It is known only from Greenland.

3. Oil-shales with *Amoeboceras* (*Euprionoceras*) *kochi*, another large distinctive subgenus, known only in Greenland and Spitsbergen. The precise date of both horizons in terms of the European zonal scheme is uncertain.

2. Shales with *Rasenia borealis* and various *Amoeboceras*. This is dated to the Cymodoce Zone.

1. Shales with *Rasenia orbignyi*, *R. inconstans* and *Amoeboceras* spp., corresponding to the Baylei Zone. This assemblage is probably represented also in Jameson Land.

Donovan states that in Traill Island and the northern area there are at least 500 m. and 635 m. respectively of black shales, largely of Lower Kimeridgian age.
UPPER OXFORDIAN (270 m.)

At top of the Oxfordian is the Pecten Sandstone (70 m.), with rare ammonites; so far only *Amoeboceras (Prionodoceras)* aff. *alternoides* (Nik.) and *A. (P.) superstes* (Buckman non Phil.) have been figured (Spath, 1935, pl. i, figs. 2, 4).

Below follow 200 m. of sandy, micaceous shales with layers of concretions. From ‘a few metres’ below the top were collected *Ringsteadia*

![Sketch-map to show the Jurassic outcrops of East Greenland. After Koch, 1950.](http://jurassic.ru/)

sp. indet., *Amoeboceras (Prionodoceras)* aff. *pseudocaelatum* Spath and *A. (P.) transitorium* Spath. Both these assemblages are of the date of the Decipiens and Pseudocordata Zones.

From somewhere in these shales (presumably lower down) was collected *Cardioceras (Subvertebriceras)* aff. *zenaidae* Ilov. (Spath, 1935, pl. ii, fig. 3), which is the sole representative of the Plicatilis Zone. Perhaps of the same date is a *Cardioceras* from Jameson Land recorded as *C. caelatum* Pavlov (ibid., pp. 74, 75).

UNDATED (200 m.)

In Milne Land no earlier Jurassic zones have been proved; under the *Cardioceras* Shales is the Charcot Bay Sandstone (200 m.), which is unfossiliferous and rests with basal conglomerate directly on ancient
granite. Nowhere in Greenland have there yet been found ammonites of the Lower Oxfordian, nor definitely of the Upper or Middle Callovian. *Kosmoceras boreale* Ravn (1911, pl. xxxvi, figs. 5, 6), from Koldeway Island, was found with *Seymourites tychonis* (Ravn) and may be the inner whorls of it and so is presumably uppermost Lower Callovian; and the ‘*Quenstedtoceras*?’ of Ravn (1911, pl. xxxvi, fig. 4) is possibly a Macrocephalitid (*Pleurocephalites*?).

**Lower Callovian (225 m.)**

For the downward succession the scene shifts to Jameson Land, where the following ammonite horizons have been recognized in the Vardekleof formation (Spath, 1932, pp. 138, 145). The same beds occur as the Yellow Series on Traill Island (Donovan, 1953) and are represented in the northern area on Wollaston Foreland (Maync, 1947, pp. 83-98, 162). The beds consist mainly of micaceous shales with occasional sandstone bands. The order is not entirely established.

4. *Kepplerites* and *Cadoceras* beds: characterized by *Kepplerites* (*Seymourites*) spp. and many *Cadoceras* spp., with which occurs a *Kosmoceras* (*Gulielmiceras*). The assemblage correlates with the Callovienze Zone. *Seymourites* occurs also in North America, Spitsbergen, Siberia and Japan.

3. *Arcticoceras* beds: this genus (based on *A. ishmae* Keyserling) is associated with *Pleurocephalites* and the horizon in that case correlates probably with the Koenigi Zone. *Arcticoceras* has already been mentioned in connexion with north Russia, Franz Joseph Land, etc.

2. *Arctocephalites* beds: this genus (based on *A. ishmae* var. *arcticus* Newton) is co-extensive with *Arcticoceras* and is presumed to correlate with at least the upper part of the Macrocephalus Zone.

1. *Cranocephalites* beds: this genus also occurs in North America and Siberia and, despite assertions that it is Bathonian, its age is now established as Lower Callovian (see p. 536).

**Bathonian and Bajocian**

Neither of these stages has yet been proved to exist in Greenland. A pelecypod fauna referred to them (Madsen, 1904, p. 204) has turned out to be Toarcian (Rosenkrantz, 1934, p. 14).

**Toarcian (30-50 m.)**

Marine Lias with the following faunas occurs in eastern Jameson Land and in a small area in southern Liverpool Land (Rosenkrantz, 1934, 1942). The principal exposures are from Cape Stewart northward along the west side of Hurry Inlet. The Toarcian beds are represented in the upper part of the 200 m. Neill’s Cliff formation and comprise more or less calcareous sandstones, often cross-bedded and even conglomeratic, with several layers of fossiliferous concretions. From them have been obtained 7 species of *Pseudolioceras*, all English and European species,
including *P. compactile* (Simpson), and correlating with the *Pseudolioceras* beds of Spitsbergen (p. 506). Most of these date to the Upper Toarcian. In addition there are *Dactylioceras groenlandicum* Ros. and *Catacoeloceras* sp., indicating the Bifrons Zone (Rosenkrantz, 1934, pls. v-viii).

**Undated (150 m.)**

The middle and greater part of the Neill’s Cliff formation consists of 150 m. of highly variable shallow-water, calcareous sandstones, micaceous shales, conglomerates, cross-bedded sandstones, etc., from which no fossils of dating value have been obtained.

**Lower Pliensbachian (3-20 m.)**

In the basal beds of the Neill’s Cliff formation a rich marine fauna occurs with (rare) ammonites. Two distinct horizons are so far known: the higher with *Beaniceras* and *Lytoceras fimbriatum*, denoting the Ibex Zone; the lower with *Uptonia jamesoni* and an extensive fauna of pelecypods, gastropods, brachiopods, etc. (Rosenkrantz, 1934, pls. iv, v, vii). A striking feature is a rock crowded with *Cardinia*, similar to the *Cardinia* beds found in England and as far away as Fergana and Indo-China. The Jamesoni bed also occurs on Liverpool Land.

**Hettangian (60 m.)**

The highest 90 m. of the Cape Stewart formation consists of plant-beds: mostly sandstones and grits with hollow casts and fragments of twigs, stems and leaves, but with shaly intercalations in which is a rich flora of large and often almost undamaged leaves. The highest 66 m. are characterized by *Thaumatopteris* and many other forms, the assemblage agreeing with the Hettangian flora of Sweden (Scania) and Germany (Harris, 1935).

**[Rhaetian (30 m.)**

The lower part of the plant-beds is similar but contains a distinct flora characterized by *Lepidopteris*, and is of Rhaetian age. The two floras are mixed in a zone only a few metres thick. This flora also agrees with that of Scania, Germany and other places (Harris, 1935). The rest of the Cape Stewart formation consists of 85 m. of barren, cross-bedded sandstones. Below are 225 m. of purple marls interbedded with limestones (upper Klitdal formation), without known fossils but presumably corresponding to the Keuper.]

**Prince Patrick Island**

On Prince Patrick Island in the Arctic Archipelago of Canada marine Jurassic has been known to exist since *Ammonites m’clintocki* was figured from there by Haughton (1858, pp. 244-5, pl. ix, figs. 2-4). The ammonite
PLATE 24.—Jurassic rocks of Neill's cliffs, Hurry Inlet, East Greenland.
(See Fig. 83.)
Plate 25.—Jurassic section, Prince Patrick Island, Canadian Arctic. (See Fig. 85.)

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was refigured by Neumayr (1885, pp. 38, 141, pl. i, figs. 5-8) who assigned it to *Harpoceras*. From the figures it appears to be a Toarcian Harpoceratid, perhaps a *Pseudolioceras* (though evolute for the genus).

During 1954 Dr E. T. Tozer of the Geological Survey of Canada measured sections on the island and collected ammonites which are being studied by Dr H. Frebold at Ottawa. He has kindly sent me a copy of his MS. preliminary report (Dec. 1954), from which he allows me to quote the discovery of ammonite faunas belonging to three stages: Toarcian (with *Dactylioceras* cf. *commune* and ‘*Harpoceras* m’clintocki’), basal Lower Bajocian (with *Leioceras opalinum*), and Lower Callovian (with *Arctoccephalites* (*Cranocephalites*) cf. *vulgaris*). There is also another Callovian horizon with a new genus. According to Dr Tozer these beds are followed by a non-marine series which is probably still Jurassic, and this is overlain with local unconformity by a further marine sequence containing *Buchia* spp.

The beds are unfolded and belong to an epicontinental series fringing the Arctic Ocean (Fortier & others, 1954) (Plate 25).

**THE ARCTIC SLOPE OF YUKON AND ALASKA**

From the mouths of the Mackenzie River for about 700 miles westward, to the entrance to Bering Straits, stretches the Arctic slope or coastal plain. Bounded on the south by the Palaeozoic Brooks Range, it is a low-lying, bleak waste of permanently-frozen Mesozoic sediments, mainly Cretaceous, intersected by frozen rivers and ending at a low coast which is sometimes overridden by sea ice. (Fig. 85, p. 537.)

On the Firth River, 35 miles on the Canadian side of the international boundary, strongly folded and semi-metamorphosed Jurassic rocks have yielded an ammonite assemblage of the Callovienne Zone, with six species of *Cadoceras* and *Pseudocadoceras*, mainly of Russian and Franz Josef Land species (Buckman in O’Neill, 1924, p. 144). It is possible that Jurassic rocks spread out under the delta of the Mackenzie River, where ‘undifferentiated Mesozoics’ are shown on the Canadian Survey map, but the only evidence so far is of Trias and Lower Cretaceous.

On the Alaskan side of the boundary, in the Canning River district, the Kingak Shale (1500 m. or more) has yielded a number of ammonite faunas ranging from Upper Pliensbachian to Upper Oxfordian, and its higher parts may include Kimeridgian and Portlandian, to judge by species of *Buchia* (Martin, 1926, pp. 262-4; Imlay, 1952, pp. 982-3). The exposed river sections have been supplemented by borings farther west, in the Barrow area, which produced additional horizons down to Lower Sinemurian. The faunas recorded by Imlay may be tabulated as follows:—

**LOWER PORTLANDIAN ? AND KIMERIDGIAN**

Upper Kingak Shale with *Buchia mosquensis*, *B. rugosa*, *B. bronni*.
ARCTIC SLOPE

UPPER OXFORDIAN

Shales with Amoeboceras (Prionodoceras); also Buchia bronni.

MIDDLE CALLOVIAN

Shales with Kosmoceras castor (Rein.) abundant.

LOWER CALLOVIAN

Shales about 165 m. lower with Artiococeras cf. kochi Spath, and at a lesser depth Pseudocadoceras growingi (Pomp.), a species recognized by Buckman from the Firth River.

LOWER BAJOCIAN OR UPPER TOARCIAN

Shales probably 600 m. below the Artiococeras horizon in the Canning River area yielded Pseudolioceras and Erycites spp. This horizon occurs also in SW. Alaska, opposite Kodiak Island. Pseudolioceras and ? Tmetoceras were also obtained in borings in the Barrow area.

LOWER TOARCIAN

In the South Barrow boring Dactylioceras and Peronoceras were obtained.

PLIENSCHIAN

Lower Kingak Shales, near the base, yield Amaltheus cf. engelhardti (d'Orb.) and Lytoceras cf. jimbrium (Sow.). This is the horizon which occurs on the opposite side of the Arctic Ocean, on the Anabar River, Siberia (p. 513). Abundant Amaltheus and a ? Crucilobiceras were also encountered in a boring in the Barrow area.

SINEMURIAN

In Avak boring Arietites aff. bucklandi (Sow.) was obtained. (The figure referred to, Wright's monograph, pl. i, fig. 1, is type of A. scunthorpeensis Spath, 1924).

Mapping has shown that the Callovian overlaps across early Bajocian and Lower Jurassic and is in turn overlapped by the Upper Oxfordian- Kimeridgian, while that is overlain disconformably by the Lower Cretaceous (Imlay, 1952, p. 983).

No signs of contemporaneous igneous activity are reported from the Jurassic of the Arctic slope.

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CHAPTER 23

THE CORDILLERAS OF NORTH AMERICA

From Bering Strait to the Isthmus of Tehuantepec the North American Cordilleras stretch for 4000 miles without interruption. The present chapter deals with the first 3400 miles, to the Mexican border and the head of the Gulf of California. The greatest width of over 1100 miles is reached in the central United States, about latitude 40° N. There, chiefly in Colorado, Wyoming and Utah, are large areas above 7000 ft., with many peaks of 12,000-14,000 ft., the highest being Mount Whitney (14,495 ft.) in the Sierra Nevada. The highest points in North America, however, are reached in the Alaska Range (Mount McKinley, 20,300 ft.) and St Elias Range in the extreme south-east corner of the Yukon, Canada (Mount Logan, 19,850 ft.).

In the simplest terms, the Cordilleras represent the products of a vast shifting geosyncline or complex of geosynclines, repeatedly sinking, filling with sediment, and buckling throughout much of Palaeozoic, Mesozoic and Kainozoic time: a typical orogen, opposed fundamentally to the kratogen of the interior of the continent, the Canadian shield and its surrounding stable platform or shelf.

Again in the most general terms, the Cordilleras are divisible longitudinally into three. On the Pacific side the outer belt runs from the Aleutian arc through the Alaska Peninsula with their great chain of recent volcanoes, and forms the Coast Ranges, the Sierra Nevada, and the peninsula of Lower (Baja) California. East of this lies a wide belt of high plateaux, troughs, and relatively short ranges, including the ‘Interior System’ of Canadian geologists and the Basin Ranges of Nevada. The third belt, overlooking the Great Plains and prairies of the interior and often bounded by low-angle thrusts, is the Rocky Mountains. None of these three subdivisions is a simple entity, but rather a complex of orogenic belts.

In Triassic and Lower and Middle Jurassic times the Pacific marginal belt, or Coast Ranges, was the site of a volcanic island festoon enclosing a trough of deposition: a concept inferred independently for the outer ranges of the Andes, as will be shown in Chapter 25. After vast extrusion of volcanic rocks lasting many millions of years, there occurred in Upper Jurassic times a major orogeny, the Nevadan (equivalent approximately to the Yenshan of eastern Asia), involving intense folding and intrusion of large batholiths, which now form the greater part of the coast ranges, from Alaska to the Sierra Nevada and Lower California. The date of these intrusions can seldom be fixed within narrow limits, but most of them are Upper Jurassic or Lower Cretaceous, or both. The outermost
zone later sank back into the Pacific and became again the site of sedimentation and of a new volcanic island festoon, which in later (Laramide) movements was deformed and raised into the coast ranges of California, Oregon and Washington.

The Rocky Mountains were in Lower, Middle and Upper Jurassic times the site of broad, shallow subsidence and moderate sedimentation, but after about Oxfordian times in the Western Interior of the United States sedimentation ceased or became predominantly, or wholly, continental. In Canada this inner trough or pan seems to have been confluent with the outer geosyncline, but on the whole instead of a predominantly volcanic filling it received normal marine sediments with suites of Liassic,
Bajocian, Callovian, and locally Oxfordian, faunas. Farther south, at least in the United States, it became separated from the coastal geosyncline by a belt of uplift, a geanticline which suffered erosion and supplied much sediment eastwards. In, probably, Kimeridgian times an extensive basin became cut off from the sea in the Western Interior of the United States, and in it was formed the continental Morrison formation with its land animals. Finally, in the Upper Cretaceous and early Tertiary, the Rocky Mountains trough and much of its shelf-facies upon the edge of the continental platform were compressed by the Laramide orogeny, with intense folding and thrusting.

Thus the outer (Coast Ranges) and inner (Rocky Mountains) belts of the Cordillera in the main are structurally of different ages, separated in time by most of the Cretaceous period: the outer ranges were first buckled in the Nevadan orogeny, the inner in the Laramide. In between was something of a no-man’s-land. It is characterized mainly by high-angle block faulting of late Tertiary date, at least in places even later. To these last movements of cordilleran evolution are due the Basin Ranges and their continuation northward in the plateaux and fault troughs of the ‘Interior System’ of Canada.

For all the Cordilleras of North America (except Alaska) a broadly consistent evolution has been worked out, but the variation is almost infinite and the complexity formidable. The broad structural and geographical features of the present day by no means coincide with those of the Jurassic. The unravelling of the tangle has proceeded much farther in North America than in eastern Asia, but although a great amount of detail has been published for many areas, there are still large regions almost unknown—particularly in NW. Canada and Alaska—and a clear picture is still a dream for the future. Even the outcrop sketch-maps for the Americas (figs. 85-88), though probably much more accurate than those for east Asia, are still of necessity mere sketches. The latest available geological maps of Canada and the United States still show vast regions as ‘undifferentiated Mesozoics’, or as ‘Trias-Jura’, or ‘Jurassic-Cretaceous’.

In some of these areas Jurassic has been marked on the accompanying sketch-maps, in others it has not, according to the present author’s personal assessment of the literature. Nevertheless such sketches are believed to be more useful than no maps at all, and less misleading than attempts at palaeogeographical maps, constructed from shaky inferences elaborated by guesswork.

Since the Jurassic of North America has an extensive literature in the English language which is readily accessible to English-speaking readers, greater compression has been considered justified than for other parts of the world where the literature is more difficult to discover and obtain and is largely in foreign languages. American and Canadian users of this book are asked on this account to excuse what may seem a disproportionate brevity or even perfunctory treatment of one of the greatest series of Jurassic outcrops in the world.

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All the outcrops being in the west, most of the faunas are recent discoveries, and it is worth reflecting that hardly any of them were known when Hyatt was working on ammonites at Harvard 60-90 years ago. In those days it was easier and preferable to visit the museums of Europe for material than to search the Rockies.

Southern Alaska

The most complete sequence of Jurassic rocks on the North American continent occurs in the coast ranges of southern Alaska, which sweep in from the half-submerged Aleutian arc, through Alaska Peninsula and Cook Inlet, through the Alaska Range, and then follow round, parallel to the Pacific coast, to merge into the coast ranges of Canada. Their outcrops, now dissected by severe glacial erosion, by inlets of the sea and by intrusive batholiths, mark the site of a major geosyncline, comparable in scale with those of eastern Asia and the rest of the Pacific seaboard of the Americas. The total thickness of Jurassic sediments amounts to about 4500 m. (Fig. 85, p. 537.)

The Lower Jurassic is mainly in volcanic facies, consisting of submarine lavas, tuffs and agglomerates, passing into and interbedded with shales, sandstones and conglomerates, in which in some districts Lower and Upper Liassic marine faunas have been found. The Middle and Upper Jurassic comprise a vast and varying pile of conglomerates, sandstones and shales, with rich ammonite faunas occurring at several horizons.

Researches are not yet sufficiently far advanced to admit of satisfactory generalization. Much detail is known of a number of scattered areas, but in between are still greater areas as yet unexplored stratigraphically or of necessity treated still as ‘undifferentiated Mesozoics’. Three excellent syntheses have been published (Martin, 1926; Smith, 1939; Imlay, 1952), and no attempt is here made to summarize once more the mass of detail marshalled in these works and in the numerous Geological Survey bulletins to which they refer.

The south Alaskan ammonites show close connexions with those of the Arctic slope, Greenland, and the Arctic Ocean generally, but in the absence of any connecting outcrops across the north-western shoulder of the continent it cannot be stated definitely whether a seaway passed this way or through the Bering Straits and over NE. Asia (cf. Crickmay, 1931, maps 4-11; Eardley, 1951, p. 517). The latter view implies an exceptional degree of disharmony between the Jurassic geosyncline and the strike of later foldings: for it seems to be generally agreed that the Rocky Mountain structures carry on NW. and then west into the Brooks Range of northern Alaska, and account, presumably, for the tightly-folded and semi-metamorphosed Jurassic of the Firth River region (p. 529). The morphic continuation of the cordilleran geanticline is assumed to be the basin of the Yukon River in central Alaska and its surrounding Palaeozoic mountains, where the Mesozoics are largely absent or represented only by

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folded Lower Cretaceous and transgressive Upper Cretaceous. This central swell experienced orogeny, with injection of batholiths, in the Middle Cretaceous, as did the Andes.

The south Alaskan Jurassic geosyncline (if this picture is correct) then corresponds only to the Coast Range geosyncline and orogen. But it presents peculiar features in the times of its foldings, which set it apart from the rest of the North American cordilleras and probably are connected with the change of strike to E.-W. and even SW. (Crickmay, 1931, p. 62; Stille, 1942, p. 77). Instead of the Nevadan orogeny at the end of the Jurassic, South Alaska suffered considerable foldings at

Table 22.—Jurassic Succession in Alaska

<table>
<thead>
<tr>
<th>Stages</th>
<th>Cook Inlet</th>
<th>Alaska Peninsula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kimeridgian and Oxfordian</td>
<td>Naknek formation: massive light-coloured sandstone, arkose and tuff, overlying grey shale with sandstone beds 1350 m.</td>
<td>1500 m.+</td>
</tr>
<tr>
<td>?</td>
<td>Chisik Conglomerate, 90 m.</td>
<td>...</td>
</tr>
<tr>
<td>Middle and Lower Callovian</td>
<td>Chinitna Shale, with subordinate calcareous and sandstone beds, 690 m.</td>
<td>Shelikof formation 1500-2100 m.</td>
</tr>
<tr>
<td>Lower Callovian, Bajocian, Upper Toarcian</td>
<td>Tuxedni Sandstone, with marine fauna and plants; subordinate shale, arkose, and conglomerate, 2400 m. Unconformity</td>
<td>Kialagvik formation 150 m.+</td>
</tr>
<tr>
<td>Lower Toarcian to Hettangian</td>
<td>Volcanic series: basic submarine lavas and tuffs, c. 300 m.</td>
<td>Sandstones, shales and volcanic rocks c. 690 m.</td>
</tr>
</tbody>
</table>

two earlier epochs: Toarcian and between Callovian and Oxfordian; and then, more like the Rocky Mountain geosyncline, vigorous refolding with injection of batholiths in the Laramide (early Eocene) orogeny (Mertie, 1930). The Laramide orogeny, on the other hand, seems to have missed northern Alaska, so that, in respect of dates of folding, the usual behaviour of the two geosynclines was here reversed (Stille, 1942, p. 76).

The type area for the Jurassic is the west coast of Cook Inlet and its continuation in the neck of Alaska Peninsula. Here the sequence may be tabulated as in table 22 (Martin, 1926, p. 134; Smith, 1939, p. 45); dates provided by Imlay (1952) are added.

The chief authorities for the ammonites in the following tabulated summary are Martin (1926) and Imlay (1952). The Callovian ammonites have been monographed sumptuously by Imlay (1953); monographs on the other faunas are urgently needed.

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CORDILLERAS OF NORTH AMERICA

KIMERIDGIAN, PORTLANDIAN ?

The latest Jurassic on some of the islands of the archipelago of SE. Alaska and in the Nutzotin Range consists of dark shales and other beds with *Buchia piochii* Gabb (Lower Portlandian?) and lower down *B. rugosa* Fischer and *B. cf. mosquensis* (v. Buch), but no ammonites are recorded.

OXFORDIAN

Beds with *Prionodoceras* ? and *Buchia bronni* (Rouill.) as in north Alaska occur in the lower part of the Naknek formation of Alaska Peninsula and Cook Inlet, and in the Chitina Valley district (Reeside, 1919, p. 30, pls. xviii, 4, xix, 1-3).

Below this, in the basal Naknek formation, are abundant *Cardioceras*, *Scarburgiceras*, etc., which indicate the presence of the Mariae, Cordatum and Plicatilis Zones (Imlay, 1952, p. 977; some figures in Reeside, 1919). Locally at the base of the Naknek on Cook Inlet is the Chisik Conglomerate, up to 80-90 m. thick, which points to a considerable local disturbance and seems to correlate with upheaval in the Harrison Lake area of Canada.

CALLOVIAN

No Upper Callovian fauna has been found, and there may be a disconformity. The Shelikof formation on Alaska Peninsula (Pompeckj, 1900, 3 pls.) and equivalent Chinitna formation of Cook Inlet have yielded magnificent Middle and Lower Callovian faunas (Imlay, 1953).

The highest third of the Chinitna contains *Phylloceras*, *Lilloettia*, *Cadoceras* (*Stenocadoceras*) and *Pseudocadoceras*; though chiefly crushed, some of the Cadoceratids resemble *C. milaschevici* (Nik.) and *C. stenolobum* (Keys.), indicating a Middle Callovian date, probably Coronatum Zone (Imlay, 1953, p. 53).

The earlier Callovian faunas are of exceptional interest on account of their possibilities for correlation with Greenland, Europe and North and South America. The middle third of the Chinitna contains many *Cadoceras*, *Pseudocadoceras*, *Kepplerites*, *Lilloettia*, *Oxycerites* and *Phylloceras*; and the lower part of this middle third also yields *Paracadoceras*, *Kheriaceras*, *Xenocephalites* and *Gowericeras*. Imlay considers this assemblage to represent the Jason Zone. The lower third of the Chinitna yields *Kosmoceras* (*Gulielmiceras*), *Kepplerites*, *Gowericeras*, *Cadoceras*, *Paracadoceras*, *Lilloettia*, *Grossouvria*, *Xenocephalites*, *Kheriaceras*, *Oxycerites*, *Phylloceras* and *Choffatia* (Imlay: 1953, pi. 54). The date of this assemblage is clearly about Koenigi or Callovienze Zone.

There is no evidence for the *Arcticoceras* or *Arctocephalites* beds, but in the Tuxedni formation on Cook Inlet the *Cranocephalites* beds are present and contain *Reinekeia* (Imlay, 1952, p. 980), which proves their Callovian age.

BATHONIAN

No proof of the existence of Bathonian has been published.
Bajocian

The middle and lower parts of the Tuxedni formation yield a remarkable variety of Bajocian ammonites. Few have yet been figured, but from the genera recorded by Imlay (1952, pp. 978-81) it appears that the following zones are represented:

Upper Bajocian: assemblage of *Sphaeroceras, Polyplectites, Leptosphinctes* and *Lissoceras* (p. 980).

Middle Bajocian:
Humphriesianum Zone: Abundant *Normannites, Teloceras* and *Chondroceras* (p. 980).

Sauzei and Sowerbyi Zones: Abundant *Stemmatoceras, Stephanoceras* and *Sonninia*, with a few *Emileia, Chondroceras* and *Lissoceras* (p. 981). Elsewhere is recorded an assemblage of *Stemmatoceras, Emileia, Lissoceras, Leptosphinctes* and an Oppelliid (p. 979). Elsewhere again, abundant *Emileia*, associated with *Sonninia, Erycites, Pseudolioceras* and an Oppelliid (p. 978).
Some of these associations seem impossible and one is forced to doubt the accuracy of the collecting or recording.

According to records (Martin, 1926, p. 153) on Cook Inlet occur the Australian and Canadian genera *Zemistephanus* and *Pseudotoites* (*Ammonites richardsoni* and *A. cf. carlottensis* Whiteaves, 1876).

**Upper Toarcian?**

On Alaska Peninsula the Kialagvik formation yields *Pseudolioceras whiteavesi* (White), which correlates with the Toarcian *Pseudolioceras* level of Greenland (p. 527), and peculiar ammonites also figured by White (1889, pls. xii-xiv) and assigned by him to ‘Lillia’ [*Phymatoceras*], by Pompeckj (1900) to *Hammatoceras*, and by Imlay (1952, p. 978) to *Erycites*, but probably referable to none of these genera. Imlay assigns these beds to the Lower Bajocian on the strength of a new record of *Tmetoceras*; but as he also records *Soninina* at the top of the same beds, it is likely that this is another case of condensation, Lower Bajocian and Toarcian here occurring in condensed form in close proximity to the Middle Bajocian.

On Cook Inlet the Tuxedni formation is unconformable on the volcanic series (Martin, 1926).

**Lower Toarcian, Pliensbachian, Sinemurian, Hettangian**

All these stages are said by Imlay (1952, p. 979) to be represented in collections from the Alaska Peninsula, from a series at least 690 m. thick. The only genera mentioned are *Coroniceras* and *Arnioceras*, indicating the Sinemurian. He also records *Coroniceras?* from tuffaceous beds on Cook Inlet; here the Lower Jurassic is presumed to be mainly in volcanic facies, represented by basaltic and andesitic lavas and tuffs about 300 m. thick (Martin, 1926, p. 134).

From the Matanuska Valley and Talkeetna Mountains Imlay (1952, p. 981) records ammonites referred provisionally to the genera *Schlotheimia*, *Deroceras* and *Xipheroceras*, the last two resembling species of the Pliensbachian.

**Western Canada**

In Canada the two troughs are distinguished by their sedimentary filling but are not easy to define accurately on the ground owing to orogenic compression, subsequent tectonic dislocations, and erosion.

To the outer or Coast Ranges trough belong the Jurassic outcrops of the SW. Yukon and most of British Columbia except the south-east corner. The filling is characterized in the Lower and Middle Jurassic by massive submarine volcanics: tuffs, agglomerates and basic lavas, with interbedded shales and argillites. The tuffs in some places continue high into the Callovian. The volcanic materials came from the west, from the inferred island festoon not far off the present Pacific coast. In central British Columbia the main Jurassic volcanic series is 5400 m. thick and follows conformably on a like thickness of volcanics assigned to the Upper
Trias. Above follow more than 1500 m. of greywackes, shales and argillites, with subordinate tuffs. Towards the coast thicknesses are smaller and much of the Jurassic is locally cut out by disconformities and minor unconformities: for instance on Vancouver Island, where Callovian rests on Toarcian, and on Queen Charlotte Islands where Albion rests on Callovian.

The inner or Rocky Mountains trough has no volcanics and consists mainly of shale, with minor quantities of fine sandstone and, sometimes, black limestone. At the top coarser sandstones come in, their constituents felspathic, and thickening westward as if derived from the rising Cordilleran geanticline. These rocks, called the Fernie group and (p. 540) basal Kootenay Sandstone, comprise representatives of nearly all the stages present in the western geosyncline, with close correspondence in most of the faunas, but the thicknesses are of the order of a tenth or twentieth: the total for the Fernie varies from 66 m. to 330 m.

The deepest part of the trough lay under the front ranges and foothills of the Rockies in Alberta and eastern British Columbia. The western boundary cannot be clearly defined (Warren, 1951). To the east the shallow sea passed far over the southern prairies, for marine Jurassic has been proved in borings under the Cretaceous of southern Saskatchewan and SW. Manitoba. These epicontinental sediments are or were continuous with those which come to the surface in the Black Hills uplift of South Dakota.

If the local unconformity and incoming of coarse sand grains at the base of the Kootenay betokens the climax of the Nevadan orogeny in the western geosyncline, the contribution of Canada to the dating of that event depends mainly on the single giant ammonite mentioned on p. 540. It appears to be Upper Portlandian, which would make the Nevadan orogeny Lower Portlandian or Upper Kimeridgian.

In the western geosyncline in Canada, however, no major unconformity or conglomerate that can be correlated with the Nevadan orogeny has yet attracted attention. Instead, in the Harrison Lake area of British Columbia a 900 m. conglomerate is intercalated between Oxfordian Cardioceras beds and Callovian with Cadoceras. This, the Kent Conglomerate, is said to rest discordantly on the Callovian and is believed to represent the upheaval and erosion of the Agassiz Mountains, and it has been equated with the Chisik conglomerate of Alaska (Crickmay, 1933a, p. 358). The Canadian batholiths, though 'Nevadan' in the loose sense of the term, are probably Cretaceous, like the Idaho batholith and those in Lower California.

The lion's share in unravelling and publishing the Jurassic faunas of Canada has been taken by Dr F. H. McLean, as shown by the long series of papers cited in the bibliography. More recently, important contributions have also been made by Warren, Frebold, and others. I am deeply indebted to these correspondents for reprints and to Dr Frebold for an advance copy of the typescript of his masterly summary of the Jurassic
of Canada (1953). For an up-to-date general picture of the geology see Hanson & others, 1947.

TITHONIAN/PORTLANDIAN/KIMERIDGIAN

On Vancouver Island marine Lower Neocomian rests on an eroded surface of a shale formation (with a median sandstone and siltstone member) in which occur Buchia cf. russiensis (Pavlow) and B. cf. rugosa (Fischer). These beds are believed to be ‘Portlandian’. Buchia mosquensis (v. Buch) also occurs in the lower Eldorado group near Lillooet, on the Fraser River, and is believed to denote approximately the same age.

In the east, at Fernie, a gigantic ammonite has been found (Frebold, 1953, p. 1239) in the base of the Kootenay Sandstone, which had usually been considered Cretaceous. The ammonite, though poorly preserved, can be seen from a photograph kindly sent me by Dr Frebold to be a Perisphinctid, and appears to be a giant member of the Dorsoplanitinae. The biplicate ribbing on its outer whorl is coarser than in most of the large Titanites and allied genera of the Upper Portland Stone, but some parallels can be found, e.g. audax Buckman (TA. vi, 1927, pl. dccxvii), glottodes (ibid. iv, 1923, pl. cdiii), zeta (ibid. v, 1923, pl. cdlii), okusensis (ibid. v, 1925, pl. dlxx), or kerberus (ibid. vi, 1926, pl. dxx), which provide a better match than the nearest Kimeridgian genera, such as Pavlovia and Paravgirgatites (ibid. iv, 1922, pl. cccviii) (Plate 26).

The basal Kootenay Sandstone usually passes down into the Jurassic Fernie group, but locally there is an unconformity between them. The upper member of the Fernie (‘passage beds’) consists of 30-60 m. of unfossiliferous sandy beds which, from their stratigraphical position are probably Kimeridgian or Lower Portlandian. In the west the Kimeridgian may be represented by shales.

OXFORDIAN

In the west the shale sequence, with Buchia bronni and B. aff. khirgensis, etc., passes down into Oxfordian beds sometimes characterized also by Buchia bronni but yielding ammonites. The latest assemblage known is one of Cardioceras canadense Whiteaves, C. lillooetense Reeside and C. whiteavesi Reeside, found at Big Creek, 90 miles NW. of Lillooet. (For figures see Reeside, 1919, pl. xvii.) (For the dating implications of these Cardioceratids see p. 548.) Traces of the same assemblage are reported from Harrison Lake (with a Phylloceras) in a 1500 m. sequence of argillite; from Vancouver Island; and from about 110 miles NNW. of Hazelton.

In another area about 100 miles east of Hazelton, in central British Columbia, records of Cardioceras (Scarburgiceras) aff. scarburgense (Y. & B.) and C. (S.) aff. praecordatum Douvillé (Lord, 1948, pp. 23-4) indicate that the Mariae Zone is represented.

In the east (Fernie) the Oxfordian is represented by Green Beds with belemnites and gastropods (Frebold, 1953, p. 1238).
PLATE 26.—Giant ammonite in basal Kootenay Sandstone, east of Fernie, British Columbia.
Plate 27.—Lower Jurassic and Triassic outcrop in typical landscape, Snake Indian Valley, north of Jasper, Alberta. T, Trias; LL. Lower Lias; To, Toarcian.
The youngest Callovian ammonites recorded from Canada seem to be *Cadoceras* cf. *doroschini* (Eichwald) in Vancouver Island, where the beds containing them rest unconformably on the Toarcian.

In Queen Charlotte Islands marine Albian rests unconformably on beds probably only a little older, yielding *Seymourites* spp., at the top of the Yakoun formation. The Upper Yakoun (about 130 m. or more) consists of sandstones and shales with many pelecypods. The ammonites correlate with the *Seymourites* beds of Alaska and Greenland. Other forms of *Kepplerites* are also present (*K. penderi* McLearn sp. and *K. newcombi* Whiteaves sp.) (McLearn, 1929, pls. i-viii). The Middle Yakoun, which may be Lower Callovian and Bathonian, consists of 360-450 m. of tuffs and agglomerates, in which so far only rare belemnites and brachiopods have been found. *Gowericeras* and *Catasigailoceras* are recorded from the Ashcroft area (Crickmay, 1930a).

In the Harrison Lake area three Lower to Middle Callovian horizons have been made out (Crickmay, 1930):

- **Upper level:** *Macrocephalites* of two new subgenera: *Lilloetia* and *Buckmaniceras*
- **Middle level:** *Cadoceras, Paracadoceras, Pseudocadoceras*, an assemblage close to that of the Chinitna Shale and Shelikof formation of Alaska (Imlay, 1952)
- **Lower level:** *Macrocephalitids* indet.

These faunas occur in about 750 m. of black shales which overlie the Middle Jurassic volcanic rocks (2700 m.). Above the shales are more tuffs, 540 m. thick, which are mainly of Callovian age, since they are overlain by beds with *Cardioceras*.

In the east, the Upper Fernie group (Corbula beds) near Blairmore yielded Lower Callovian *Macrocephalitidae* described by Buckman (1929, pls. i-iii). He assigned them to three new 'genera'. According to Spath (1932, pp. 13, 33) the commonest ('*Miccocephalites*') are the same as *Arctocephalites*, but Warren (1947, p. 43) considers them closer to *Cranocephalites*; but since the difference between these is only of subgeneric rank (Donovan, 1953) the point is academic. Frebold (1953, pp. 1237-8 and in lit.) has found *Eurycephalites muelleri* (Imlay) and *Cadoceras* in the same beds.

Immediately above these beds is a marker horizon, the Gryphaea bed (1-52 m.) with *Macrocephalites, Gowericeras* or *Seymourites*, and Perispinctids (Frebold, 1953). In the Highwood-Elbow area, Alberta, *Arcticoceras, Cadoceras* and *Proplanulites* occur (Allan & Carr, 1947, p. 23).

The Callovian is the only stage recognized unequivocally, by ammonites—*Macrocephalitids*—in the Jurassic formations which have been proved by borings to extend far to the east, under the Cretaceous plains of southern Saskatchewan and Manitoba (references in Frebold, 1953, p. 1241).
BATHONIAN

In the west the Bathonian is probably represented, if at all, by volcanic rocks, and no evidence for it has been found. In the east, the Middle Fernie may comprise sedimentary representatives in the lower part of the Corbula munda beds. It is in the Middle Fernie that the only Bathonian ammonites have been recorded: Oppelia (Oxycerites) of the group of O. fallax (Guéranger) and O. aspidoides (Oppel) (Frebold, 1953, p. 1237).

BAJOCIAN

No Upper Bajocian has been proved in Canada. Like the Bathonian, it may be represented by some of the submarine volcanic series—tuffs, agglomerates, sandstones and shales—which reach 450 m. in thickness in Queen Charlotte Islands and are widespread in British Columbia (Middle Yakoun formation).

The Humphriesianum and Sauzei Zones are well developed and widespread, in the Lower Yakoun formation of Queen Charlotte Islands (marine tuffs, sandstones and shale, 60 m.) and across British Columbia and Alberta, where the fauna occurs in the Middle Fernie group (shales with some more or less sandy limestone beds and lenses). The abundant ammonites include species of Stephanoceras, Stemmatoceras, Teloceras, Zemistephanus, Normannites (including Kanastephanus and Itinsaites), Chondroceras (including Defonticeras and Saxitoniceras) and Frogdenites?, which have been figured chiefly by Whiteaves (1876-84; 1909), McLearn (1927; 1929, pls. ix-xvi; 1930; 1932; 1932a) and Warren (1947).

On Maude Island in Skidegate Inlet, Queen Charlotte Islands, there is evidence of two distinct horizons. On the south-east shore of the island occurs an assemblage of Stephanoceras skidegatense (Whiteaves) and various species of Chondroceras, which on palaeontological grounds would be assigned to the Humphriesianum Zone. On the north-west shore of the island is a different assemblage, comprising Zemistephanus and many Normannites, and probably the rarer Pseudoitoites carlottensis (Whiteaves) (McLearn, 1949, pp. 10, 13). The Canadian Zemistephanus and Pseudoitoites are not identical with the Australian at specific level, and the associated Normannites are believed to be more advanced than the Australian, perhaps derived from Australian-type Otoites. The Canadian assemblage is therefore probably somewhat later than the Australian, hence probably Sauzei Zone.

The Sowerbyi Zone is represented as a distinct horizon in the Hazelton group of British Columbia by an assemblage of Somninia and Witchellia (= ‘Sonninites’) with the local Sonninid genus Guhsania (McLearn, 1926). This horizon lies between two volcanic series and is near the base of the Hazelton group (which is up to 3000 m. thick). Fontannesia, also of this age, is recorded from the Ashcroft area (Crickmay, 1930a, p. 27); and a Somninia is reported from the Middle Fernie.

The only Lower Bajocian ammonites yet known from Canada are also from the lower part of the Hazelton group: Tmetoceras regleyi
(Dumortier) and a problematic form, from the Whitesail Lake area, British Columbia. Probably they are of the age of the Scissum Zone. (Frebold, 1951, pl. xv.)

TOARCIAN

Upper Toarcian assemblages are reported from the 2700 m. Laberge Series near Lake Laberge, at the source of the Yukon River: Grammoceras and Dumortieria (Buckman in Cockfield & Bell, 1926, p. 21); from central British Columbia: Grammoceras aff. saemanni (Struck.), Reynosoceras aff. ragazzonii (Hauer)*, Haugia aff. grandis Buck. (Lord, 1948); and from the upper part of the Lower Fernie near Jasper: Dumortieria and Hammato­ceras, with Posidonia (Collet, 1931, quoted in Frebold, 1953). Pleydellia may possibly occur in the Yukon (Frebold, 1953).

Lower Toarcian assemblages of Harpoceras and Dactylioceras, or Peronoceras (Porpoceras), occur in the same areas and others (see, e.g. Frebold, 1951, p. 15, pl. vi, fig. 4). They are best known in the Maude formation of Queen Charlotte Islands. From the same formation comes a peculiar Harpoceratid genus Fanninoceras, believed to be of about the same age (McLearn, 1932, pls. iii-ix; 1949, p. 9). Harpoceras and Fanninoceras occur together on Vancouver Island (Jeletsky, 1950, and in Frebold, 1953).

In places the Toarcian is transgressive and in parts of the Fernie area it cuts out the Lower Lias entirely. In the west it is largely volcanic, the fossiliferous beds being interbedded with tuffs and agglomerates.

PLIENSIFICIAN

Amaltheus and Prodactylioceras are recorded from the Laberge series, Yukon (Buckman in Cockfield & Bell, 1926), and Platypleuroceras from central British Columbia (Lord, 1948).

SINEMURIAN

The Sinemurian, with, in a few places, evidence of the Hettangian as well, is represented in the west mainly by volcanic tuffs and agglomerates, up to some hundreds of metres thick, with fossiliferous sediments inter­stratified. In the east it is represented by the lower part of the Lower Fernie group (altogether only 24-60 m. thick), which consists mainly of dark shales and, locally, a basal conglomerate.

In this stage is perhaps the most widespread single Jurassic ammonite fauna in Canada: the Arnioceras-Arniotites assemblage of the Semi­costatum Zone. It occurs among the tuffs and lavas of Vancouver Island and in Queen Charlotte Islands (Maude formation), inland from Vancouver in the Hope area, in the Yukon, and in the east in the Lower Fernie group (Warren, 1931). Arniotites was first described from Vancouver Island by Hyatt as Triassic, but it was shown by Crickmay (1928) to be Liassic and very close to Arnioceras. From casts kindly sent me by the Geological

* If correctly identified this should be earlier.
Survey of Canada I doubt whether it or the closely-similar *Melanhippites* Crickmay can be distinguished generically from *Arnioceras*.

In the Tyaughton Lake area (about 110 miles north of Vancouver) a more varied suite has been collected (Frebold, 1951, pls. v-xiv), comprising a well-preserved assemblage of the Bucklandi Zone: *Arietites bisulcatus* (Brug.), *Coroniceras* (*Metophioceras*) *latisulcatum* (Quenst.), *Vermiceras scylla* (Reynes) and *Agassiceras* cf. *scipionianum* (d'Orb.). In addition *Asteroceras* cf. *stellare* (Sow.) occurs; this should be younger than the *Arnioceras* fauna (Obtusum Zone), but *Arnioceras* or *Arniotites* is not found here. *Arietitids* are also reported farther east in some outcrops of the Lower Fernie.

**Hettangian**

In the same Tyaughton Lake area two separate assemblages were collected at a number of localities, comprising respectively *Psiloceras canadense* Frebold and some other ammonites (Planorbis Zone) and *Schlotheimia* cf. *acuticosta* Buckman (Angulata Zone) (Frebold, 1951, pls. i-iv.). Thus it appears that the Hettangian and Lower Sinemurian faunas are fully represented in western British Columbia and largely in European development at specific level. The beds consist of dark argillites, locally containing limy concretions and some shale, and they appear to rest conformably on the Upper Trias where not faulted against it.

[Rhaetian]

This stage may be represented in the Sutton formation of British Columbia, which yields *Choristoceras* and *Myophoria* and thus correlates with Rhaetian which lies conformably between the Norian and Hettangian in western Nevada (Muller & Ferguson, 1939, p. 1607).

**Western Interior of the United States**

South of the Canada-United States border the two Jurassic troughs—Rocky Mountain and Pacific—become more clearly differentiated and require separate treatment as two distinct provinces. Marked southward increase in the amount of sand in the Rocky Mountains trough, thickening of the sand westward, and the predominantly eastward set of its current bedding, indicate that the Cordilleran geanticline became higher and wider southwards. Somewhere about the border between Nevada and Arizona, in the region of Las Vegas, it joined a transverse east-west uplift which closed the Rocky Mountains trough on the south and divided its waters permanently from those of the extended Gulf of Mexico.

The Rocky Mountain or Western Interior trough thus formed a large blind-ended, bag-shaped basin, communicating with the open sea only at the north-west end, in British Columbia. Sediment is thickest on its western side and thins out eastward to a feather-edge against the stable Palaeozoics surrounding the shield.

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PLATE 28.—The Sentinel, Zion National Park, Utah. Jurassic sandstones and shaly Trias.

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PLATE 29.—Jurassic sandstone country, Arches National Monument area, Utah.

Photo Jack Breed, Georgetown, Mass.

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The predominant sediment laid down in this inland sea was sand.

Like other large inland seas, of which the first that comes to mind is the Trans-Erythraean trough (pp. 298, 302), its Jurassic record begins with thick sandstones devoid of marine fossils, and probably of continental and even largely subaerial origin, which cannot yet be definitely apportioned between the Upper Trias and Lower Jurassic. In the south of the basin, in northern Arizona, southern Utah and southern Nevada, these sandstones (Wingate and Navajo) form the famous Vermilion Cliffs and White Cliffs of the Glen Canyon area and Zion National Park, with their wonderful erosion features such as Rainbow Arch (pi. 29). Farther north the Navajo passes into the Nugget Sandstone. The Navajo alone has a maximum thickness in southern Nevada of over 1000 m. The total volume of sand present has been estimated at not less than 50,000 cubic miles, and (as with the Nubian Sandstone) most of it came from the destruction of older sandstones.

Into the basin from the north came three major Jurassic marine transgressions, bringing faunas already met with in Canada and Alaska and varying the sedimentary succession with limestones, marls and shales. The first transgression was the Middle Bajocian (? coinciding with an unconformity in Alaska : p. 535); the second the Lower Callovian; the third uppermost Callovian (Lamberti Zone) and Lower Oxfordian, lasting to the beginning of the Upper Oxfordian (early Plicatilis Zone). Not all parts of the basin were completely inundated. As might be expected, the palaeontological record is much more complete in the north, in Montana, Wyoming and South Dakota. Southward and towards the margins of the basin the marine formations pass irregularly into red beds. Gypsum also formed over large areas at different times.

The last Jurassic formation of the Western Interior, the Morrison, is non-marine but has a very wide distribution and overlaps all the earlier formations, especially in the south. Unlike the early Jurassic non-marine sandstones, it has a varied lithology: interbedded with coloured sandstones and conglomerate are red and green shales, and in places limestones, the shales and limestones carrying flora and fauna of great interest. The deposit is fluviatile and lacustrine and in many ways reminiscent of the European Purbeck-Wealden, although now believed to be earlier (Kimmeridgian). Its deposition must have been preceded by earth-movements and extensive erosion, and the earth-movements appear to have raised a barrier across northern Montana which shut out the sea and formed an enclosed basin.

Owing to the Laramide orogeny the Jurassic of the Western Interior presents almost every possible aspect tectonically. Its eastern feather-edge is buried beneath Cretaceous and Tertiary cover under the Great Plains. It first rises to view as narrow ring-outcrops around the Black Hills uplift of South Dakota. This outermost ripple of the Rockies is separated from the front range in Wyoming by a broad, deep trough filled with thousands of metres of later sediments: the total tectonic relief

2 M
of this first 'ripple', from crest of Black Hills to inner trough, being around 20,000 ft. Finally, beyond the mighty tectonic chaos of the Rocky Mountain ranges it flattens out in the south-east to build some of the great plateaux of Utah, Arizona and Nevada already mentioned, with their canyons and encircling cliffs.

An orderly stratigraphy for this vast region has been obtained above all by the researches and brilliant syntheses of R. W. Imlay (1947, 1948, 1949, 1952), on whose work the following brief summary is necessarily based. Ver Wiebe (1933) and G. T. Schmitt (1953) have given an exhaustive treatment of the stratigraphy from a non-palaeontological standpoint. In the following summary the complex formational terms are eliminated as much as possible in the interests of world-perspective; readers who require these terms must refer to the works quoted.

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KIMERIDGIAN/PORTLANDIAN?

Morrison formation (60-120 m.; max. 300 m. in the west): the highest Jurassic formation over a vast area of Colorado, Utah, Wyoming, Montana, New Mexico and Arizona. It consists of sandstones and greenish clays or shales, which may be altered fine tuff, with abundant bentonite locally, and passes in short distances entirely into unfossiliferous white or purplish sandstone. The base overlaps all the underlying Jurassic and transgresses on to the pre-Cambrian in Colorado (Mook, 1916, 1918; the former with complete bibliography).

The fauna of the Morrison is entirely freshwater and terrestrial. The most famous fossils are giant dinosaurs, including *Atlantosaurus*. They agree most closely (though not exactly) with those of the Tendaguru Beds of Tanganyika, which are interbedded with marine strata yielding Upper Kimeridgian ammonites (see p. 333). There are also turtles, fish and mammals. The mammals have their nearest counterparts in the Purbeck Beds of England, and being highly peculiar genera and families, point to fairly close age relations (Simpson, 1926, pp. 212-4; 1929); but their value for exact correlation is tempered by the fact that mammals are unknown in the earlier marine Upper Jurassic of Europe. Some ostracods also are closely comparable to Purbeckian forms. In several places the Morrison formation yields different silicified faunules of small freshwater gastropods and a few pelecypods, with characean plants (Branson, 1935; Henderson, 1935; Stanton, 1915; White, 1886; Yen & Reeside, 1950; Yen, 1952). These, however, are less like those of the English Purbeck Beds than the latter are like those of the Cretaceous Bear River formation of Wyoming, which is now considered Albian (see Arkell, 1941, p. 125). This points to a pre-Purbeckian age for the Morrison.

OXFORDIAN/UPPER CALLOVIAN

Redwater Shale member (24-57 m.) at top of the Sundance formation. Greenish grey shales, richly fossiliferous, especially in Wyoming and the Black Hills of South Dakota. Contains also glauconitic sands at base, some limestones higher up, and at top sandy beds; becomes sandier westward (Imlay, 1947).

This marine episode brought in an extremely varied and interesting fauna of Cardioceratidae, monographed by Reeside (1919). There is marked resemblance at generic and subgeneric level with European, especially English, forms, but only one (doubtful) case of specific identity. The placing of such forms from a different continent in the taxonomic subdivisions established in Europe, especially from figures and descriptions only, admittedly must have a strong subjective element. Nevertheless, it has been attempted by Imlay (1947, p. 264) with a knowledge of the American forms and using my figures of the English forms *; for what it is worth I therefore now offer my interpretation of Reeside’s figures and descriptions based on some 30 years’ familiarity with the English

Cardioceratidae. Though we differ in many details we agree that besides
the majority of species clearly indicating both Cordatum and Mariae Zones
of the Lower Oxfordian there are minorities which can only be of the age
of the Lamberti Zone (Upper Callovian) and Plicatilis Zone (Upper
Oxfordian). In the following list the references are to Reeside’s plates
and figures.

1. Quenstedtoceras (Lamberticeras?) collieri Reeside, i, 1-8.
2. Quenstedtoceras (Eboraciceras) hoveyi Reeside, i, 9-14; ii, 1.
3. Quenstedtoceras (Eboraciceras) tumidum Reeside, iv, 8-10; v, 3-4.
4. Quenstedtoceras (Eboraciceras) subtumidum (W. & H.), iv, 16.
5. Quenstedtoceras (Pavloveceras) latum (Reeside), xx, 7-16.
6. Goliathiceras spectum (Reeside), iv, 5-7; v, 1-2.
7. Goliathiceras crookense (Reeside), ix, 2-4.
8. Goliathiceras russelli (Reeside), xiii, 2-3; xiv, 3-5.
9. Goliathiceras crassum (Reeside), xii, 3-4; xiii, 1; xiv, 1-2.
10. Goliathiceras albianense (Reeside), xxiii (non xxiv, 1-2).
12. Cardioceras (Scarburgiceras) cordiforme (M. & H.), vii, viii, ix, 1.
13. Cardioceras (Scarburgiceras) reesidei Maire, viii, 4-5 only (type).
14. Cardioceras (Scarburgiceras) martini Reeside, ix, 5-8.
15. Cardioceras (Scarburgiceras) schucherti Reeside, xi, 3-5.
16. Cardioceras (Scarburgiceras) wyomingense Reeside, xv, 12-17.
17. Cardioceras (transitional, Scarburgiceras-Cardioceras) auroraense Reeside, x.
18. Cardioceras (Cardioceras) hyatti Reeside, xv, 1-4.
19. Cardioceras (Cardioceras) distans (Whitfield), xv, 18-24; xvi.
22. Cardioceras (Scoticardioceras) alaskanum Reeside, vi, 7-10.
23. Cardioceras (Scoticardioceras) stillwelli Reeside, vi, 11-14.
25. Cardioceras (Vertebriceras) obesum Reeside, xv, 9-11.
26. Cardioceras (Sagitticeras) haresi Reeside, xix, 4-12.
27. Cardioceras (Sagitticeras?) obtusum Reeside, xx, 1-6.
28. Cardioceras (Subvertebriceras) canadense Whiteaves, xvii, 5-11.
32. Cardioceras (subgen. nov.) platensæ Reeside, ix, 9-12.
33. Cardioceras (subgen. nov.) bellofourchense Reeside, xi, 1-2; xii, 1-2.
34. ? Pachyceras incertum (Reeside), xx, 17-20; xxi; xii.

Using the numbers in this list for brevity, the age-indications are as
follows:—

1-4 Upper Callovian, Lamberti Zone
5, 14-17 Lower Oxfordian, Mariae Zone
6-13, 18-27 Lower Oxfordian, Cordatum Zone
28-31 Upper Oxfordian, Plicatilis Zone

No doubt future collecting will determine whether four horizons can be
distinguished in the field, or whether all or any combinations of the four
are blended. (Cf. Crickmay, 1936: it is not clear why it is a ‘gross error’
(p. 554) to take nos. 2-4 in the above list at their face value.)

In England Scoticardioceras is more characteristic of the Plicatilis
Zone, but the American forms (21-23) are not like the English in ribbing
habit and probably are earlier. Several of the species of Scarburgiceras
are very close to English forms of both Mariae and Cordatum Zones, and
one may be identical (C. reesidei Maire; Arkell, 1946, op. cit., p. 307).
C. (S.) schucherti most resembles C. (S.) mirabile Arkell (Mariae Zone). C. (C.) lilloetense seems to belong to the group of C. persecans Buckman (Cordatum Zone). The Vertebriceras are most like Cordatum Zone forms; C. (V.) stantoni is close to C. (V.) gracile Arkell. I have not attempted to subdivide the Goliathiceras, but at least G. russelli and perhaps several others are probably Pachycardioceras, as Imlay suggests.

It is curious that other families of ammonites are almost absent (see however, Imlay, 1947, pp. 260-1). In other regions, especially England and Europe, they abound at every level represented by these Cardioceratids.

Elsewhere some elements of these faunas have been found in the basal Curtis formation of the Uinta Mountains in Utah and Colorado, and in Yellowstone National Park, etc. (Imlay, 1952, pp. 964-5; 1947, pp. 260-1; Crickmay, 1936).

LOWER CALLOVIAN

In the lower part of the Sundance formation in the Black Hills and Wyoming, and in the equivalents in Utah, Arctoceras henryi (Meek & Hayden) is common, with Arctoceras spp. and many pelecypods. In the Wind River Basin, Wyoming, the Arctoceras beds are succeeded by beds with Gowericeras spp. In the Rierdon formation of Montana these two zones occur with Kepplerites (Seymourites) beds above, and beds with Arctocephalites below. The following six zones have been made out in this and other Rocky Mountain states, and the ammonites have been well figured (Imlay, 1948, 1953);

Zone of Seymourites mclearni Imlay, with Kosmoceras, Grossouwria and Macrocephalitids
Zone of Seymourites tychois (Ravn), with Cadoceras spp.
Zone of Gowericeras subitum Imlay, with Cadoceras spp., Xenoceralites shoshonense (Imlay) and rare Perisphinctids
Zone of Gowericeras costidensum
Zone of Arctoceras codyense, with Cadoceras and small Arctocephalites
Zone of Arctocephalites spp.

The exact correlation of these zones with those recognized in Europe presents many difficulties. It has been fully discussed by Imlay (1948, 1953), who has been able by the use of these zones to make widespread correlations through the Western Interior states (1952). The occurrence of Macrocephalitids at the top agrees with Canada and has its counterpart in England, though there they are commoner below; and the absence of Macrocephalitids at the bottom agrees with Greenland. Kosmoceras at the top and Gowericeras in the middle of the Lower Callovian also agrees with England; and the presence of Xenoceralites in the Gowericeras zones, since it occurs with Reineckea in South America, further indicates that these zones cannot be low in the Lower Callovian. The Arctoceras and Arctocephalites zones (and also Crancephalites of Greenland) are all

http://jurassic.ru/
Cordilleras of North America

closely bound together palaeontologically and form a unit which is by no means too large to equate with the immensely thick Macrocephalus Zone of, for instance, Cutch (p. 391). Even ‘Procerites’ can be Callovian, as Imlay points out; and apart from this doubtful determination there is no evidence for anything Bathonian. In this connexion the excellent discussion of the Greenland evidence by Donovan (1953, pp. 130-3) should be read; though it does not seem to me to be necessary to doubt the generic identity of the American Gowericeras which are at least as like the European forms as are other North American ammonites such as the Cardioceratidae and Stephanoceratidae.

Some of the ammonites figured by Imlay, as Cadoceras muelleri, C. tetonense, C. piperense, from the Gowericeras beds, are astoundingly like European Morrisiceras of the Middle Bathonian, and seem to go best in the South American Callovian genus Eurycephalites, which Burckhardt in 1903 mistook for Morrisiceras (see p. 584).

Bathonian?

The Gypsum Spring formation of the Western Interior region contains in its upper part gastropods likened by Imlay (1947, p. 242) to forms from the English Great Oolite. The position of this horizon is below the Callovian faunas just discussed and above the Middle Bajocian Stemmatoceras-Defonticeras zone. No unequivocally Bathonian ammonites are known, nor any datable to Upper Bajocian.

Middle Bajocian

The middle part of the Gypsum Spring formation of central Wyoming and southern Montana, the lower part of the Sawtooth formation of western Montana, and the lower part of the Twin Creek limestone of western Wyoming and eastern Idaho contain a fauna characterised by Chondroceras (Defonticeras) oblatum (Whiteaves), Zemistephanus vancouveri McLearn and Stemmatoceras (Imlay, 1948). In Montana Teloceras is also recorded (Imlay, 1952, p. 968). In many places this zone contains limestones, and it represents a marine transgression from the west. The fauna is clearly the same as that of the Middle Bajocian in Canada.

Undated (Lias ?). (Up to 1000 m.)

The marine Middle Bajocian in Wyoming, Idaho and South Dakota rests on the Nugget Sandstone, which may be a continental equivalent of the Lower Fernie of Canada, but bears little resemblance to it. No marine fossils occur, and there is much coarse current-bedding, with polished sand grains and pebbles. In Arizona and parts of Nevada the Navajo Sandstone, probably equivalent stratigraphically, has yielded inconclusive reptilian remains. These sandstones are doubtless equivalent in a general way to the Lias. (Imlay, 1952, pp. 664, 666.) Further thick sandstones underneath (Wingate formation) may be basal Liassic or Upper Triassic.

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PACIFIC BORDER OF THE UNITED STATES

The great belt of deeply-sinking narrow troughs, volcanic activity and Jurassic orogeny, already described in Alaska and British Columbia, continues through the Pacific border states of Washington, Oregon and California, with part of western Nevada.

Here the master event was the Nevadan orogeny. By means of close ammonite stratigraphy the date of this revolution has been pinned down within narrow limits. It occurred between (certainly) Lower or (probably) Middle Kimeridgian, and Tithonian: that is, in the Upper Kimeridgian, or possibly Lower Portlandian. The stratigraphy of the whole region divides itself into two epochs, before and after the orogeny, for the revolution caused not only violent folding and thrusting and the injection of the mighty granodiorite batholith of the Sierra Nevada, but westward migration of the geosyncline to a fresh site.

The centre of pre-Nevadan sedimentation lay over the region of the Sierra Nevada, with the adjacent parts of western Nevada on the east and the Great Valley of California on the west. Here sedimentation was continuous from the Trias (Norian and Rhaetian) into the Hettangian.

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http://jurassic.ru/
and Sinemurian, with ammonite faunas of all four stages. Preliminary movements occurred in the Pliensbachian, when masses of coarse conglomerate were formed, with some folding and incipient thrusting, followed closely by volcanism (Dunlap formation). This episode may possibly coincide with a major orogeny in Oregon, where the Upper Trias was intensely folded before the locally lowest Jurassic beds were laid down—the earliest dated being Pliensbachian. After this orogeny in central Oregon there was no volcanism, but in California volcanic activity continued intermittently in the Toarcian, Bajocian and Callovian. The total thickness of deposits of these ages is from 1500 to 4500 m. and in places contains about 420 m. of pillow lavas overlain by up to 450 m. of tuffs, radiolarian cherts, and shales. These volcanics occur through all the outcrops of California and south-western Oregon. The lavas, which are all submarine, range from rhyolite to basalt, with augite-andesite predominant. Volcanic centres can be recognized, in the form of necks and concentrations of flows and coarse agglomerates and breccias. There are also many and complex intrusions (Taliaferro, 1942).

Volcanic activity tended to die down in the last episode (Mariposa shale or slate) before the Nevadan orogeny: that is, during the Lower and perhaps Middle Kimeridgian; though there were still extrusions of greenstone and tuff.

The Nevadan orogeny produced violent deformation of all preceding rocks, involving them in overturned folds and major thrusts, in which Palaeozoics were thrust eastward over the Jurassic. Following quickly upon these movements, the huge batholiths of the Sierra Nevada and its satellites were intruded, preceded by some basic intrusions. Similar structures and batholiths continue southwards to form most of the long peninsula of Baja California, but the evidence suggests that these are Lower Cretaceous, like the great Idaho batholith.

After the Nevadan orogeny a new geosyncline formed to the west of the old one, over the site of the present Coast Ranges. Like its predecessor this too received sediment and volcanic material from the west; from which it is again inferred that a volcanic island festoon lay offshore in what is now the Pacific. This trough may have received in places up to 7,000 m. of sediment and volcanic rocks, all within the Tithonian period (sensu lato). These rocks, since folded in successive Cretaceous, Tertiary and even Pleistocene orogenies, now build the Coast Ranges with their characteristic shaly aspect, so different from the serrated ridges and peaks of the Sierra Nevada, carved from the granodiorite batholith.

The end of the Jurassic is marked by another orogeny, the Diablan, which occurred between the Tithonian and Valanginian and is therefore dated to the only stage unrepresented by fossiliferous sediments in the region, the Berriasian.

The complex history thus briefly sketched has been hammered out by many geologists working over a period of more than half a century, but is pre-eminently to the credit of Professor N. L. Taliaferro (1942, http://jurassic.ru/
1943) and F. M. Anderson (1933, 1945) for the post-Nevadan history, while the pre-Nevadan history in Oregon and Nevada owes most to the work of Lupher (1941) and Muller & Ferguson (1936, 1939).

Table 23 (based on Taliaferro, 1942, p. 107, emended) summarizes the stratigraphy of the Upper Jurassic with its complicated and oft-modified terminology.

**Table 23.** Upper Jurassic and Lower Cretaceous, California and Oregon

<table>
<thead>
<tr>
<th>Stages</th>
<th>Formations (California &amp; Oregon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Albian</td>
<td>Horsetown and Paskenta—Shasta group and Franciscan (pars)</td>
</tr>
<tr>
<td>Aptian</td>
<td></td>
</tr>
<tr>
<td>Barremian-Valanginian</td>
<td></td>
</tr>
<tr>
<td>Berriasian</td>
<td>Absent. Diablan orogeny</td>
</tr>
<tr>
<td>(? Upper and) Middle Tithonian/Portlandian</td>
<td>Knoxville/Franciscan (pars)</td>
</tr>
<tr>
<td>Upper Kimeridgian (Lower Tithonian)</td>
<td>Absent. Nevadan orogeny</td>
</tr>
<tr>
<td>Middle? and Lower Kimeridgian</td>
<td>Mariposa Slate (California) and Galice formation (Oregon) and</td>
</tr>
<tr>
<td>Upper Oxfordian</td>
<td></td>
</tr>
<tr>
<td>Middle and Lower Callovian</td>
<td>Amador group (California) and Dothan group (Oregon)</td>
</tr>
</tbody>
</table>

The Lower and Middle Jurassic in the Sierra Nevada are together over 6000 m. thick, while the Upper Jurassic of the Coast Ranges may be at least 7500 m. thick: a total of 13,500 m. (Taliaferro, 1942 pp. 104, 109). A large part of the supposed Upper Jurassic may be Cretaceous.

**Tithonian**

Knoxville formation (probably 3000 m. +), passing down into the Franciscan formation (probably 6-7000 m.). The Knoxville consists chiefly of shales, in which occur *Buchia piochii* and other species of *Buchia*, and a poorly-preserved ammonite fauna correlating with the Middle Tithonian *Substeueroceras* and *Durangites* beds of Mexico, including *Berriasella storrsi* (Stanton), *Protothurmannia rezamoffiana* Crickmay, *Kossmatia dilleri* (Stanton), *K. tehamaensis* Anderson, *Durangites aff. vulgaris* Burckhardt, *Substeueroceras [Parodontoceras?] stantoni* Anderson, *'Aulacosphinctes' (?) spp.*, *Protacanthodiscus crossi* Anderson, *Phylloceras* (3 spp.), *Lytoceras*, etc. (Crickmay, 1932; Anderson, 1945; Taliaferro, 1943, p. 198; Imlay, 1952, p. 974). The lowest 360 m. are unfossiliferous.

According to Taliaferro (1942, 1943) the lower part of the Knoxville is equivalent to the upper part of the Franciscan and they grade into one another vertically and laterally. Arkosic sandstone is the dominant sediment of the Franciscan; interbedded with it are shales, silts and
carbonaceous layers passing to impure coal. In the middle and upper parts of the formation are great thicknesses of volcanic rocks: pillow lavas, vesicular basalts, andesites and dacites, tuffs and agglomerates interbedded with limestones and radiolarian cherts; and the whole is intruded by a variety of hypabyssals. The cherts are best developed where the volcanic rocks are at their maximum, and the whole is clearly a shallow-water succession. Many of the Knoxville fossils, including ammonites, were collected from shales below pillow lavas and cherts of Franciscan type (Taliaferro, 1943, p. 197). From boulders of the chert have been obtained two snouts of *Ichthyosaurus* which compare best with *I. posthumus* of the Solnhofen Slates (Upper Kimeridgian, Lower Tithonian).

According to Taliaferro (1943, pp. 190-195) both Franciscan and Knoxville are overlain unconformably throughout the Coast Ranges by the Paskenta formation, which contains a marine Valanginian fauna. Part of the Franciscan at the type locality in San Francisco, however, is Cretaceous, for it has yielded the Albion ammonite *Douvilleiceras* (Schlocker, Bonilla & Imlay, 1954).

**LOWER (AND MIDDLE?) KIMERIDGIAN; AND UPPER OXFORDIAN?**

Along the west side of the Sierra Nevada the Mariposa Slates, which pass into the Galice formation in Oregon, have yielded *Amoeboceras (Amoebites) dubium* (Hyatt) (Reeside, 1919, p. 38, pl. xxiv, figs. 5-8) a Lower Kimeridgian form; also poorly-preserved Perisphinctids, *P. virgulatiformis* Hyatt and *P. mühlbachi* Hyatt, which Crickmay (1933, pp. 56-7, pls. 16-18) interprets respectively as *Virgatosphinctoides* [Middle Kimeridgian] and *Dichotomoceras* [Upper Oxfordian—Lower Kimeridgian]. The preservation of the material, however, renders generic placing hazardous. From agglomerates at Longtown Ridge, *? Divisosphinctes* or *? Pachysphinctes* is recorded (Imlay, 1952, p. 976).

**MIDDLE AND LOWER CALLOVIAN**

The Mariposa Slate apparently reaches down into the late Lower Callovian, for it has yielded *Képplerites* (Growericeras? or *Seymourites*) (?*) lindgreni* Hyatt sp. (Crickmay, 1933, p. 57, pl. 17, figs.9, 10) and Macrocephalitids or Cadoceratids. (*Catacephalites* was based on a squashed Cadoceras.) *K. lindgreni* seem to be much like *Seymourites* figured from Canada by McLearn (1929, pls. i-viii). The equivalent Amador formation of the Sierra Nevada is partly volcanic in the lower layers, containing pillow basalts, tuffs and agglomerates; it has yielded *? Grossouvria* (Imlay, 1952, p. 975). At Mount Jura in the northern Sierra Nevada, *Reineckeia (Reineckites) dilleri* (Crickmay 1933b, p. 914, pls. 32, 34) is sufficiently common to have been proposed as a zonal index. Some hundreds of feet lower was found *Choffatia hyatti* Crickmay sp. (1933b, pl. 33), which much resembles some European forms of the Macrocephalus Zone (subbakeriae group). In central Oregon *Lilloetia* and *Képplerites*
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(Gowericeras ?) occur in the Trowbridge Shale, thus correlating with Canada and Alaska (Lupher, 1941, p. 264).

**BAJOCCIAN**

In central Oregon a series of formations has been distinguished with rich Middle and Lower Bajocian ammonite faunas as follows (Lupher, 1941):—

1. Izee group.

   Snowshoe formation (840 m.). Sandstones grading to shales with flinty nodules. *Skirroceras* cf. *leptogyrale* Buckman and *S. sp.*., *Witchellia* aff. *simulans* (Buck.) and *W. aff. felix* (Buck.), *Sonninia* (Papilliceras) *stantoni* Crickmay, *S. cf. blackwelderi* Crickmay, *Hebetoxities* cf. *hebes* Buck., *H. cf. clypeus* Buck. The age of the last two in England, according to Buckman, is the upper part of the Sowerbyi Zone (Laeviuscula Sub-zone), but all the others are of the Sauzei Zone. *Stemmatoxities* and *Normannites* occur in a conglomerate derived from this formation.

   Hyde formation (324 m.). Massive medium-grained sandstones with *Skirroceras* and Sonninids as above.

   Colpitts group: Warm Springs formation (30-90 m.) and Weberg formation (30-67 m.). Limestones, sandstones and shales, with abundant ammonites in both subdivisions. They include (not differentiated) a profusion of Sonniniidae, many like those of the Sowerbyi Zone figured in Buckman’s monograph, including *Euhoploceras*, also *Witchellia* (‘Zugophorites’, ‘Zugella’), *Docidoceras* spp., all of the Sowerbyi Zone, and also *Praestrigites* (*Deltostrigites*) cf. *deltatus* (Buckman) and *Tmetoceras* cf. *scissum* (Ben.), of the Lower Bajocian.

   The Sowerbyi and Sauzei Zones are also represented in the Mormon formation (283 m.) at Mount Jura, California, as shown by *Sonninia schucherti*, *S. stantoni*, *S. blackwelder*, *S. juramentanum*, *Normannites reesidei* and *Chondroceras russelli*, all of Crickmay (1933b, pp. 909-913, pls. xxvii-xxxii). *Holcophylloceras* occurs here.

**TOARCIAN AND UPPER PLIENSBOCHIAN**

The next-lower formation in central Oregon, the Nicely Shale (40 m.), contains fossiliferous nodules with *Amaltheus* cf. *reticulatus* (Simpson), *Amauroceras* sp. nov., *Harpoceras* sp. nov., *Platyparites* sp. nov. and ‘early Hildoceratidae and Dactylioceratidae’ (Lupher, 1941, pp. 240, 246). The same forms are found in the underlying Supplee formation (12 m.). The age from this appears to be Upper Pliensbachian, perhaps transitional to Toarcian. *Harpoceras* is also recorded from the Dunlap formation of western Nevada, where it has been taken for basal Toarcian (Muller & Ferguson, 1939, Table 3 and p. 1621). The Dunlap formation contains thick conglomerates of local pebbles and its upper part is largely volcanic; the conglomerates and local erosional unconformities are taken to indicate uplift and folding during the Pliensbachian or possibly early Toarcian (ibid. pp. 1616-7).
LOWER PLEISNBACHIAN AND UPPER SINEMURIAN

The Donovan formation, the lowest Jurassic beds recognized in central Oregon, seems to straddle these two stages. It consists of less than 60 m. of sandstones and sandy shale with negligible amounts of limestone and conglomerate. The red sandstones yield abundant pelecypods, also \textit{? Uptonia} (Polymorphitidae, perhaps not this genus) and \textit{Coeloceras} cf. \textit{pettos} (Quenst.) of the Jamesoni Zone, also \textit{Eoderoceras} cf. \textit{impavidum} (Buck.) and \textit{Paltechioceras} ("\textit{Metachioceras}") of the Raricostatum Zone (= \textit{Armatum Zone}) of the Upper Sinemurian (Lupher, 1941, p. 235). The \textit{Eoderoceras} fauna of this zone also occurs in the top of the Sunrise formation in western Nevada (Muller & Ferguson, 1939, p. 1612) and \textit{Echioceras} has been found at Mount Jura (Crickmay, 1933b, p. 909, pl. xxvii, figs. 1-5).

LOWER SINEMURIAN

Oolitic limestones 22.5-25.5 m. above the base of the Sunrise formation, western Nevada, contain \textit{Arietites bisulcatus} (Brug.), \textit{A. rotator} (Sow.), \textit{Megarietites meridionalis} (Reynès) and \textit{Tmaegoceras} spp. (Muller & Ferguson, 1939, pp. 1611-2). From the same beds probably came \textit{Coronioceras} (\textit{Metophioceras}) \textit{crossmanni} (Hyatt) and perhaps \textit{Arnioceras woodhulli} Hyatt (Crickmay, 1925).

HETTANGIAN

The lowest 22.5 m. of the Sunrise formation consists of argillaceous and cherty limestone interbedded with shale and has yielded \textit{Psiloceras} spp., \textit{Euphyllites}, \textit{Waehneroceras}, \textit{Phylloceras}, \textit{Schlotheimia} and \textit{Chlamys} aff. \textit{textorius} (Quenst.) (Muller & Ferguson, 1939, p. 1611).

[RHAETIAN

The Sunrise formation follows conformably on Rhaetian beds with \textit{Pteria contorta} (Portlock) and \textit{Chroistoceras marshi} (Hauer) and underlain by the Norian stage with a rich ammonite fauna (Muller & Ferguson, 1939, pp. 1605-9). In Oregon, however, the Upper Trias and unfossiliferous beds above it (which may be Jurassic) are acutely folded and overlain unconformably by Jurassic in which the lowest dated stage is Pliensbachian.]
CHAPTER 24

MEXICO AND THE GULF REGION

MEXICO

Most of Mexico is a continuation of the Cordilleras of North America. In it are still recognizable representatives of the Pacific geosyncline, the Cordilleran geanticline, and an analogue of the Rocky Mountain trough.

The Pacific geosyncline continues southward through the northeastern state of Sonora and the long peninsula of Lower California and intervening Gulf of California, which may be a lineal descendant of the ancient geosyncline. In Lower California, however, no fossiliferous rocks older than Cretaceous have been found, and though from the lithology and the intrusive batholiths the peninsula would appear to be a continuation of the Sierra Nevada and Coast Ranges, both the batholiths and the sediments are somewhat later. The only Jurassic known in NW. Mexico is some small outliers of Lias, mainly continental but partly marine, in the state of Sonora.

The Cordilleran geanticline is continued in a general way, considerably narrowed, by the main NNW.-SSE. mountain range, the Sierra Madre Occidental, which though thrown up in its present form in the late Tertiary and even later, was already a land barrier in the Jurassic.

To the east of the barrier lay a broad basin of Jurassic deposition, analogous with the Rocky Mountain trough and ancestral to the Gulf of Mexico, though differing greatly in outline. Like its northern analogue, this trough was deepest along its western side, which developed as a geosyncline running obliquely SSE.-NNW. through what are now the Sierra Madre Oriental and the high central plateau (Mesa Central). It was in this geosyncline, open only at the south-east to the Gulf of Mexico, bounded on the west by the Cordilleran geanticline and on most of the east by a finger-like promontory from the northern land, that nearly all the Jurassic rocks of Mexico accumulated.

The outstanding features of the Jurassic faunas of Mexico are their Mediterranean connexions and their evident severance from those that lived in the tectonically analogous Rocky Mountain trough of the United States and Canada. It is this discontinuity, and also the tectonic discontinuity in the southern part of the country, that make it logical to treat Mexico and the Gulf region in a separate chapter.

The tectonic discontinuity consists in the sudden change of strike of the mountain ranges and fold axes to E.-W. in the south of Mexico, in conformity with the general trend of the folding in Central America and the Greater Antilles. Palaeozoic, Cretaceous and Tertiary folds all follow this trend in the Central American-Antillean region. Lithology
and faunas in southern Mexico indicate that in the Jurassic the same grain was followed by a seaway which at times linked the Gulf of Mexico with the Pacific and afforded a migration route across southern Mexico. It was not always open, and from its postulated closings and openings has been called the Balsas portal (Schuchert, 1935, p. 119). The times when it probably opened were the Upper Jurassic and Lower Cretaceous, at least intermittently (Imlay, 1940). A more permanent connexion between the Atlantic and Pacific Oceans lay farther south, through the Caribbean and across Costa Rica and Panama (fig. 88).

The possibility of a more northerly connexion between the Mexican and Pacific troughs by way of a Sonoran portal (Imlay, 1940) cannot be excluded. The occurrence of outliers of marine Sinemurian in western and north-western Sonora (Burckhardt, 1939, pp. 23-4, 41-2; Imlay, 1952, p. 973) suggests the possibility of a seaway by this portal in early Jurassic times. *Arnioceras* and other marine fossils are interbedded in some of these outliers with a continental series (Barranca formation) which is in places as much as 750 m. thick. Further discoveries may show whether this fauna has closer affinity with those of southern Mexico or those of western Nevada and Oregon.

The remarkable correspondence between the faunas of Mexico and the Mediterranean region, especially the south of France, at numerous successive levels of the Upper Jurassic, was made clear by Burckhardt as early as 1903 and again fully reviewed in 1930 (pp. 106-111). Burckhardt, however, pointed out a number of differences, which are enough to make detailed correlation difficult. The most striking is the abundance of the peculiar Mexican Oppeliid genus *Mazapilites* in the critical Upper

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**Fig. 88.—Palaeogeographic sketch-map of middle America in the Upper Jurassic. Based on Imlay, and corrected to 1954. (From *Journ. Paleont.*, 1941 modified.)**
Kimeridgian (to Lower Portlandian?) part of the succession, above the Beckeri Zone and below the definite Tithonian. This part of the sequence is still badly in need of further investigation. A general difference is the comparative rarity of Phylloceratidae and Lytoceratidae in the Mexican Kimeridgian and Tithonian, whereas in the Mediterranean area they are the dominant ammonites in numbers of individuals, though not in numbers of species. It is noteworthy that these families should be rare in Mexico in beds carrying an otherwise typical Tethyan fauna, whereas they are abundant in the Caucasus in beds carrying an otherwise typical NW European fauna (see p. 362).

Burckhardt (1910, 1911) believed that the Kimeridgian and Tithonian of Mexico contained a number of 'boreal' genera such as Simbirskites, Craspedites, Kachpurites, Virgatites, but this was contested by Uhlig (1911), and although Burckhardt in his last work (1930, p. 110) maintained his views, Uhlig is now generally held to have been right. The question will be dealt with further in connexion with the Andes of Argentina (p. 580).

No orogeny involved Mexico during the Jurassic or Lower Cretaceous, but earth-movements perhaps synchronous with the Dunlap (Upper Pliensbachian) and Nevadan (Upper Kimeridgian) orogenies can be detected by local overlaps and disconformities or by interruptions of the marine sequence. For instance the Sinemurian and Lower Pliensbachian are marine, with a full ammonite sequence, although plants are present at several horizons; but above the Jamesoni Zone the marine record is cut short and a purely continental regime of plant-beds persists until the Middle or Upper Bajocian.

A great intercalation of red beds and gypsum (Huizachal formation) in the Upper Jurassic, up to 420 m. thick, is believed to be mainly of Oxfordian age (Imlay & others, 1948). It has a basal conglomerate up to nearly 50 m. thick, and other conglomeratic lenses may occur at any level. In eastern Durango this formation contains andesitic lavas 150 to 300 m. thick, interbedded with red shale and sandstone derived largely from disintegration of the lava. The age of these beds is a difficult problem, in the absence of fossils. They are, however, overlain disconformably by the Upper Oxfordian (La Gloria formation), which in its basal conglomerate contains pebbles derived from the red beds. In other places the junction is marked by an angular unconformity. The red beds usually rest on Palaeozoic or older basement rocks and in these places may be of any date between Oxfordian and Permian; but in the Huesteca area of Veracruz, Puebla and Hidalgo they overlie marine Lower Jurassic, and they are believed to correlate with similar but thinner red beds and gypsum in southern Mexico which are mainly of Lower Oxfordian age. (For summaries and discussion of the evidence see Imlay, 1943, pp. 1475-9; 1952, p. 972; Imlay & others, 1948, pp. 1753-61). It is possible that the earth-movements that caused this widespread continental episode in Mexico, with its conglomerates and volcanic activity, were in a general
way contemporary with the Agassiz orogeny of Canada and the formation of the Chisik conglomerate of Alaska; but both those events can be tied down to a much narrower time-interval on the Callovian-Oxfordian boundary.

The Nevadan orogeny is not discernible as such in Mexico but may be represented by non-sequence between Kimeridgian and Tithonian. As will be seen from the summary that follows, however, more stratigraphical collecting is required before the existence and precise extent of such a gap can be satisfactorily established.

Some further volcanic activity at the end of the Jurassic is indicated by tuffs and bentonitic shales in the Upper Tithonian in southern Mexico.

A complete picture of the ammonite faunas of the Middle and Upper Jurassic of Mexico is presented in four sumptuously-illustrated monographs by one of the most able and distinguished students of the Jurassic, the Swiss geologist Carl Burckhardt, who died in 1935. The monographs describe the Upper Jurassic faunas of Mazapil (1906), San Pedro del Gallo (1912) and Symon (1919-21), and the Middle Jurassic and Callovian faunas of the states of Oaxaca and Guerrero (1927), and they were followed by a brilliant synthesis and discussion of the whole Mexican Mesozoic (1930). Further figures and new information have since been published in important papers by Imlay (1939, 1939a, 1943, 1943a; and Imlay & others, 1948) and Mülleried (1942; and Burckhardt (posthumous) & Mülleried, 1936). The Jurassic floras were monographed by Wieland (1914). Comprehensive general accounts of Mexico and the adjacent

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FIG. 89.—Jurassic outcrops in Mexico. The broken line indicates approximately the northern boundary of buried Jurassic rocks under the Gulf Coastal Plain of the southern United States.
areas of Central America, the Gulf region and Antilles, have been published by Schuchert (1935) and Sapper (1937), and a synopsis of the Jurassic of the whole region by Imlay (1943).

In connexion with the upper part of the following summary, use should be made of the correlation table for the Tithonian of South America and Mexico on p. 581.

**Upper Tithonian**

At Mazapil this consists of 10 m. of shaly and marly limestones with black cherts containing *Substeueroceras* cf. *koeneni* (Steuer) and *Berriasella* cf. *calisto* (d'Orb.). At Symon, Durango, from 21 m. of shaly limestone forming the top of the Jurassic were collected *Substeueroceras* sp., *Pardonoceras* spp., *Proniceras* cf. *idoceroides* Burckhardt, *Berriasella zacatecana* Imlay, and *Aulacosphinctes*? (Imlay, 1939, p. 9). The fauna comprises many species of all these genera, plus *Micracanthoceras* spp. and *Hildoglochiceras* spp. (For complete list see Imlay, 1939, table 9; many figures in Burckhardt, 1906, 1921, and Imlay, 1939). *Proniceras* was placed by Burckhardt (1930, table 6) at the base of the Tithonian as here understood, below the *Durangites* and *Kossmatia* beds, but Imlay (1939, p. 23) states that this was an error, based on relative geographical position of separate outcrops, which might have been faulted. He has proved that it occurs at the top, with *Substeueroceras*.

This fauna correlates with the zone of *Substeueroceras koeneni* in Argentina, there also recognized by Leanza as the highest zone of the Jurassic (see p. 582).

In southern Mexico the Tithonian Pimienta formation consists of tuffs and bituminous and bentonitic shales with lenses of limestone and a few thin bands of chert. From it have been obtained *Substeueroceras*, *Pardonoceras*, *Himalayites*, *Corongoceras*, *Hildoglochiceras*, *Pseudolissoceras* and *Durangites* (Imlay, 1952, p. 971). In the type area in the southern Sierra Madre Oriental the thickness of the Pimienta is 100-200 m. (Heim, 1926).

**Middle Tithonian**

To this division belongs the next-lower horizon, characterized by numerous species of *Durangites* and *Kossmatia*, together with subordinate *Hildoglochiceras* and *Micracanthoceras*, and *Grayiceras*? *mexicanum* (Burckhardt) (which Burckhardt figured, 1912, pl. xxxiv, figs. 18-22, as a *Simbirskites*, but which Spath in 1923 likened to forms from the Spiti Shales). Many figures in Burckhardt, 1906, 1912, 1921; Imlay, 1939; list in Imlay, 1939, table 8. This horizon correlates with a Tithonian fauna in California (see p. 553).

**Lower Tithonian and Upper Kimmeridgian**

Between the Middle Tithonian *Durangites* and *Kossmatia* beds and the Middle Kimmeridgian *Hybonoticeras beckeri* beds is a series of strata characterized primarily by Perisphinctids of great variety and presenting great...
taxonomic difficulty, and (in the lower part at least) by the peculiar Oppeliid genus *Mazapilites*, not known outside Mexico (see Burckhardt, 1921, pls. i-iii, v-xiv, and list in Imlay, 1939, table 7). Imlay (1939, 1943) has figured a number of new forms from these beds and made valiant efforts to sort out the systematics of the Perisphinctids and the detailed succession. It is still impossible, however, to place all the forms satisfactorily in existing genera, or to draw a definite boundary between Tithonian and Kimeridgian.

The presence of Lower Tithonian in the upper part of these beds, probably above the range of *Mazapilites*, is proved by undoubted *Virgatosphinctes*, correlating with the Lower Tithonian of Argentina and farther afield (e.g. *V. cf. denseplicatus* Waagen sp., *V. adkinsi* Imlay, *V. chihuahuensis* Imlay (1943), *V. aguilari* Burck. sp., 1906 pl. xxvii, 6-9). The predominant Perisphinctids, however, are a different group which seem to fall for the most part into the genus *Aulacosphinctoides* (Burckhardt, 1921, pls. v-xiv, sub. *Aulacosphinctes*), characteristic of the Lower Tithonian and Upper Kimeridgian of Spiti, New Zealand, etc. Many of the species have a notable frequency of simple ribs, which strongly recalls the genus *Torquatisphinctes*, and if, as Imlay holds, both genera are represented, it is likely that these beds reach down into the Middle Kimeridgian. Another pointer in the same direction is the occurrence of forms of Perisphinctids (*P. mexicanus* Burckhardt, 1906, pl. xxxi, figs. 6-9) which appear to belong to the genus *Virgataxioceras* of the Beckeri Zone, and the overlap, according to Burckhardt, of *Mazapilites* and *Hybonoticeras*. Other forms occur which Imlay (1943, pp. 532-3, pls. 88, 89, 91) assigns to the late-Middle and early-Upper Kimeridgian genus *Subplanites*, the genus to which *P. burckhardti* Blanchet (1923) probably belongs (type Burckhardt, 1921, pl. xiv, figs. 1-3); and *Perisphinctes nikitini* Burckhardt (1906, pl. xxxii, figs. 1-4) seems to be a *Subdichotomoceras*. Another fragment figured by Burckhardt (1906, pl. xxxii, fig. 2) may be identical with an early *Virgatosphinctes* of the Neuburg Lithographicum Zone, *V. eystettensis* Schneid (1914, pl. iii, fig. 5). With these forms occur a considerable variety of *Aspidoceras* and *Physodoceras*, *Taramelliceras*, *Pseudolissoceras*, *Haploceras*, etc. It is difficult to believe that careful stratigraphical collecting will not one day yield a sequence and solve the problems.

Some ammonites, mostly indeterminate fragments, that may represent a different Upper Kimeridgian fauna of the Pectinatus Zone have been figured from an isolated outcrop near Las Cuevas in eastern Durango (Imlay, 1939, p. 33-4). They have been assigned to Callovian genera and dated (p. 21) to the 'Middle Oxfordian', but they bear a suggestive resemblance, in the photographs, to *Pectinatites* (pl. 7, fig. 7) and *Wheatleyites* (pl. 7, fig. 1; pl. 5, fig. 8; pl. 6, fig. 1; pl. 8, figs. 1, 2).

**Middle and Lower Kimeridgian**

The Middle Kimeridgian is represented most recognizably by beds with *Hybonoticeras* cf. *beckeri* (Neum.), *H. cf. harpophorum* (Neum.), *H. cf.
knopi (Neum.), H. cf. hybonotum (Oppel) and H. cf. autharis (Oppel), a remarkably south European assemblage of the Beckeri Zone. With them occur the earliest Mazapilites, Physodoceras and a few Perisphinctids.

The Lower Kimeridgian is the most richly fossiliferous and characteristic stage in Mexico, with an immense fauna of Idoceras and many other genera. Two zones are recognizable, an upper with Idoceras durangense and Glochiceras fialar, a lower with Idoceras of the group of I. balderum. Both must be mainly Lower Kimeridgian, for the higher zone contains many Involuticeras and Streblites, with Ochetoceras and Sutneria, also Pararasenia Zacatecana (Burckhardt). Besides the genera mentioned there are numerous Aspidoceras, Nebrodites, Taramelliceras, Haploceras, etc., with subordinate Perisphinctids and some Phylloceras and Lytoceras. (For lists see Imlay, 1939, tables 4 and 5; numerous figures in Burckhardt's Mazapil (1906), San Pedro (1912), and Symon (1919-21) monographs and in Imlay, 1939). The Glochiceras fialar fauna also occurs in the Taman formation (altogether over 1000 m. thick) in the southern Sierra Madre Oriental (Heim, 1926).

Many of the later Mexican Idoceras are clearly related closely to Ataxioceras, from which the ventral smooth band alone provides a doubtful distinction (Burckhardt, 1912, pls. xxvi-xxxi). Peculiar local genera are Subneumayria, type S. ordonesi Burckhardt sp. (1906, pls. i, ii), and Epicephalites, type E. epigonus Burckhardt sp. (1906, pi. iii), both probably Rasenids related to Involuticeras.

Oxfordian

Ochetoceras beds (100 m. ±) at San Pedro del Gallo: shales and sandy marls with nodules and a black limestone band containing O. canaliculatum (d'Orb.), O. pedroanum Burck., O. mexicanum Burck., Taramelliceras neohispanicum Burck., Discosphinctes virgulatus (Quenst.) var. carribbeanum (Jaworski), Euaspidoceras (Burckhardt, 1912, pl. v, 5, 8, 9; pl. vii, 4-22). The date of this assemblage is probably Bimammatum Zone.

Perisphinctes beds (150 m.) at San Pedro del Gallo: marls and shales with beds of sandstone and limestone and many pelecypods, including Trigonia hudlestoni Lycett. All the Perisphinctes figured from these beds are typical Dichotomosphinctes, strongly resembling common forms of the Plicatilis Zone, with which the beds certainly correlate (Burckhardt, 1912, pls. ii-vii). There are also Taramelliceras spp. and a Creniceras (pl. vii, 15-17). A characteristic Cuban form occurs: P. plicatiloides O'Connell (Burckhardt, 1912, pl. iii, 3-6).

Below these beds are 600 m. or more of shales and sandstones, with Nerinean and coralline limestone, resting on red shales, marls and sandstones, all without ammonites. In Zacatecas the Nerinean and coralline limestones are 500-1000 m. thick (Burckhardt, 1930, table 6). In eastern Mexico are up to 420 m. of red beds of uncertain date but approximately Lower Oxfordian, the Huizachal formation (Imlay & others, 1948). This formation unconformably overlaps all previous Jurassic beds on to
Palaeozoic or older rocks, but is said to be itself unconformably overlain by the Upper Oxfordian. Perhaps the explanation is that the red beds are of different ages in different places, since Burckhardt described them as underlying the Upper Oxfordian without a break in Durango.

**Callovian**

Upper Callovian (Athleta Zone) is represented at El Consuelo, Oaxaca, and Cualac, Guerrero, by an assemblage of Peltoceratids, with which are associated Reineckeids and Perisphinctids. Characteristic forms are *Peltoceras aff. athleta* (Phil.) and *P. cricotum* Burck., *Subgossouwria suborion* (Burck.), *S. neogaeum* (Burck.), etc. (Burckhardt, 1927, pls. xxx-xxxiv.) Ammonites identified with the Callovian genera *Pseudopelto- ceras?*, *Subgossouwria?* and *Indosphinctes?* have also been figured from an isolated outcrop in Durango (Imlay, 1939, pp. 33-4) but, as remarked above (p. 562), from the figures they could be Upper Kimeridgian *Pectinatites* and *Wheatleyites*.

In the Cualac district, Guerrero, there lies beneath the Athleta Zone a series of *Reineckeia*-bearing marls and shales, 660 m. thick, which contain Macrocephalitids in the lower part and bridge the Middle and Lower Callovian (Burckhardt & Mulleried, 1936, pp. 310-12; many figures in Burckhardt, 1927, pls. xv-xxix). *Erymnoceras mixtecorum* (pi. xiii) was found at another locality, El Consuelo, in the *Reineckeia* beds (see Burckhardt & Mulleried, 1936, p. 312). Among the Macrocephalitids are *Eurycephalites boesei* and *Xenocephalites nikitini*; and the spindle-shaped Tulitid, *Kheraiceras v-costatum*, occurs (pl. xv).

**Bathonian**

Under the Callovian of Cualac, according to Burckhardt & Mulleried, follow 250-300 m. of sandstones with pelecypod shell-beds. In the upper part of these beds are marls with some poorly preserved ammonites, of which the only one determined is *Epistrenoceras paracontrainium* Burckhardt sp. (1927, pp. 80, 94-5, pl. xvi, figs. 14, 15). This genus is known nowhere in the world from any stage but the Bathonian.

The Lower Bathonian yields a characteristic ammonite fauna of the Zigzag Zone at several localities in Oaxaca (summarized, Burckhardt, 1930, p. 25, as ‘Bajocian Moyen’). From nodules embedded in clay-shales, Burckhardt figured (1927, pl. xii) *Zigzagiceras (Procerozigzag) floresi* Burckhardt sp., aff. *crassizigzag* Buckman and allied forms (pls. xii, figs. 10-16, 18-20, misidentified as Middle Bajocian *Stephanoceras*). With them are associated small Perisphinctids, some of which appear to be *Siemiradzkia* (pl. xi, fig. 8) or *Planisphinctes* (pl. xi, figs. 5-7), or both, misidentified as *Dactylioceras*.

**Bajocian**

Although most of the supposed Middle Bajocian Stephanoceratids are Lower Bathonian *Zigzagiceras*, there remains *Stephanoceras undulatum*
Burckhardt (pl. xii, figs. 1-4) which is a Normannites and can only be Bajocian. Some doubtful forms on pl. xi (figs. 5, 11, 12) could also be Bajocian (Leptosphinctinae ?). A Garantiana ? fragment found at another locality (pl. xvi, figs. 10, 11, 16) could be Upper Bajocian or Bathonian. It appears therefore that further search of the lower layers of nodules in these beds may reveal a larger Bajocian fauna. Further researches would be of great interest, for the Bajocian should be less meagrely represented in Mexico, and it is important to establish the age of the beds with nodules which overstep on to ancient mica-schists in some places in Oaxaca (Burckhardt, 1930, p. 25).

TOARCIAN has not been proved in Mexico but may be represented in some parts by continental deposits with plant remains.

PLIENSBACHIAN

The Upper Pliensbachian is believed to be represented by plant-beds. A single Lower Pliensbachian marine fauna of the Jamesoni Zone has been found in shaly clays with marcasite concretions, which have yielded species of Uptonia and Polymorphites. These beds are grouped with the Huayacocotla formation (below). Arieticeras occurs (Erben, 1954).

SINEMURIAN

The Huayacocotla formation (300-390 m. or more) in northern Veracruz, northern Puebla and eastern Hidalgo, consisting of shales with subordinate sandstone and conglomerate and some lenses of limestone, has yielded a succession of 9 ammonite zones spanning the whole Sinemurian (Burckhardt, 1930, pp. 9-23; Imlay & others, 1948). The ammonites have not been figured and until this is done comment must be reserved. The succession recorded by Burckhardt is:

Beds with Microderoceras cf. bispinatum and Eoderoceras cf. armatum
Beds with Echioceras raricostatum, etc.
Beds with Arnioceras cf. james-danae Barcena
Beds with Arieties cf. deciduus Hyatt
Beds with Vermiceras cf. bavaricum
Beds with Oxynoticeras aff. oxynotum and aff. guibali
Beds with Euagassiceras cf. sauzeanum d'Orb. [= resupinatum Simpson], etc.
Beds with Arnioceras cf. geometricum, etc.
Beds with Arieties aff. bisulcatus, etc.

The base of the formation has not been observed. It is presumed to rest on metamorphic rocks, pebbles of which occur in its conglomerates.

CENTRAL AMERICA

In Chiapas, Guatemala and Honduras there is a widespread continental formation, the Todos Santos Beds, consisting of yellow, red and brown
sandstones, marls, shales and conglomerates. The thickness varies, but 250 m. is normal for Chiapas. The beds rest unconformably on folded Palaeozoics and on gneiss. The upper part of the formation is proved by marine intercalations to be Cretaceous (Sapper, 1937, pp. 26-8) but plant-beds in the lower part ('several hundred metres') contain species reported to be identical with some of those in the Lower and Middle Jurassic of Oaxaca (Mülleried, 1942, p. 129). That marine Jurassic exists in some parts of Central America is indicated by reports of *Amaltheus* in river gravels in Honduras (Sapper, 1937, p. 28) and 'a few ammonites similar to *Macrocephalites* at Tegucigalpa, also in Honduras (Haas, in Imlay, 1952, p. 970).

**MALONE MOUNTAINS, WEST TEXAS**

The Jurassic sea of the Mexican geosyncline extended all through the northern state of Chihuahua and came to an end just beyond the frontier in New Mexico and the extreme west corner of Texas. In trans-Pecos Texas the plains are broken by a small, isolated mountain group, the Malone Mountains, near Torcer station, in Hudspeth County. These provide the most northerly outcrops belonging to the southern sea. The length of the range is only 6½ miles and the width 2½ miles, with a relief of about 700 ft. above the surrounding plain. There are also some outlying parallel hills a mile to the north-east.

These small arid mountains and hills are built largely of folded Jurassic rocks, the Malone formation, about 300 m. thick, which rests unconformably on fossiliferous Permian and is overlain conformably by more than 900 m. of Lower Cretaceous. The Malone is a near-shore marine formation with a rich pelecypod and somewhat sparse ammonite fauna, which has given rise to prolonged controversy, having been regarded by some geologists as Jurassic and by others (notably Kitchin, 1926) as in part Jurassic (the ammonites) and in part Cretaceous (many of the pelecypods, especially the *Trigoniae*).

The ammonites have been figured by Cragin (1905) and revised by Albritton (1937), who has also revised the stratigraphy and found that the *Trigoniae* and other pelecypods asserted by Kitchin to be Cretaceous in reality are found in the lower part of the formation, in the same beds as Lower Kimeridgian ammonites, and below beds (Upper Malone) with Tithonian ammonites (Albritton, 1937; 1937a; 1938, with detailed geological map of the area).

The succession is as follows:—

**[VALANGINIAN]**

Torcer formation (about 120 m.). Black impure limestone, sandstone, sandy shale, and occasional beds of limestone conglomerate. Age given by the genus *Neocomites* but fauna sparse. At the base a quartzitic sandstone and chert-pebble conglomerate member, with average thickness of 12 m.]
MALONE MOUNTAINS, WEST TEXAS

[BERRIASIAN AND UPPER TITHONIAN missing]

MIDDLE TITHONIAN

Upper Malone formation (45-99 m.). Predominantly limestones, but the highest 7 to 8 m. consists of sandy limestone and sandstone and is the only part in which fossils have been found. At the top were collected Kossmatia aguilerai (Cragin) and K. zacatecana Burckhardt. (The lower part could represent the Lower Tithonian, which is not necessarily missing.)

KIMERIDGIAN

Lower Malone formation (0-205 m.). Thin-bedded sandstone, sandy shale, impure limestone, and limestone conglomerates. Ammonites are practically confined to the highest 30 m. They include Haploceras cragini Albritton, Idoceras schucherti (Cragin), J. clarki (Cragin), Physodoceras smithi Albr., P. booni Albr., P. bikeri Albr., Aspidoceras laevigatum Burckhardt, Nebrodites nodocostatus Burckhardt, and two Perisphinctids, 'Lithacoceras' (?) malonianum (Cragin) and 'L' (?) shuleri Albr. (The latter bears no resemblance to any Lithacoceras and is not identifiable from the figures, but might be a crushed Katroliceras or Subdichotomoceras; the former is perhaps a Progeronia).

Idoceras ranges from the top of the Lower Malone down to within 30 m. of the base, and below it no ammonites are known. At least six-sevenths of the Lower Malone is therefore Lower Kimeridgian, of the age of the Idoceras beds of Mexico. The basal 30 m. is undated.

The Malone formation thins rapidly towards the east and north, and since it contains fossil driftwood (one log 15 ft. long and 2 ft. thick) and abundant conglomerate, the shore probably lay not far in that direction. Mapping shows that the Malone rests with angular unconformity on the Permian. The basal part contains some gypsum, probably reworked from the Permian below.

BURIED JURASSIC OF THE SOUTHERN UNITED STATES

As remarked above (see fig. 88) the Mexican geosyncline in Jurassic times was partly separated from the Gulf of Mexico by a long, narrow peninsula, possibly tapering to a chain of islands, which projected south across eastern Mexico from the North American continent, somewhat as Florida does to-day. East of this the Gulf of Mexico extended north of its present shores to fill a large bay over eastern Texas and the states of Louisiana, southern Arkansas, Mississippi and western Alabama, embracing much of the Gulf coastal plain and lower Mississippi valley.

The Jurassic rocks which formed at the bottom of this bay are buried beneath thick cover of Cretaceous and Tertiary sediments and were discovered only by deep drillings for oil. Examination of the drill cores has yielded much information on the thickness, facies and age of the

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Jurassic formations present and led to many interesting deductions (Imlay, 1941, 1943, 1945; Swain, 1944, 1949).

The Jurassic (which is all Upper Jurassic) thins northward, from over 2000 m. in NE Louisiana to 600 m. and less under Arkansas. The thinning is accompanied by overlaps within the system and by change of facies from shallow off-shore sediments in the south to shallower near-shore in the north. Besides many well-preserved ostracods (Swain, 1949), pelecypods, gastropods and ammonites have been figured (Imlay, 1945). The Tithonian and Kimeridgian succession is comparable lithologically and palaeontologically with the La Casita formation in northern Mexico. It has yielded *Glochiceras fialar*, *Metahaploceras* and three forms of *Idoceras* comparable with Mexican species. Beneath these were found Upper Oxfordian Perisphinctids. This is the earliest fossil assemblage proved. The age of the lowest, unfossiliferous formation (Eagle Mills) is problematic. It consists largely of red beds and contains masses of salt. These beds may be equivalent to Lower Oxfordian red beds and salt in Mexico (as believed by Imlay), or to the saline series with intercalations of fossiliferous marine Permian on which the Upper Jurassic is transgressive in the Malone Mountains (see e.g. Eardley, 1951, p. 544). (For the latest summary of the evidence and arguments, see Imlay, 1952, pp. 973-4). The Eagle Mills formation rests with a basal conglomerate on Palaeozoic or presumed-Palaeozoic rocks, including siltstone, phyllite, schist, etc. (Imlay, 1943, p. 1434).

The formations may be tabulated as follows:

<table>
<thead>
<tr>
<th></th>
<th>Max. thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tithonian?</td>
<td>1200 m.</td>
</tr>
<tr>
<td>Lower Kimeridgian</td>
<td>unconformity 144 m.</td>
</tr>
<tr>
<td>Upper Oxfordian</td>
<td>500 m.</td>
</tr>
<tr>
<td></td>
<td>530 m.</td>
</tr>
</tbody>
</table>

Cotton Valley group: marine in the south, with *Idoceras* fauna in lower part, and *Exogyra virgula*; passing north into red beds and clastics

Buckner formation: red shales, anhydrite and some dolomite; few fossils, none diagnostic

Smackover formation: oolitic limestones in upper part with *Perisphinctes* spp.; lower part darker with argillaceous layers

Eagle Mills formation: red beds and salt, with basal conglomerate

The Buckner formation indicates regional uplift in latest Oxfordian or earliest Lower Kimeridgian times, and this was followed by some gentle folding and a transgression, which produced regional unconformity at base of the Lower Kimeridgian *Idoceras* beds. This corresponds to the beginning of the fossiliferous Jurassic sequence in the Malone Mountains. The Cotton Valley group in places has a basal conglomerate,

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and in SW. Alabama (that is, towards the north-east) this rises diachronically and at the same time becomes thicker and coarser and contains pebbles derived from the Appalachian Mountains, which are consequently inferred to have experienced a revival of uplift at this time. ‘It seems logical to correlate the uplift of these mountains with the Palisade disturbance, which formed block mountains from Nova Scotia to the Carolinas sometime after the Upper Triassic and before the Upper Cretaceous’ (Imlay, 1943, p. 1474).

According to Swain (1949, p. 1250) the movements between Upper Oxfordian and Lower Kimeridgian in the southern States were insignificant compared with later ones which occurred at or near the end of the Kimeridgian. In that case ‘the most intense interval of uplift of Jurassic time’ (Swain) coincided with the Nevadan orogeny.

CUBA

Excepting only Kiogar in the Himalayas with its ‘erratic blocks of Malla Johar’, no small Jurassic area in the world has proved so baffling to geologists or produced so many conflicting interpretations as the Organ Mountains in Pinar del Rio province in western Cuba. In the geological literature on this region published during the last 35 years it is standard practice for every account to contradict its predecessors on almost all important points. The same formations have been declared to be Palaeozoic, Jurassic, and Upper Cretaceous, the Jurassic has been stated to be 120 m. thick in one account and 10,500 m. thick in another; the junction between the Upper Oxfordian and Tithonian has been interpreted as a major unconformity demonstrably due to an important Jurassic
orogeny, and as a thrust fault of Crétaceous date; the formations below the plane of discontinuity have been described by many observers as a metamorphic basement complex, consisting of crumpled schists, phyllites and marbles, whereas the latest writer asserts that they are not metamorphosed and are normal Upper Cretaceous sediments overridden by a thrust sheet.

The stratigrapher unable to visit Cuba and see for himself can hold no opinions, but after reading the accounts by Brown & O'Connell (1922), Lewis (1932), Schuchert (1935), Dickerson & Butt (1935) and Palmer (1945), he turns thankfully to the publications of the palaeontologists, where he is on firmer ground.

From the palaeontological studies it is certain that Cuba has so far produced two ammonite assemblages, Upper Oxfordian and Middle Tithonian (the latter equivalent to the Durangites zone of Mexico). Dickerson & Butt (1935) believed that these two faunas were separated by a major unconformity and asked us to believe that the concretions that have yielded hundreds of well-preserved, undeformed, Upper Oxfordian ammonites came from the metamorphic Cayetano formation of schists and phyllites beneath the unconformity. Unfortunately Schuchert (1935, p. 495, and underline of fig. 81) swallowed this. Palmer (1945), for whom the unconformity is a low-angle thrust plane, derives the Oxfordian ammonites more happily from above it. He states that the concretions with ammonites come from 120 m. of 'very thinly bedded shaly limestone of almost schistose structure', which he names the Jagua formation, and that this is the lowest formation of the thrust sheet; and that the Cayetano formation underneath (up to 10,200 m. thick), though very sparsely fossiliferous, is probably Upper Cretaceous.

Above the Oxfordian Jagua formation, according to Palmer, follow conformably the beds yielding the second ammonite fauna, which Imlay (1942) in a detailed monograph proved to be of the age of the Durangites zone, namely Middle Tithonian (= Upper Portlandian of Imlay). These beds have always been called Vinales Limestone, but Palmer (1945, p. 7) seeks to restrict this term to the upper part, which yields mainly aptychi, and asserts that most of the ammonites come from the lower part, which he calls the Quemado formation (thickness 1320 m.). The aptychus beds account for at least another 390 m. Both historically and palaeontologically it seems preferable, with Imlay (1952, p. 969) to regard the aptychus beds and Quemado as subdivisions of the Vinales Limestone (total thickness about 1700 m.). The outcrop cannot be shown on fig. 91 because all available geological maps include the Vinales Limestone with the Cretaceous.

The crucial point remains the nature of the junction between the Oxfordian Jagua and the Middle Tithonian Vinales (Quemado), and on this Palmer is reticent, though he does not remark on any physical break, and shows them as in normal, conformable contact in the structural diagram here reproduced (fig. 92). From the absence of the whole...
Kimeridgian and Lower Tithonian, however, a large non-sequence must be inferred, and from the fact that the Oxfordian is confined to the west end of the island while the Tithonian occurs over a much larger area almost to the east end, a regional unconformity is probable. Palmer, indeed, seems to suggest this, when he ascribes the restricted distribution of the Oxfordian to overlap by the Tithonian (1945, p. 26).

![Map of western Cuba](http://jurassic.ru/)

**Fig. 91.**—Sketch-map of western Cuba. After Palmer, 1945.

According to Palmer's interpretation (figs. 91, 92) the Oxfordian has been thrust up southwards from beneath the Gulf of Mexico.

Palmer’s finding that the aptychus beds are later than most of the Middle Tithonian ammonites confirms a remark by O'Connell in 1921 (quoted by Schuchert, 1935, p. 516), that 'a definite horizon has been traced for several miles, at which nothing but aptychi and an occasional small *Haploceras* are found'. Imlay (1952, p. 969) states that in several of the collections studied by him ‘the ammonites and aptychi are associated and in some cases are even on the same rock slabs. Also, some of the collections consisting mostly of aptychi have Portlandian ammonites such as *Pseudolissoceras* and *Virgatosphinctes*'. However, it is possible that not all the mixed collections of ammonites and aptychi came from the main aptychus beds, which O’Connell and Palmer both observed to be separate. In a thickness of 1700 m. it would not be surprising to find that there are

![Section through the Organos Mountains](http://jurassic.ru/)

**Fig. 92.**—Section through the Organos Mountains, western Cuba. After Palmer, 1945. The 'scar' on the south marks the south edge of the overthrust.
representatives of both Tithonian and Neocomian, even though Upper Tithonian ammonites have not been found. This might account for the inclusion in the collections of so many anomalous uncoiled ammonoids of strongly Cretaceous affinities.

The Middle Tithonian having received expert treatment in the readily-accessible monograph by Imlay (1942) there is no need to list the species. The genera include Phylloceras, Metahaploceras, Pseudolissoceras, Hildoglochiceras, Simoceras, Virgatosimoceras, Aspidoceras, Physodoceras, Virgatosphinctes, Corongoceras, Dickersonia, Micracanthoceras, Durangites, Lytohoplites, Parodontoceras, Berriasella, Spiticeras and various ‘heteromorphs’. Dickersonia has not been found outside Cuba. Three species of ‘Berriasella’ are added by Sanchez Roig (1951, pls. 21, 22), but one (pl. 22, figs. 3, 4) seems to be an Oxfordian Dichotomosphinctes (?) aff. ouatius Buck.). It can perhaps be assumed that a similar mistake in collecting was responsible for the record by Brown & O'Connell (1922) of Bajocian in Cuba on the strength of a Strenoceras sp. nov., considering the strong resemblance to this genus of some Cuban Corongoceras and Dickersonia (cf. Imlay's pls. 5 and 6). No ammonites earlier than Upper Oxfordian have ever been figured from Cuba, although Bajocian and Bathonian have been quoted without evidence (Schuchert, 1935, p. 520; Palmer, 1945, p. 6).

The rich Upper Oxfordian fauna, on the other hand, still lacks a reviser. Figures of variable quality (some unrecognizable) have been published by Sanchez Roig (1920, 1951), O'Connell (1920) and Jaworski (1940). Dr Sanchez Roig in his latest paper (1951) still assigns some of the forms to Kimeridgian genera (Ataxioceras and even Virgatosphinctes) but these are misidentifications. In my opinion his Virgatosphinctes (pl. 20, figs. 1, 2) is the inner whorls of an Upper Oxfordian Perisphinctes sensu stricto, and his Ataxioceras lictor cubanensis (pl. 23) is a typical Arisphinctes, close to P. (A.) ringsteadensis Arkell, and its date is early-Bimammatum Zone; it has no resemblance to Progeronia lictor (Fontannes) of the Kimeridgian. Jaworski (1940, p. 134) and Imlay (1952, p. 969) were right in concluding that all the ammonites from the Jagua formation figured hitherto either are Upper Oxfordian or belong to peculiar local subgenera or genera (such as Vinalesphinctes), some not yet named, but not inconsistent with a Bimammatum Zone dating. Having been concerned with European Perisphinctids of Oxfordian age for more than thirty years, I think it worth while to attempt a revision on the basis of the published figures. Professor Jaworski sent me a few specimens from Cuba before the war and my comments are incorporated in his valuable paper (1940, pp. 124, etc.). The extraordinary suture of Perisphinctes plicatiloides as figured by O'Connell, which I pointed out (1939, Mon. Am. Engl. Corallian Beds, p. 149) seemed to set it apart from all European subgenera, was found by Jaworski (1940, p. 120) to have been misinterpreted.

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**TRINIDAD**

**UPPER OXFORDIAN AMMONITES OF THE JAGUA FORMATION**
(SR = Sanchez Roig)

*Phylloceras jaguaense* SR
*Phylloceras lagunasense* SR
*Glochiceras* aff. *microdomum* (Oppel) (Jaworski, 1940, p. 97)
*Ochetoceras canaliculatum* var. *burckhardti* O'Connell
*Ochetoceras mexicanum* Burekhardt (O'Connell, 1920)
*Ochetoceras* (*Cubaocchetoceras*) *imlayi* SR (includes 'Neoprionoceras' *girardoti* Jaworski, 1940)
*Ochetoceras* (*Cubaocchetoceras*) *constanciae* SR
*Euaspidoceras* *vignalense* Spath SR 1951, pl. 28
*Vinalesphinctes* *rogi* Spod (Jaworski 1940 and SR)
*Vinalesphinctes* *brodermanni* SR
*Vinalesphinctes* *grossicostatum* SR sp. (sub *Arisphinctes*)
*Perisphinctes* of the following subgenera:—
*Perisphinctes* *sensu stricto*
*Perisphinctes* *anconensis* SR (sub *Virgatosphinctes*)
*Perisphinctes* *diversicostatus* SR (deformed; sub *Dichotomosphinctes*)
*Dichotomosphinctes* *spathi* SR (note lappet)
*Discosphinctes* *antillarum* Jaworski
*Discosphinctes* *cubanensis* SR sp. (sub *Ataxioceras lictor*)
*Discosphinctes* *carribeanus* Jaworski (sub 'Planites' *virgulatus*)
*Discosphinctes* *guanensis* sp. nov. (Per. *Planites* *virgulatus* var. *guanensis* SR, non *Per. Discosphinctes* *guanensis* SR)
*Orthosphinctes* *cubanensis* SR (sub *Ataxioceras*), including *P. delatorii* O'Connell

Second subgen. nov. *petrosus* SR (sub *Ataxioceras*)

**TRINIDAD**

It is possible that the Vinales Limestone is represented among partly metamorphosed limestones and schists of unknown age that form the axial mountain range of the island of Hispaniola (Haiti), but no fossils have been found. Otherwise the only other Jurassic in the West Indian islands is in Trinidad.

Trinidad is a direct continuation of the northern coastal mountains of Venezuela, from which only a narrow channel separates it, and it is a long way from Cuba and the Gulf of Mexico. Nevertheless it is described in this chapter because it is one of the West Indian islands and is more likely to be looked for in a chapter on middle America than in one on South America. No Jurassic is known in eastern Venezuela, and Trinidad is nearly as remote from the Jurassic in the West Venezuelan and Colombian Andes as from that in Cuba.

This extremely isolated occurrence of Jurassic was discovered in the
Northern Range, a schist chain about 50 miles long by 10 miles wide, densely clad in jungle, which is a detached fragment of the Caribbean Range of Venezuela. In eastern Venezuela transgressive Cretaceous rests on Palaeozoics and Trias, but the age of the schists and associated metamorphics is unknown in either Venezuela or Trinidad. They are believed to be Palaeozoic by some (Liddle, 1946, pp. 691, 702) and Cretaceous by others (Bucher, 1952, p. 79).

Caught up in the schists and obviously incorporated tectonically are isolated blocks and lenses of limestone. Some of these exposed on the north-east corner of Trinidad had been found to contain Upper Cretaceous fossils. In 1938 excavations for a dam at Hollis Reservoir, on the south flank of the North Range, exposed under schists a mass of dark flaggy limestone from which some recognizable Upper Jurassic ammonites were obtained (Hutchison, 1938). They were identified as *Virgatosphinctes transitorius* (Zittel), zonal index fossil of the European Tithonian (Spath, 1939). Subsequently 'further ammonites of Tithonian-Neocomian age' have been reported (Suter, 1951, p. 190; Barr, 1952).

It thus appears that the Cretaceous transgression on the south side of the Caribbean may have begun with the Tithonian, as in Cuba; and the major orogeny to which the Tithonian and Cretaceous rocks have been subjected in Trinidad is consistent with Palmer's interpretation of the structures in western Cuba (see p. 571).
CHAPTER 25

THE ANDES OF SOUTH AMERICA

For 5000 miles, from the Caribbean Sea to Cape Horn, the Andes build an unbroken rampart along the coast of South America. On the east lie the plains of the South American or Brazilian shield, with its continuations in Guiana and Patagonia, subdivided by forested downwarps forming the Amazon and Parana basins. On the west lies the Pacific. Between these two level and rigid tracts, the one sial, the other sima, rise the Andes, bounded by belts of major faults. The range consists essentially of a high plateau, up to 10,000 ft. above the sea, formed largely of folded Mesozoic sediments covered with Mesozoic, Tertiary and Recent volcanic rocks, from which rise two lines of great Tertiary to Recent volcanoes. The central Andes, the widest and highest part, opposite the re-entrant in the middle of the west coast of the continent, reach a width of 300-400 miles. Northward and southward the ranges narrow to less than 100 miles and finally break down. At Cape Horn the trend-lines swing round eastwards into the South Antilles loop, largely submerged beneath the sea; at the north end they fan out in the Columbian virgation.

This great meridional line of weakness differs fundamentally from the Alpine-Himalayan ranges of southern Eurasia, although broadly contemporaneous. The Andes, though by no means simple in structure, show no recumbent folds or major low-angle overthrusts: nappe structures are absent, and inverted folds exceptional (Douglas, 1920, p. 57; Heim, 1949). Instead of a broad mobile belt like the Tethys geosyncline, becoming crushed and underthrust by the approach of two sialic continental shields, the Andes have arisen mainly through magmatic activity along the continental slope. The Mesozoic sediments from end to end are due to marginal encroachments of the Pacific Ocean over the South American shield.

Along this continental slope in Triassic times a submarine swell began to be formed off-shore by uprise of a batholith elongated parallel to the coast. As it rose it enclosed a trough in which the Jurassic sea laid down sediments ranging from Hettangian to Tithonian, varying in completeness from place to place as movements of the crust caused transgressions at one time or place and regressions at another. Volcanoes rose along the swell, which at this stage probably resembled the island arcs of the present-day Pacific and Indonesia (Gerth, 1939, p. 11). Volcanic activity, at least in the central region, reached a climax in the Kimeridgian, with the outpouring of enormous sheets of basic lavas (the 'porphyrite formation') and explosion-pyroclastics. Finally, in the Upper Cretaceous the batholith underlying the island arc underwent major upheaval, folding the Jurassic rocks to the east of it, and giving birth to the coastal cordillera.

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The inner cordillera, with its chain of youthful volcanoes, was upheaved in two further spasms, in the early and late Tertiary. These movements involved further folding of the Mesozoic rocks and some metamorphism, with uplifts of up to 14,000 ft. in the central Andes, and were accompanied by further massive outbursts of volcanic activity.

According to Gerth, the leading authority on the Andes (1939, p. 59), the four successive stages of uplift (Upper Jurassic, Upper Cretaceous, early Tertiary, late Tertiary) were accomplished in waves which moved from west to east, each wave of uplift farther east than its predecessor.
PLATE 30.—Folded Jurassic limestones in the Peruvian Andes, near Oroya, about 80 miles east of Lima.
and causing eastward migration of the sedimentary trough or foredeep on the continental side. At the same time the terrane to the west of each wave tended to subside, and the oldest strips have partly foundered beneath the Pacific. Moreover, he attributes the folding of the Jurassic sediments in the foredeep, and their ultimate thrusting against the shield, to gliding eastward from the brows of the rising ranges. This picture resembles in a remarkable way that produced by Italian geologists to explain the structures of the Apennines and the problems of the Argille scaglioise (see p. 213).

The position of the foredeep trough during the Jurassic can be deduced from three parallel facies strips. In the centre is a strip of shales and limestones with ammonites; to the east is a more littoral development, with brachiopods and corals in some of the stages; to the west are tuffs, agglomerates and submarine lavas, sometimes interbedded with thin bands of limestone containing marine fossils. In position the Jurassic trough does not precisely coincide with any particular part of the modern Andes but tends to wander across them obliquely, especially in southern Argentina; the movements, being probably due to random migration of magma at depth, did not always follow the same lines.

As in so many parts of the world, the Trias closed with major volcanic eruptions and terrestrial sedimentation, preserving in places a Rhaetic flora, here allied to floras of Australia and New Zealand. The Lower Lias was a time of comparative quiet, during which the sea transgressed eastward all along the Andes, from Colombia and Equador to as far as latitude 45° S. in Patagonia, laying down shales and limestones or sandstones with typical European ammonite faunas. During the Lower and Middle Toarcian in places submarine lavas were erupted and the sea retreated locally. Perhaps to this time belong reefs of Liassic corals at Arequipa in south Peru, which are interbedded with lavas in a 900 m. volcanic series which there rests directly on ancient gneiss (Jenks, 1948). (This series underlies nearly 4000 m. of normal sedimentsaries also assigned to the Jurassic.)

In the Middle Bajocian there was another marine transgression, bringing in once more a rich European ammonite fauna. The Upper Bajocian and Bathonian are unrepresented by ammonites and there may have been another regression at this time, or else a rise of the barrier cut off ammonite immigration. In Patagonia the whole Middle (and perhaps Upper) Jurassic appears to be represented by continental deposits 500-1000 m. thick. The faunal gap in the central region coincides with a phase of minor intrusions.

The Lower and Middle Callovian, with abundant Macrocephalitid and Reineckeid ammonites, represent another period of transgression and deposition; but at least on the coast of Peru and north Chile there were further submarine eruptions with formation of pillow-lava. The period of marine deposition was brought virtually to an end by temporary uplift of the island arc to form a barrier which cut off the foredeep.
trough from the open sea, converting it into a chain of evaporating-basins. In them were deposited gypsum and anhydrite, which reach a maximum thickness of about 300 m. in the central Andes. In the Caracoles area of north Chile the gypsum follows upon fossiliferous marine beds with typical Upper Oxfordian ammonites, and in the Neuquen area of Argentina it is overlain by and passes laterally into shales with Lower Kimeridgian ammonites. From this it may be inferred that the gypsum is of uppermost Oxfordian date (Bimammatum Zone), but it is not necessarily contemporary in all parts of the Andes.

In parts of west-central Argentina the main gypsum formation is overlain by up to 1000 m. of lavas, crystalline tuffs and explosion-pyroclastics (the 'porphyrite formation'). These rocks first attracted the attention of Darwin on the voyage of the 'Beagle'. They contain peculiar transitions from lava to breccia and conglomerate, the last formed, apparently, by contemporaneous erosion of volcanic rocks at sea-level. Towards the east they pass laterally into conglomerates, arkoses and other coarse clastic sediments. The relation of these rocks to the marine Lower Kimeridgian of Neuquen is unknown, but it seems probable that they are equivalent to continental sandstones and red clays which overlie the Lower Kimeridgian and that the volcanic episode they record coincides with the major stratigraphical break everywhere apparent in South, as in Central, America below the transgressive Tithonian.

The Tithonian transgression carried the sea farther east and south than ever before in the Mesozoic: even in northern Peru and far south into Patagonia. The new marine series begins usually, but not always, with a basal conglomerate, and consists of an immensely thick shale formation with subordinate limestones. Over 7 degrees of latitude in Argentina, from Neuquen to the vicinity of Aconcagua, there are at or near the base a few metres of limestone crowded with *Virgatosphinctes* spp. of the Lower Tithonian. Upon this follow shales and limestones, altogether well over 1000 m. thick, with distinct Middle and Upper Tithonian, Berriasian and Valanginian ammonite faunas. In Patagonia volcanic activity continued, for the Tithonian shales are underlain, overlain and interfingered with porphyritic lavas and contain thick beds of tuff.

In the northern Andes (NE. Peru, Equador, Colombia, Venezuela) absence of marine Jurassic faunas between Sinemurian and Tithonian (and usually absence of those also) makes it impossible to decipher the history so clearly. In this region the Upper Jurassic is believed to be represented by the La Quinta formation and its equivalents (formerly classed as 'Giron formation', which included Trias and Permain) (= Chapiza formation of east Equador). It consists largely or wholly of red beds: sandstones, dark red shales, with basal polygenetic conglomerate locally, and often containing extensive pyroclastic rocks, lavas and intrusives, especially towards the top. These beds overlap the marine Sinemurian discordantly in east Peru and transgress on to the Carboniferous there and in eastern Equador, and on to older crystallines in
parts of Colombia and Venezuela. They usually pass upwards without a break into similar beds believed to be Lower Cretaceous. On the east side of the Central Cordillera of Colombia, however, the red beds are overlapped by Lower Cretaceous strata dated to the Barremian at latest (Trumpy, 1943). The thickness of the red beds is usually about 2500 m. in east Peru and east Equador, and from 500 m. to 3000 m. in Colombia and Venezuela, but in the Cesar Valley in the north of Colombia it exceeds 4000 m. (For east Peru see Huff, 1949; for east Equador, Tschopp, 1945; for Colombia and Venezuela, Oppenheim, 1940, Trumpy, 1943; general, Hedberg, 1942).

In the areas of marine deposition, correspondence of the South American
Jurassic ammonites with European genera and other species is striking at all stages. There was formerly thought to have been an important influx of Indian ammonites into South America with the Callovian (Jaworski, 1923), but this has proved to be an illusion. Revision by Spath of the Cutch Jurassic ammonites described by Waagen, on which previous identifications with Indian species had been based, showed that in each case the South American species had been misidentified. Of the six species of Indian Macrocephalites and three species of Indian Perisphinctes listed from South America by Stehn (1924), only one is not rejected or queried by Spath in his revision (and that one, M. magnumbilicatum Waagen, is not confirmed by Spath for South America). A few Indian species from the Callovian upwards are to be expected in South America (pre-Callovian ammonites do not occur in Cutch), for another point brought out by the revision of the Cutch ammonites is their close affinity with the European. On the other hand none of the distinctively Indo-Madagascan genera are known from South America (e.g. Bouleiceras of the Toarcian, Obtusicostites, Sindeites, etc. of the Callovian). Instead, there are correspondences with Western Australia and Canada in the Bajocian (Pseudotoites).

Many of the Andean, like the Mexican, Tithonian ammonites were assigned to 'boreal' Russian genera such as Virgatites, Craspedites, Simbirskites (Burckhardt, 1903, 1911; R. Douville, 1910), but this was contested by Uhlig (1911), and most of the disputed forms have since been provided with new generic names. (Good figures of most of these ammonites will be found in Burckhardt, 1903; Krantz, 1926 (reduced to §); and Krantz, 1928). Burckhardt, however, still maintained his views to the end (1930, p. 110), and in particular renamed as Craspedites limitis the form previously figured by him as Perisphinctes aff. erinus (d'Orb.) (1903, p. 52). Even Spath as late as 1931 (Cutch, p. 527) assigned Perisphinctes mendozanus Steiger (1914, nom. nov. for Burckhardt's 'scythicus', 1903, pl. vii, figs. 1-8) and P. argentinus Haupt (1907, pl. viii, fig. 1) to the boreal genus Dorsoplanites, but five years later, after studying the genus, he thought the resemblance 'probably entirely superficial' (Spath, 1936, Med. om Grønland, 99, p. 72). Leanza (1945, 1947) still admits the Russian genus Riasanites in Argentina.

For the sake of brevity, the whole Andean province is tabulated below as a single series of outcrops. Detailed regional treatments will be found in Gerth (1935) and for the individual countries in useful books by Steinmann (1929) for Peru (available in German and Spanish editions), by Brüggen (1950) for Chile, by Windhausen (1931) and Weaver (1931) for Argentina, and by Fergugio (1949) for Patagonia. For cross-sections of the Andes see Douglas (1914, 1920-1), Jenks (1948) and Gonzales (1950). A superb map is available (Stose, 1950), but this does not show some of the small but important outcrops of marine Jurassic (e.g. at Caracoles) as distinct from the volcanic rocks.

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[Valanginian]

To this stage Leanza (1945) assigns two zones: Neocomites wichmanni Leanza below and Olcostephanus curacaoensis (Weaver) above, the latter with Lissonia riveroi (Lisson), which occurs in equivalents of part of the Mulichinco formation (Weaver, 1931, p. 57).

[Berriasian]

Mulichinco formation. In central and south central Neuquen this consists of an average thickness of 500 m. of sandstones, conglomerates

<table>
<thead>
<tr>
<th>Table 24.—Correlation Table for the Tithonian of South America and Mexico</th>
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<tbody>
<tr>
<td><strong>Argentina</strong></td>
</tr>
<tr>
<td>Spiticeras damesi</td>
</tr>
<tr>
<td>Argentiniceras noduliferum</td>
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<tr>
<td><strong>Tithonian—I.Upper</strong></td>
</tr>
<tr>
<td>Substeueroceras koeneni</td>
</tr>
<tr>
<td>Corongoceras alternans</td>
</tr>
<tr>
<td><strong>Tithonian—Middle</strong></td>
</tr>
<tr>
<td>Windhauseniceras internispinosum</td>
</tr>
<tr>
<td>Pseudolissoceras zitteli</td>
</tr>
<tr>
<td><strong>Tithonian—I.Lower</strong></td>
</tr>
<tr>
<td>Virgatosphinctes mendozanus</td>
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and red shale, of continental origin, but northward it is replaced by marine shales and limestones with ammonites, and is reduced to 200 m. Farther north, in Mendoza, continental beds die out entirely and the shale-limestone series is unbroken from Tithonian to Hauterivian or higher (Weaver, 1931). Leanza (1945, 1947) recognizes two zones:—

Zone of Spiticeras damesi (Steuer) and Cuyaniceras transgrediens (Steuer), with abundant Cuyaniceras spp. (= Odontoceras auct. = Steueroceras Cossmann), Neocomites spp., Thurmanniceras spp., Spiticeras spp. and Pseudoblanfordia australis (Burckh.).

Zone of Argentiniceras noduliferum (Steuer), with Berriasella laxicosta (Steuer), Frenguellliceras spp., Neocosmoceras egregium (Steuer), Substeueroceras, Groebericeras, etc.]
THE ANDES OF SOUTH AMERICA

UPPER TITHONIAN

Quintuco formation. Shales, mainly dark or black, which in central Neuquen have an average thickness of 500 m.; southwards they tend to become calcareous and sandy. Leanza (1945) has reduced the five zones of earlier authors to three, but the lowest is here transferred to the Middle Tithonian (which alters the thickness distributed between the Upper and Middle divisions).

Zone of *Substeueroceras koeneni* (Steuer), with *Aulacosphinctes mangaensis* (Steuer), *A. asulensis* Leanza, *Berriasella fraudans* var. *inflata* Leanza, *Parodontoceras callistoides* (Behr.), *Micracanthoceras vetustum* (Steuer), *Riasanites rjasanensoides* Krantz (1928, pl. iv, fig. 7), *Spiticeras acutum* Gerth and *Aspidoceras longaevum* Leanza.

Zone of *Corongoceras alternans* (Gerth), with *Berriasella* spp., *Micracanthoceras* spp. and *Corongoceras rigali* Leanza.

Leanza (1947, pp. 837-40) points out that the Damesi Zone correlates with the Berriasian Boissieri Zone of Europe, while the assemblage of the Koeneni Zone corresponds well with that of the Upper Tithonian Transitorius (= 'Privasensis') Zone in Europe. In support of this Leanza reaffirms that, as already maintained by Mazenot (1939), *Parodontoceras callistoides* (Behrendsen) is not the same as the species so called by Kilian in 1907 from the Berriasian of SE. France and Andalusia. On the other hand, Leanza still identifies some South American ammonites from the Koeneni Zone with species of *Riasanites* of the Ryazan Beds of Russia. If this identification is correct, it confirms the supposition that the Ryazan Beds of Russia are condensed and comprise representatives of the highest Jurassic as well as the lowest Cretaceous (see p. 492).

MIDDLE TITHONIAN

Zone of *Windhauseniceras internispinosum* (Krantz), with *Wichmanniceras mirum* Leanza, *Aspidoceras steinmannii* Haupt and *A. neuquenensis* Weaver. This zone is the Upper Tithonian of Weaver (1931, p. 46) and was placed at the base of the Upper Tithonian by Leanza, but since it corresponds with nothing in the European Upper Tithonian, it is now dropped into the Middle Tithonian, unrepresented in the classic area.

Zone of *Pseudolissoceras zitteli* (Burckhardt), 70 m. Calcareous sandy shales and sandstones or marls with nodules. *Neocheotoceras waageni* (Zittel), *Glochiceras parabolistriatum* Krantz, *Pseudolissoceras pseudolithicum* (Haupt), *Aspidoceras steinmannii* Haupt, *Simoceras aff. volanense* (Oppel). (See Krantz, 1928, pl. iii, fig. 7; Weaver, 1931, pp. 46-7; Gerth, 1935, table VIII, p. 295). *Pavlodia (?) windhauseni* Weaver (1931, pl. 44, fig. 300) suggests at latest a Lower Portlandian date.

LOWER TITHONIAN

Zone of *Virgatosphinctes mendozanus* Burckhardt, 25 m. Ferruginous limestones and dark grey shales, passing into bituminous limestones with shale partings. More than 75 per cent. of the ammonites belong to

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Virgatosphinctes mendozanus Burck.; also V. australis Burck., V. mexicanus Burck., V. choiciensis Burck., V. lotenoensis Weaver and abundant Inoceramus curacoensis Weaver. (Weaver, 1931, pp. 46-7; Gerth, 1935, table VIII). Perhaps ‘Anavirgatites baylei’ Spath came from this horizon in Chile (Bayle & Coquand, 1851, pl. ii, fig. 2). A monograph by Indans (1954) of the Perispinctids from the Virgatosphinctes bed at the base of the Tithonian in south Mendoza shows that in addition to this genus the assemblage comprises typical Aulacosphinctoides (pl. xviii, figs. 1-7) and species indistinguishable from Torquatispinctes (pl. xx, figs. 2, 3) as in Mexico, also Pseudinvoluticeras (pl. xv, 1) and the Dorsoplanites-like forms mentioned above (pl. xx, figs. 1, 4, 5).

The preceding synopsis of the Tithonian and Berriasian of Argentina follows the important revisions by Leanza (1945, 1947) with some stratigraphical information from Weaver (1931). For numerous figures of the ammonites from Argentina, Peru and Chile see Behrendsen (1891-2), Burckhardt (1903), R. Douvillé (1910), Favre (1908), Feruglio (1937), Gerth (1925a, 1926a), Haupt (1907), Krantz (1926, 1928), Leanza (1945), Lisson (1908, 1937), Rivera (1951), Steuer (1897), Welter (1913), Indans (1954).

UNDATED

In Neuquen province, Argentina, the Tithonian shales rest transgressively upon a considerable thickness of varicoloured sandstones and red clays or clay shales of continental facies, which at Chacay-Melehue rest in turn upon the marine basal Kimeridgian beds mentioned below (Leanza, 1947a). These unfossiliferous beds are presumably the same as the upper part of the Loteno formation of Weaver, perhaps the highest 103 m. down to the conglomerate (bed E) containing pebbles of acid lava in the Picun Leufu anticline (Weaver, 1931, p. 42); for the mysterious ‘Lusitanian Virgatosphinctes’ of bed N (ibid., p. 43, pls. 45, 46) have proved to be, what they always looked in the drawings, Callovian Reineckiae (Herrero-Ducloix & Leanza, 1943). In Chubut 500-1000 m. of continental deposits intervene between the pre- or early-Tithonian volcanics and marine Toarcian (Feruglio, 1949, p. 89).

LOWER KIMERIDGIAN

Immediately underlying the continental sandstones and shales at Chacay-Melehue is a slightly dolomitic limestone containing Nebrodites, Idoceras, Aspidoceras, Streblites (Pseudoppelia) and aptychi, assignable to the lowest subzones of the Tenuilobatus Zone. The beds overlie and also pass laterally into the main Gypsum formation (Leanza, 1946, 1947a).

Marine beds of about the same age occur also at Caracoles, near the frontiers of Chile, Argentina and Bolivia, whence have been figured the Crussol species Perispinctes roubyanus and Nebrodites doublieri (Steinmann, 1881, p. 298, and figs.).

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UPPER OXFORDIAN

In the Caracoles area the Gypsum formation immediately overlies marine beds containing *Perisphinctes (Arispinctes) harringtoni* Leanza, which is very close to the European *P. cotoreoi* Sim., *Euaspidoceras cf. perarmatum* (Sow.), *Ochetoceras cf. canaliculatum* (Buch) and *Trimarginites cf. arolicus* (Oppel), providing accurate correlation with the Plicatilis Zone (= Transversarium Zone) of NW. Europe (Steinmann, 1881, pp. 297-8, pls. ix-xii; Stehn, 1924, p. 63, pls. ii, v; Leanza, 1947b and pl.).

The same zone, with *Perisphinctes* spp. as in England, is also found underlying the main gypsum in Arroyo de la Manga, Mendoza (Stipanicic, 1951). Combined with the evidence from Neuquen mentioned above, this dates the Gypsum formation to uppermost Oxfordian (Bimammatus Zone) and basal Kimeridgian.

CALLOVIAN

In the Caracoles area the Callovian comprises at least 100 m. of limestones and marls, in which can be recognized an upper zone (60-70 m.) with numerous Reineckeidae and subordinate Macrocephalitidae, and a lower zone (30-40 m.), with numerous Macrocephalitidae but no Reineckeidae (Steinmann in Stehn, 1924, p. 60). These faunas are extremely rich and widespread in Peru, Chile and Argentina. Locally higher beds with *Hecticoceras* spp. and *Parapatoceras* (Stehn, 1924, pl. ii, fig. 5) can be separated (Gerth, 1935, p. 264), and *Peltoceras* is reported, in association with Reineckeids (Stehn, 1924, p. 139).

On the coast close to the Chile/Peru frontier, a hill called Morro de Arica exposes 45 m. of red shales with veins of gypsum, resting upon Callovian *Posidonia* shales interbedded with pillow-lavas. From the lower shales with pillow-lavas Douglas (1914, pp. 8, 9) collected two small specimens of a tumid *Macrocephalites*, and from shales higher up a crushed Kosmoceratid (recorded as *K. cf. ornatum*) with a lappet, which compares best with *K. (Gulielmiceras ?) zortmanense* Imlay, from the *Kepplerites mcleani* zone of the western United States (see p. 549). (Douglas' specimens are in Oxford University Museum, nos. JU 3-5.) The Caracoles *Kosmoceras dunkeri* Steinmann (1881, p. 272, pl. xii, fig. 9) likewise may be one of the *Gowericeras* fauna so well represented in the western United States and Alaska and figured by Imlay.

The Macrocephalitidae and Reineckeidae of South America have been described and figured in numerous works, of which the principal are by Burckhardt (1903), Steinmann (1881), Stehn (1924) and Herrero-Ducoloux & Leanza (1943). Besides species allied to European and Indo-Pacific forms but in most cases not conspecific as would appear from published lists, there are peculiar genera such as *Eurycephalites* (based on *Macrocephalites vergarensis* Burckhardt, which was erroneously compared with *Morrisiceras* and mistaken for Bathonian), *Xenocephalites* (based on *M. nequenensis* Stehn) and the Reineckeid *Neuqueniceras* (based on *Perisphinctes steinmanni* Stehn). The usual Grossouvriae abound. *Oppelia*
exotica Steinmann (1881, pl. xi, figs. 5, 6) appears to be an Oxycerites. Xenoceratalites and probably Eurycephalites occur in the Lower Callovian of the western United States (see p. 550).

Bathonian and Upper Bajocian

No ammonites indicative of these stages have yet been found in South America. The 'Lissoceras psilodiscus' figured by Stehn (1924, pl. iv, fig. 1) was misidentified. So also was the 'Stephanoceras bullatum' figured by Gottsche (1878, pl. viii, fig. 1), which is a Callovian ammonite, found in company with Reineckia. At least in the Caracoles area, the main Macrocephalites beds are separated from the Middle Bajocian by 15-20 m. of beds almost devoid of fossils.

Middle Bajocian

Humphriesianum Zone. This zone seems to be represented in Peru and Chile but not in Argentina, to judge by records and some figures by Steinmann (1881, pl. xii, fig. 7) and Mörcke (1894, p. 20). The fauna needs re-investigating.

Sauzei and Sowerbyi Zones. These zones are represented by the so-called Sauzei Limestones, or Sonninia Beds, crowded with ammonites and other fossils, which mark a constant and widespread episode from Peru to Patagonia. The ammonites have been well figured by Gottsche (1878), Tornquist (1898) and Jaworski (1914-15, 1926, 1926a). The dominant genera are Sonninia, Witchellia, Emileia, with Otoites, Chondroceras, Fontannesia, Eudmetoceras, Bradfordia, etc., as well as Pseudotoites closely allied to Western Australian species (Tornquist, 1898, pl. v, figs. 1, 4; pl. vi, fig. 2). What appears to be an early Leptosphinctes (Jaworski, 1926, pl. xiii, fig. 8) was found in the Sauzei Beds, and may be compared with the Middle Bajocian record of the genus from Alaska; the nearest European species, L. davidsoni Buckman (1921, vol. iii, pi. CCI), occurs in the Subfurcatum Zone, basal Upper Bajocian, in which Teloceras still persists in Europe. The early Oppeliid, Bradfordia morickei Jaworski sp. (1926, pl. xi, fig. 9), is closely comparable with European species from the Sauzei and Sowerbyi Zones, which occur from Dorset to Sicily (= 'Iokastelia' Renz, 1925). Eudmetoceras gerthi Jaworski sp. (1926, pl. xii, fig. 5) also denotes the Sowerbyi Zone. This assemblage is therefore not Lower Bajocian as supposed by Jaworski (1926, Tafel X, facing p. 426), even though locally below the range of Sonninia.

Lower Bajocian and Uppermost Toarcian

Immediately below the Sonninia and Emileia beds at Espinazo Pass are calcareous sandstones full of Meleagrinella substrata, which yield Tmetoceras regleyi (Thiollière) (Gottche, 1878, pl. ii, fig. 3; Tornquist, 1898, p. 6) and thus correlate with the regleyi horizon in Canada and the Scissum Zone of Europe. ‘Harpoceras concavum’ is also recorded with Tmetoceras, but the identity of this requires confirmation.
THE ANDES OF SOUTH AMERICA

At Cerro Puchen is a fauna of 'Harpoceratids' which probably have been rightly taken for the Pleydellia assemblage (Gröber, 1918, pp. 17, 28, 30), namely: 'Harpoceras' malarguense, puchense and argentinum Burckhardt (1903, pl. i), but it is difficult to judge from drawings alone. In the same zone are said to occur Erycites aff. fallax (Benecke) and Eudmetoceras klimakomphalum (Vacek). Gröber (1918, p. 30) stressed the identity of this fauna with the San Vigilio fauna of the Southern Alps; but the San Vigilio fauna is a condensed mixture of Lower and Middle Bajocian. Planammatoceras and various other Hammatoceratids occur in Argentina, Chile and Peru.

The rarity of unequivocally Lower Bajocian ammonites among published figures from South America may be due to unfavorable facies, for the prevalent deposits in the part of the column that might be expected to belong to the Lower Bajocian are often black shales and black shaly and cherty limestones with Posidonia alpina, a notoriously inhospitable environment for ammonites.

TOARCIAN

Perhaps the latest definitely Toarcian faunule yet found in South America is that with Sphaerocoeloceras brocchiiforme Jaworski and Dumortieria pusilla Jaw. from Arroyo Negro in Mendoza province (Jaworski, 1926). Farther south, in Chubut, Sphaerocoeloceras is recorded with various Toarcian ammonites (Feruglio, 1949, pp. 106–8).

In Chile there is a strong representation of the Phymatoceras (= 'Lilia'), Haugia and Brodieia (= 'Brodiceras') fauna of the basal Jurense Zone (Lilli - Variabilis Subzones), closely resembling forms figured by Denckmann from Doernten and a collection sent me from Baluchistan (Mörcke, 1894, pl. i, figs. 1-5, pl. iii, fig. 2; Jaworski, 1926, pl. xiii, fig. 2).

Lower and Middle Toarcian ammonites include Dactylioceras cf. raquinianum (d'Orb.) from Caracoles (Steinmann, 1881, pl. xii, fig. 6) and various Dactylioceras and Harpoceras with Phylloceras partschi from Chile and Argentina (Gerth, 1935, table VII, p. 269; Feruglio, 1949, pp. 106–8). In Patagonia the Lias, with Toarcian ammonites near the top, is about 875 m. thick (Feruglio, 1949, p. 89). This compares with about 900 m. at Arequipa in south Peru (Jenks, 1948).

In Peru both Upper and Middle Lias, probably with representatives of the Middle and Upper Jurassic, are developed as poorly-fossiliferous limestones. They form the Upper Calcareous Series, more than 1300 m. thick, which rests in some places conformably on Lower Lias shales and in others unconformably on Carboniferous rocks, and is succeeded conformably by Lower Cretaceous sandstones (Harrison, 1943, p. 7).

PLIENSCHAZAN

Much of the Pliensbachian is developed in shelly facies, from which in some parts of Peru well-preserved silicified fossils are obtainable, but no ammonites. A notable feature is the occurrence of the earliest known

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Stomechinus (Tilmann, 1917, p. 696); the next-oldest known is an abundant species in the Bouleiceras bed of Arabia. In Chile and Argentina the facies is more favorable for ammonites.

The Domerian is represented in Argentina by the remarkable Italian species, Diaphorites vetulonius Fucini (Jaworski, 1915, pl. viii, fig. 4), and probably by some of the Hildoceratidae listed by various authors (summarized by Gerth, 1935, table VII). The Davoei Zone is represented in Chile by Prodacltylioceras (Möricke, 1894, pl. ii, fig. 6), the Ibex Zone in Argentina by Tragophylloceras wechsleri (Oppel) (Jaworski, 1915, p. 393 and figs.), and the Jamesoni Zone by Uptonia jamesoni (ibid., p. 451); but whether these and associated ammonites are stratigraphically separable as in Europe remains to be proved by future field-work. In Patagonia Prodacltylioceras is recorded with Toarcian species (Feruglio, 1949, p. 108), which must surely result from a misidentification.

SINEMURIAN

The Upper Sinemurian is widely distributed from Neuquen northwards into Peru by beds with Eoderoceratids, Echioceratids and Oxynoticeratids. They include Eoderoceras armatum (Sow.) (Jaworski, 1915, p. 451), Crucilobiceras cf. subarmatum (Y. & B.) (Rigal, 1930, pl. ii, fig. 4), Gleviceras behrendseni Jaworski sp. (1926, pl. xi, figs. 3-5) and Echioceras cf. rari­costatum (Zieten) (Douglas, 1921, p. 264), etc. At Piendra Pintada, on about latitude 40° S., Oxynoticeras occurs in plant-beds.

The Lower Sinemurian with Arietitidae (Arnioceras and inner whorls figured on same slab as ‘Psiloceras?’) occurs in black shales below the red beds in Colombia (Trumpy, 1943, pl. i) and in east Equador (Tschopp, 1945; 1948) and NE. Peru (Huff, 1949) in dark bituminous, siliceous or dolomitic limestones, which in east Equador are 1500 m. thick (Santiago formation). Farther south in Peru and in north Chile a suite of black bituminous shales and platy limestones (up to 540 m. thick in Peru) yield many European Arietitidae of the Bucklandi Zone, including Arietites, Metophioceras, Vermiceras, with Arnioceras, etc. (Tilmann, 1917, pp. 656-67, pls. xxi-xxiii; Harrison, 1943, p. 7). Arietites is also recorded from the eastern side of the Andes in Argentina (Behrendsen, 1891-2, p. 369). Microderoceras occurs in Peru. In Neuquen the lower zones at least are developed in littoral facies and there are sandstones full of Gryphaea, differing slightly from G. arcuata (Jaworski, 1914, p. 323). It seems probable, therefore, that at least in Peru all the zones of the Sinemurian are present, with essentially European ammonite faunas.

HETTANGIAN

The Planorbis Zone is developed in Peru as dark limestones and marls with Psiloceras and Caloceras (Tilmann, 1917; Harrison, 1943). Supposed Psiloceras figured from Colombia (Trumpy, 1943, pl. i) appear to be inner whorls of the associated Arnioceratinae. In Peru, however, a fine-ribbed Schlotheimiid, S. cf. angustisulcata (Geyer), occurs in the Sinemurian.

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Arietitid beds (Tilmann, 1917, pl. xxi, figs. 1, 2). In Argentina the Hettangian is probably represented by coral limestones and sandstones (Jaworski, 1914, p. 323).

The Lias in some places rests on plant-bearing sandstones believed to be Rhaetian, in which *Estheria, Unio* and fish occur (Gerth, 1935, pp. 225-9). In east Equador there is a lithological passage up from marine Trias (Tschopp, 1945). In many other places, from Venezuela in the north (Oppenheim, 1940) to Patagonia in the south (Feruglio, 1949, p. 109), the Lias or its supposed equivalents transgress on to Palaeozoic and pre-Cambrian rocks.

**The South American Shield**

The description and correlation of the continental deposits and eruptive rocks of the shield lie outside the scope of this book. The dating of these rocks, as of their counterparts in the south of the African shield, is a specialized enquiry which will demand more field-work and perhaps will be solved only by introduction of new techniques. Sedimentary petrology and micropalaeontology have as yet been little employed.

The upper part of the great 'Santa Catarina System', the lower parts of which are Palaeozoic, consists of unfossiliferous aeolian sandstone (Botucatu Sandstone, 0-300 m.) overlain by the Sera Geral fissure-eruptives of the Parana basin, which are the largest known mass of volcanic rocks in the world. These two formations correspond with the Cave Sandstone and Stormberg Lavas of South Africa, and it is customary to regard them as Rhaetian (Gerth, 1935, table VI, p. 251).

It is sometimes argued that some if not all of the Sera Geral lavas may be Jurassic (Gordon, 1947, p. 17), but this depends at present on personal evaluation of the time-significance of the Botucatu Sandstone and two unconformities which separate the lavas from the highest fossil-bearing beds of basal Upper Triassic age.

In either case, whether these lavas are Rhaetic or Liassic, the shield during the whole Jurassic period was a land-area, about which at present next to nothing is known.
CHAPTER 26

THE SOUTHERN ANTILLES AND ANTARCTICA

In Tierra del Fuego the Andean folds trend east and are continued by a submarine ridge which passes through South Georgia and bends round on itself through the South Sandwich, South Orkney and South Shetland Islands to join on to the finger-shaped promontory of Grahamland, Antarctica. This great loop was aptly named by Suess in 'The Face of the Earth' (1909, vol. iv, p. 496) the Southern Antilles. In recent literature it is sometimes called the Scotia arc. Through it the Andean foldings join South America to Antarctica. They deploy through the western part of the continent and run out to sea again in the Edsel Ford Range on Marie Byrd Land. Beyond this their course is conjectural, but a submarine ridge joining the Balleny and Macquerie Islands to New Zealand suggests a second eastward-thrusting loop, more open than the southern Antilles, and completing the orogenic girdle of the Pacific.

West Antarctica, through which the fold-ranges pass, differs fundamentally from east Antarctica, which is a shield comparable stratigraphically and tectonically with the shields of South Africa, South America and Western Australia. On the usual peneplaned basement complex of crystalline pre-Cambrian rocks there rests in east Antarctica a series of horizontal sedimentaries, ranging from Cambrian to Trias, with in particular a thick development of Devonian, Carboniferous, Permian and Triassic sandstones (the Beacon Sandstones). Like the Karroo in South Africa and the Permo-Trias in Tasmania, the Beacon Sandstones are intruded by a system of dolerite sills and dykes of probably Rhaetian or early Liassic date.

The shield is truncated abruptly about longitude 170°, from Cape Adare in Victoria Land towards the South Pole, by a mighty fault, marked out by a line of volcanoes, most famous of which is the still-active Mount Erebus. The downthrown area underlies the Ross Sea and Ross ice barrier and probably continues across the ice-covered waist of the continent to the Weddell Sea. It represents a narrow foredeep, between the edge of the shield and the folds of the orogen. Usually along such contacts the edge of the shield has tended to underthrust the advancing folds. Probably the same has happened here, but the great fault (to the youthfulness of which the active volcanoes testify) has come into being since and let down the underthrust edge of the shield under the Ross Sea.

The fold ranges of west Antarctica consist of thick sedimentaries with batholiths of grey and pink granite injected among them and in the cores of the major anticlines, but no evidence has yet been obtained of the age of the sediments or the date of the folding. The sediments where studied

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in the Edsel Ford Ranges consist of a singularly homogeneous and indi-
visible series of fine-grained sandstones and arenaceous shales, in a
condition of low-grade metamorphism, so slight as to amount to little
more than induration, though tending to production of quartzites and
slates. No trace of a fossil has been found. The thickness is estimated
at not less than 4500 m.; but not enough field-work has yet been done to
overcome the difficulties resulting from intricate folding and the distortion
due to the granite intrusions (Passel, 1945). Fairbridge (1949) has
remarked that this series sounds like flysch and might well be Mesozoic.

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Most of the islands of the southern Antilles loop are volcanic, but the largest, South Georgia, is an exception. This consists of several thousand metres of fine-grained sedimentaries—greywackes, shales and tuffs—more or less acutely folded, which appear to be a continuation of the Cretaceous flysch zone of Patagonia and Tierra del Fuego, Darwin's 'clay-slate' formation. A few ammonites have been found. One was tentatively identified with *Acanthoceras* (Gregory, 1915), but later finds of *Puzosia*, *Tropaeum* and *Sanmartinoceras* have proved that the upper part at least of the sediments (Upper Cumberland Bay Series) is Aptian (Wilckens, 1937, 1947). One of the ammonites was found in the same beds as problematica which had previously been identified with Lower Palaeozoic corals (Gregory, 1915). It seems that there is no palaeontological evidence for any sediments earlier than Cretaceous in the island (Holtedahl, 1929; Wilckens, 1932), though it is likely that the basal Cape George Series is Palaeozoic. The Falklands, on the other hand, contain no solid formations younger than Trias (Adie, 1952, 1952b).

The only common Jurassic fossils yet known from the Antarctic regions are plants. They have been found in Grahamland, both at the extreme tip, at Mount Flora, Hope Bay (Halle, 1913, Adie, 1952a) and in Alexander I Land in the extreme south-west of the peninsula (Wordie, 1948, p. 68), where also Upper Jurassic ammonites are reported (Adie, 1952a, p. 396; Cox, 1953, p. 3). The Jurassic ammonites so far found are said to be Perisphinctids; an indeterminate fragment has also been figured from James Ross Island (Spath, 1953, p. 3, pl. xii, fig. 5), but the others are still unpublished. The famous plant-beds of Hope Bay occur in the lower part of the mountain, in hard slaty shales that have been folded in Tertiary times. A lacustrine origin is probable. The beds probably represent a continuation of some part of the Jurassic plant-beds of Patagonia, now much better known than when Halle's monograph was published (see Feruglio, 1949, ch. viii). The Hope Bay flora comprises at least 42 identified forms, chiefly ferns, cycadophytes and conifers. They are not stunted, and belong to the cosmopolitan warm-temperate Jurassic flora. The closest affinity is with the Middle Jurassic flora of Yorkshire, with which there are nine species in common, but there are also strong links with India and Australia.

At present Grahamland and the adjacent islands are almost completely covered in permanent ice, and rock protrudes only here and there. The only living flora is a meagre growth of mosses and lichens. The conclusion is therefore inescapable that in Jurassic times Antarctica had a much milder climate. Fossil shells and plants show that the climate was also temperate in the Tertiary. The glacial geology, however, indicates much more severe glaciation in the Quaternary than at present.

The small islands of Snow Hill and Seymour, close to Hope Bay, have yielded a beautifully-preserved Upper Cretaceous (Sennonian) ammonite fauna, which likewise shows no signs of polar characteristics, but has some species in common with contemporary assemblages in Chile, California, and elsewhere.
Japan, Natal, India and New Zealand (Kilian & Reboul, 1909; Spath, 1953). (Owing to erroneous comparison with a Canadian Jurassic ammonite, Kilian & Reboul produced one of the curiosities of palaeontological nomenclature: they founded the genus *Seymourites* with the Canadian species as type, with the result that the name has to be applied to a Callovian genus of ammonites which does not occur in the southern hemisphere.)

A marine Aptian fauna with ammonites also occurs in Alexander I Land (Cox, 1953).

Summaries of the geology of Antarctica have been published by Furon (1936), Taylor (1940), Wade (1941), Wordie (1948) and Fairbridge (1949, 1952), and of South Georgia by Trendall (1953).
PART VIII

GENERAL SURVEY AND CONCLUSIONS
CHAPTER 27

THE OCEANS

All the occurrences of Jurassic formations chronicled in the preceding chapters amount to little more than relics of marginal lappings of the sea around the edges of the continents; the sole exception being the Tethys, a sea which stretched across southern Asia from west to east along the band that was destined to emplace the great Tertiary mountain chains.

Despite modern advances in geophysical techniques, we are not in sight of being able to distinguish and date sedimentary systems hidden beneath the ocean floors. Accordingly the only way that light can be thrown at present on the major distribution of land and sea and the extent of the oceans at any particular period is by extrapolation from study of the fossil faunas in the fringing sediments deposited at times of transgression. Those faunas when properly correlated and dated give some idea of the contemporaneity or otherwise of transgressions in different parts of the world, and tell us something of the migration routes that were open across the seas, and so indirectly of the existence and extent of the seas themselves.

Most of the immense literature on the old controversy about the permanence of the oceans consists of arguments drawn from the distribution of land and freshwater faunas, recent and fossil. Nearly all of it (as summarized, for instance, by J. W. Gregory in his two presidential addresses to the Geological Society of London, 1929 and 1930) is highly uncritical, based on the assumption that if animals or fossils on different continents are sufficiently similar they require land bridges to provide migration routes across the oceans. Too little account was taken of the immense time factor involved, and the rare chance possibilities of crossings by adult or larval individuals under the influence of currents or wind storms, which, when suitably multiplied by such a time factor, become probabilities. This has been shown ably and convincingly by Simpson (1952). As he states, 'a possible event, however improbable it may be as an isolated occurrence, becomes probable if enough time elapses'; and the degree of probability is increased in proportion to the size of the population involved as well as to the time available, for both increase the opportunities.

In contrast to most of the preceding literature, our study is of migrations of marine organisms. They have the advantage that whereas all land animals can conceivably cross the sea and populate distant continents, no means have been suggested whereby marine animals such as ammonites can cross continents. Even here a caveat must be entered, however. At the present time both freshwater and marine molluscs and lowlier organisms can cross wide tracts of land in a very short time, carried on the
feet of birds, either as eggs, or larvae, or small imagos. A striking instance of this is the lake Birket Qarûn, in the Faiyum, Egypt, which has been fed by a branch from the Nile and has contained the normal Nile fauna of Corbicula and other molluscs for tens of thousands of years, as may be seen by the abundance of shells in its high Pleistocene beaches, in which they are associated with Palaeolithic implements. During the early years of the present century the need for more cultivable ground led to artificial shrinkage of the lake to a point where salinity suddenly made the water suitable for marine or brackish mollusca. A survey of the fauna in 1907 made no mention of any marine forms. By 1927, however, the dominant mollusca in the lake were Cardium edule and Scrobicularia cottardi, two forms characteristic of the saline lakes near Alexandria (Gardner, 1932, p. 84). They were so abundant by 1927 that their shells formed a continuous beach mound for many miles along the lake shore (Sandford & Arkell, 1929, pi. xi). More than 100 miles of dry desert separate the Alexandrian lakes from the Birket Qarûn, but there is a constant traffic of duck between the two, and the lakes are visited by flocks of flamingos. There can be no doubt that the mollusca were in some way transported by these birds, probably in mud adhering to their legs.

In Jurassic times air-transport was perhaps more restricted, but with Archaeopteryx and flying reptiles on the scenes, it cannot be affirmed as impossible that marine organisms could have been carried across isthmuses by air. And as Simpson has shown, anything that was not impossible becomes a fair probability when there is so much credit to draw on in the bank of time.

However this may be, we shall here attempt a review of some of the features of distribution of fossil marine faunas which have a bearing on migration routes and the extent of the oceans in at least one geological period.

As a preliminary it should be stated that at no time in the Jurassic were marine transgressions over the continents so extensive as to warrant the assumption that the main oceans could have been dry land, least of all the Pacific. Maps (e.g. Haug, 1900; Gregory, 1930, p. xci) which show the Pacific as mainly dry land, on which the water is reduced to narrow strips, necessarily imply a compensating inundation of the continents of an order far greater than is warranted by the known distribution and facies of the sediments. Even the greatest transgressions, such as that of the Upper Jurassic across Russia, from the Arctic Ocean to the Baltic and Caspian, are negligible compared to the effects of emptying the Pacific. Furthermore, such transgressive seas were always shallow, as is apparent from the sediments and faunas they left behind. Nor were they contemporary everywhere. The Liassic period, for which Gregory shows the Pacific almost drained of its water, was a period of regression compared with the Upper Jurassic; a truth already pointed out three-quarters of a century ago by Neumayr.

We cannot get rid of the water in the oceans by postulating enlarged

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ice-caps in the Mesozoic, since a rich temperate flora lived simultaneously in Greenland and Grahamland, nor by postulating a permanent dense cloud-cover full of suspended water, since neither the flora nor the fauna admit of such an assumption; and jellyfish washed up at Solnhofen in Bavaria were dried so rapidly by hot sun that they did not have time to decompose or to be caught by the next tide and destroyed while still soft. Moreover, since the Jurassic period there have been major orogenies, which indicate considerable shrinking of the lithosphere without corresponding reduction of the hydrosphere, so that there is now more sea relative to the surface of the solid earth.

Accordingly we have to construct our maps so as to accommodate at least as much water as there is on the earth at present; which leaves us the choice between supposing that the major oceans were more or less as they are now, or arranged in some radically different way. Before investigating the second alternative it behoves us to weigh what evidence there is for and against the first. Indeed, the first alternative is so infinitely simpler and a priori more probable, that very cogent evidence needs to be adduced before any reasonable man should want to abandon it. (See Jeffreys, 1952, chs. 11, 12).

The following pages briefly review the evidence for the Jurassic period.

**Pacific Ocean**

The Pacific Ocean is surrounded by a ring of Jurassic rocks from New Zealand to Patagonia. That this was a geosynclinal ring is not disputed. But if it surrounded a vast Pacific continent as inferred by Haug (1900), Kober (1928, p. 361) and others, the faunas should show a complete lack of cross-connexions; which they do not. To account for supposed connexions between the Lias of Japan and western North America, and the Tithonian of New Guinea and Chile, Gregory (1930, p. cxi) postulated two separate, long, narrow, east-west seas dividing the continent into three parts. Both these postulates incur the insuperable difficulty of displacing the water from nearly half the globe without providing adequate accommodation for it elsewhere.

The alternative hypothesis, eloquently elaborated by Stille (1944, 1948), that the whole Pacific is and always has been a primordial ocean (Urozean) with a relatively rigid floor (Tiefkraton), avoids these fundamental difficulties and is to that extent preferable. There is no warrant, however, for supposing that the Pacific half of the earth’s surface necessarily had a much simpler history than the other half. There are indications that uniformity is by no means the rule: for instance the large area in the middle covered by coral islands must have been sinking steadily for thousands of feet in Tertiary to Recent times, and on the border of the coral island zone there is evidence for migrating anticlines and synclines (Chubb, 1934). As compensation for these sinking areas, other areas (such as the western Albatross plateau?) may well have undergone elevation.
When in the light of these reflections we examine the Jurassic faunas of the surrounding geosynclinal seas without bias, we find almost (but not quite) all the evidence equivocal. The presumption of a complex history is borne out by the diversity of phenomena in the different stages of the Jurassic. For instance, in the Callovian, Oxfordian and Kimeridgian there is a marked boreal influence far down the American side: *Seymourites* and *Cardioceras* extend from Alaska down to the Western Interior of the United States, and *Buchia (Aucella)* even to Mexico; and on the Asiatic side *Seymourites* is said to extend down to Japan. In the Middle Bajocian, on the other hand, a southern fauna essentially similar to that in Argentina and Indonesia extends through Canada to Alaska. This is the same arrangement as is found in Europe and western Asia, where Lower and Middle Jurassic faunas at home in the Tethys extend to the edge of the Arctic Ocean, and Upper Jurassic faunas at home in the north extend to the northern edge of the Tethys (Chapter 28).

In attempting to draw conclusions from comparisons across the Pacific it has to be borne in mind that Indonesia and the Gulf of Mexico are antipodal, so that any genera or species common to opposite sides of the Pacific would have had no farther journey if they migrated round the opposite hemisphere. Most of the assemblages on both sides are, in fact, more like Old World faunas of the same age than like their contemporary assemblages on the opposite side of the Pacific. This fact invalidates both the instances on which Gregory based his two landlocked, elongated Pacific seas—the 'North Pacific Liassic sea' and 'Spiti-Chile' Upper Jurassic sea (1930, p. xci). The Sinemurian ammonites in British Columbia are identical at specific level with those in NW. Europe; the Liassic ammonites of Japan are mainly Toarcian and Upper Pliensbachian and so not comparable with most of those in British Columbia, but in any case their relationships are closest with those of the Tethys, chiefly in southern Europe. As to the Tithonian assemblage of the 'Spiti-Chile sea', it is world-wide. So also are the Hettangian ammonites (not considered in Gregory's map), which are represented by an essentially similar assemblage, the *Psiloceras* fauna, in the South Island, New Zealand, in New Caledonia, Indonesia and Indo-China, and also in both North and South America. All the forms are comparable with European ammonites, more or less closely.

The same difficulty invalidates the arguments for a west-east connexion across the Pacific from the Himalayas and Indonesia to South America in the Callovian, stressed by Jaworski and others (see p. 580). This was based on misidentifications. When the ammonites are examined critically it is found that all the species common to Asia and South America also occur in Europe. On the other hand, there are a number of peculiar South American Macrocephalitids (e.g. *Xenocephalites*) which have since been found in North America and even Greenland and Alaska, but not in Asia, and these demand free migration north-and-south along the east side of the Pacific.
The only fossils that could be of real significance in this problem would be peculiar genera or species occurring on both sides of the Pacific but not found in western Asia, Africa, or Europe. A special search has been made for such forms, but only two genera have been found, and they are both Middle Bajocian. They are the Stephanoceratid genera *Pseudotoites* and *Zemistephanus*, both found in Western Australia and in Canada and Alaska and one of them in Argentina, but nowhere else. Since they do not occur in the extensive Bajocian outcrops in the Old World, they must have crossed the Pacific, and almost at right-angles to all the lines drawn on Gregory's hypothetical map (Arkell & Playford, 1954) (fig. 96).

Another pointer to uninterrupted sea-connexion across the Pacific is provided by the genus *Idoceras* of the Lower Kimeridgian. The group of *I. durangense* Burckhardt is extremely abundant in and characteristic of the Kimeridgian of Mexico and Texas, and has been found also in the South Island, New Zealand, and in the Sula Islands, Indonesia. This instance is not conclusive, for a single species occurs also in Sicily and the southern Alps (*I. dedalum* Gemm.); but considering the abundance of the group in Mexico, direct migration from its chief centre in Mexico across the Pacific and Atlantic provides the most probable explanation of its distribution.

These facts are consistent with and support such inferences as that no land lay south-east of Japan during the Jurassic (p. 418) and that the absence of red beds from the whole geological column in New Zealand indicates that those islands have never formed part of an extensive land-mass (p. 453).
Concerning the Indian Ocean there has been almost unanimity that it once was largely dry land, the eastern half of the great equatorial continent of Gondwanaland, which lasted through the Palaeozoic and began to founder at the end of the Jurassic. The western half, or African-Brasilian continent, must have been more or less completely separated from the eastern half by the Jurassic gulf which reached southward from Tethys across Arabia and Somaliland and the western part of the Arabian Sea, down the east coast of Africa, into the Mozambique Channel. This was shown as a geosyncline passing right through the Mozambique Channel on Haug’s earlier map (1900, p. 632), and as a blind-ended gulf in his later map (1910, p. 1112) and Dacque’s (1910, p. 164). Uhlig (1911) also regarded it as open only in the Neocomian.

The eastern half of Gondwanaland, known as the Australo-Indo-Madagascan continent or more briefly Lemuria, is supposed to have joined eastern Madagascar, peninsular India, and the Australian shield. A second southerly gulf from Tethys is now supposed to have more or less separated the Australian shield and has been called the Westralian geosyncline (Teichert, 1939). This extended south from the Timor-East Celebes geosyncline and its waters overlapped Western Australia, leaving there various epicontinental Jurassic sediments.

The Maldive and Seychelles archipelagos have continental rocks, and Stille (1948, p. 25) classes the Indian Ocean as a ‘new ocean’.

The distribution of Jurassic faunas supports the hypothesis of a Lemurian continent, or at least suggests that a land barrier joined Madagascar to peninsular India and prevented direct migration between the Mozambique and Westralian gulfs.

It was long ago pointed out by Haug, Uhlig, Lemoine and others, that the Upper Jurassic faunas of East Africa and Madagascar have close affinity with those of Cutch. Further discoveries in the last forty years have greatly strengthened these ties and have proved others, just as close, between East Africa and Arabia and Baluchistan in the Lower and Middle Jurassic (not represented in Cutch, where the earliest known ammonite fauna is Lower Callovian). For almost the whole Upper Jurassic the ammonite faunas of Madagascar and East Africa are closely comparable with those of Cutch and both areas yield such special elements as the ‘late Macroecephalitids’, Mayaites and its allies, and peculiar Perispincitids such as Obtusicostites and its allies, not found in Europe. These areas were already in free communication when the first Jurassic transgression occurred at the beginning of the Toarcian, as shown by the existence of the specialized Hildoceratid genus Bouleteceeras, found in Madagascar, Kenya, British Somaliland, central Arabia and Baluchistan, but nowhere else in the world except Portugal. In the Bajocian the most conspicuous feature of the fauna in Arabia and Sinai was the peculiar genus Ermoceras, since found to have migrated along the African coast as far as western Algeria and reported in the Pamirs, but nowhere else in the world.

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Of these peculiar endemic elements only the Mayaitids have been found in Indonesia, which was in any case known to have been in communication with the Himalayas and Baluchistan by way of the Tethys. If there had been an alternative direct route for migration across the Indian Ocean a much greater community of faunas might have been expected.

Conversely, the Westralian gulf in the Bajocian was populated by a prolific assemblage of Stephanoceratids, of which the most characteristic were the genera already mentioned, *Pseudotoites* and *Zemistephanus*. Although these migrated to Canada, Alaska and Argentina, and *Pseudotoites* at least is found in the Moluccas, they are known nowhere else in the Old World. The Bajocian of Western Australia is not of the right zone to contain *Ermoceras* (early Upper Bajocian) but there are in the Old World, including East Africa, Arabia and Persia, plenty of occurrences of Middle Bajocian faunas in which *Pseudotoites* and *Zemistephanus* and the peculiar Australian *Fontannesiae* might be expected if they could have crossed the Indian Ocean as they could the Pacific.

In this connexion it is worth recalling that when the specialized Indonesian Triassic pelecypod genus *Indopecten* was found in Persia and Oman it was argued that, being such a large and conspicuous form, it could hardly have escaped detection in the Himalayan Trias if that had been its route of migration, and that a direct route across the Indian Ocean was therefore more likely; this involving the conclusion that Lemuria had already broken down by the Upper Triassic (Douglas, 1929, p. 631). Within a few years of publication of this conclusion, however, *Indopecten* was announced from the Attock district in the western Himalayas (Cox, 1935, p. 3).

**South Atlantic Ocean**

South of the points where the Atlas Mountains in Morocco and the Caribbean Coast Range of Venezuela and North Range of Trinidad strike so spectacularly out to sea, no Jurassic rocks are known on the Atlantic side of either Africa or South America. This has often been taken to imply that in Jurassic and earlier times the South Atlantic did not exist, an explanation which may be correct. Nevertheless, it is not necessarily correct, and all interested in the question should read the symposium on the subject published by the American Museum of Natural History (Mayr, editor, 1952). It should be borne in mind that the ring of Jurassic rocks encircling the Pacific, which produces so strong a contrast with the South Atlantic, is on the site of a vast system of geosynclines, which has no parallel on the margins of any other ocean; and that but for the orogenic buckling and uplift of the geosynclines, which elevated marginal Pacific sediments high into the air, the existence of these sediments might not be known.

According to Kober (1928) an orogenic belt, and by implication a preceding geosyncline, runs down the middle of the Atlantic parallel to the coasts and is the cause of the Mid-Atlantic ridge, now almost completely

submerged. If such a geosyncline exists and is as old as those surrounding the Pacific or crossing Asia, it must have cut across the hypothetical western part of Gondwanaland. Stille (1948), however, is not impressed by the Mid-Atlantic ridge and visualizes the Atlantic as two primordial oceans separated by a primordial land-bridge which joined the bulge of West Africa to the bulge of Brazil.

In the absence of Jurassic deposits, Jurassic stratigraphy can throw no light on this ocean, except in an inconclusive negative sense.

**North Atlantic Ocean**

On the western side of the North Atlantic there are no Jurassic rocks between the Gulf of Mexico and NE. Greenland, a distance of 3500 miles. This is a longer stretch than either coast of the South Atlantic, from Morocco to the Cape or from Trinidad to the Horn; yet it does not imply non-existence of an ocean, for Jurassic outcrops occur in a string along the east coast from Norway and Scotland to Morocco, and there are Tithonian aptychus beds in the Cape Verde Islands (Pires-Soares, 1953).

Stille (1948) regards the North Atlantic as a primordial ocean, separated from a much smaller basin, the 'primordial Scandic', to the north, by an ancient land-bridge joining the British Isles by way of Iceland with South Greenland and Nova Scotia. British palaeogeographical maps (e.g. Wills, 1951) still follow Haug (1900, 1910) in showing the whole North Atlantic occupied by a continent in Mesozoic times. Several lines of evidence, however, throw doubt on the validity of this assumption, at least for the Jurassic, and go further in casting doubt on the existence in the Jurassic of any barrier between the Atlantic and Scandic Oceans. Three significant facts are:

1. The Toarcian, Upper Oxfordian, Kimeridgian and Lower Portlandian ammonite faunas of NE. Greenland and Spitsbergen show such frequent identity, often at specific level, with their counterparts in England that it is certain that the Scandic (and therefore also Arctic) Ocean was in direct connexion with the waters that covered large parts of Scotland and England. The British and European faunas clearly spread north into the Scandic at these times. The influx of deltaic material into Yorkshire and NE. Scotland during the Bajocian and Bathonian was a temporary interruption of normal deposition, presumably due to upheaval of the Scandinavian shield. At this time there was a temporary barrier against free migration of ammonites, for Bajocian and Bathonian faunas do not occur in Greenland or Spitsbergen.

2. The remarkably rich ammonite faunas of the Middle Bajocian of western Scotland (Skye and Raasay) have their nearest connexions in Dorset. Since no such ammonites lived in the Cotswolds or Midlands of England, an open sea route round the west of Ireland seems more likely.

3. In the Pliensbachian of Dorset and Portugal is found a peculiar Polymorphitid genus Dayiceras, known nowhere else in the world. Even bearing in mind the case of Indopecten in the Himalayas (p. 601), it is
incredible that this genus should exist undetected in the French Lias, which has been studied and repeatedly monographed for more than a century. A suggestive similarity in the facies of the Kimeridgian of Asturias (p. 234) to that of Dorset is a pointer in the same direction: namely, open sea connexion across the Bay of Biscay and west of the present Iberian peninsula. That this sea route was open in the Aptian is proved by several striking species of large gastropods (Cassiope) common to Spain and Dorset but not found in France (Arkell, 1947, p. 169).

Another point on which analysis of Jurassic faunas throws some light is the likely order of distance between the western end of the Mediterranean and the Gulf of Mexico when the faunas lived. All authors seem agreed that these areas were connected by sea in the Jurassic, even though interpretations vary. Haug showed his usual type of narrow, long geosyncline connecting the two, with a firm migration arrow along the centre; this was still more or less the view of Kober (1928, pl. ii) and Gregory (1929, p. cxix); Uhlig, who believed that ammonites migrate along coastal waters, saw in the north shore of the hypothetical Gondwanaland the desired route; and Stille (1948) retains the same shoreline as the southern boundary of his primordial North Atlantic Ocean. According to the hypothesis of continental drift, however, no such long migration route has to be provided, for in the Jurassic, before the drifting apart of South America and Africa, the Gulf of Mexico and the western end of the Mediterranean would have lain close together.

It happens that in Portugal and in Cuba there are two of the richest faunas of late-Upper Oxfordian ammonites known anywhere. Both comprise enough links with faunas in England and elsewhere to make their dating and contemporaneity virtually certain. Yet these two faunas are decidedly different: there is no identity at specific level, and Cuba has two subgenera of Perispinctes which cannot be matched in Europe, and an endemic genus, Vinalesphinctes, which may possibly be a local, parallel, development to Ringsteadia and Pictonia, but is quite different from anything in Portugal or elsewhere.

Again, in the Kimeridgian of Mexico, there are abundant links which make dating virtually certain, but the swarm of Idoceras all have a peculiar local stamp, and the endemic genera Mazapilites, Epicephalites and Subneumayria are altogether original. The same is true for the Tithonian, in which among many common Tethyan genera are found peculiar endemic forms in abundance, such as Dickersonia (Cuba) and Durangites (Cuba, Mexico and South America).

Considering how uniform these faunas are throughout the Mediterranean region, and how Tithonian faunas in the eastern Tethys extend from Spiti and Nepal to Indonesia and New Guinea, and taking into account the evidence of the Oxfordian faunas also, it is impossible to believe that the Gulf of Mexico region was substantially closer to the Mediterranean region in the Jurassic than it is now.

In a northerly direction from Tethys, of course, the Upper Jurassic
faunas in Europe change fundamentally in a few hundred miles; but the
Upper Jurassic of the Gulf of Mexico is essentially Tethyan and Pacific,
containing conspicuously such genera as Idoceras, Simoceras, Hybonoticeras,
and is absolutely devoid of northern elements. It can, therefore,
only be compared with the Tethys.

I have pointed out previously (Arkell, 1949, p. 415) that a more compact
arrangement of the continents, as envisaged by advocates of continental
drift, would make the world-wide dispersal of so many Jurassic ammonites
easier to understand, but any such general considerations are outweighed
by these particular discrepancies between contemporaneous faunas on
opposite sides of the Atlantic. The evidence here is positive and it
weighs heavily against the drifting apart of the New and Old Worlds since
the Jurassic.

ARCTIC OCEAN

The Arctic is the last of the primordial oceans recognized by Stille
(1948). All workers on the period seem to have been agreed that it was
in existence during the Jurassic. Even Haug (1910, p. 1113) showed it
as an ocean at this period: the seat of Neumayr's boreal province, from
which migration arrows issued across Alaska and the North Sea and
Barents Sea, all pointing south.

Until the Middle Jurassic no distinctive Boreal realm (meaning a
fauna special to the Arctic regions) seems to have existed.

From the Callovian onwards to the Portlandian inclusive, however,
high northern latitudes have a number of distinctive faunas, and the fact
that their distribution is governed only by latitude and not at all by
longitude—they occur at the northern rim of both the Old and the New
World—indicates that their home was the Arctic Ocean.

There appear to have been in the Jurassic four portals through which
the Arctic Ocean communicated with southern seas: (1) through the
Scandic, between Norway and Greenland, into the North Atlantic and
across most of Britain and the North Sea into the heart of Europe; (2)
across the Barents shelf and Kara Sea into European Russia and thence
to the Caspian, with a shorter gulf east of the northern Urals into the
basin of the lower Ob; (3) across eastern Siberia by way of the Lena and
Verkhoiansk Mountains to the Sea of Okhotsk and lower Amur, to connect
with the Pacific faunas of Japan; and (4) a less certainly located portal,
which carried the boreal faunas down the west side of North America,
either by way of the Bering Straits or up the Mackenzie valley in NW.
Canada.

Some of the distinctive ammonites which inhabited these portals and
fanned out from their southern approaches are:

Callovian: Cranocephalites, Arctocephalites, the Cadoceratidae and the
Kosmoceratidae.

Oxfordian: Cardioceras and its many subgenera, replaced by Amoeboceras
in the Upper Oxfordian and Lower Kimeridgian.

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Kimeridgian: *Aulacostephanus* and *Rasenia*; these like *Cardioceras* reached as far south as the Rhone valley as rarities, and may (unlike *Cardioceras*) have migrated into Mexico.

Portlandian and Lower Volgian: the Dorsoplanitinae and Virgatitinae.

Upper Volgian (Purbeckian?): the Craspeditidae.

The distribution of these genera and families presupposes free intercommunication by way of an Arctic Ocean and therefore confirms the general conclusion that that ocean is primordial.

**Summary**

The evidence from Jurassic stratigraphy requires the existence in Jurassic times of the North Pacific, North Atlantic, Scandic and Arctic Oceans; it requires at least a barrier across the Indian Ocean from Madagascar to Ceylon and peninsular India; it has nothing to contribute to the problem of the existence or non-existence of the South Atlantic.

Differences between contemporary faunas on opposite sides of the Atlantic, in the Gulf of Mexico region and the western Mediterranean region, are incompatible with the idea that these areas were much closer together in the Jurassic period.
CHAPTER 28

MARINE REALMS AND CLIMATE

FAUNAL REALMS AND PROVINCES

The existence of marked faunal realms or provinces in the oceans and seas at the present day led long ago to a quest for evidence of similar phenomena in the Mesozoic. The present differentiation of marine faunas is a complex resultant of climatic and geographic factors. Where circumstances are favourable, southern or tropical faunas may grade imperceptibly into temperate or northern faunas, but in other circumstances the transition from one extreme to another may be astonishingly abrupt. For instance, the Indian Ocean fauna of corals and large, brightly coloured echinoids and molluscs, including the giant clam, occupies the whole Red Sea up to the head of the Gulf of Suez, whereas on the opposite side of the 100-mile Suez isthmus the Mediterranean fauna holds sway. Very little mixture has taken place even during almost a hundred years since the canal has been cut. Without knowing the geographical lay-out, no geologist finding these two faunas in strata a hundred miles apart would dream of correlating them. Moreover, if the needful small subsidence of the isthmus allowed one fauna to spread over the territory of the other and oust it, the two faunas would be found in sequence in the territory of the one that had been vanquished, and there would be nothing in the territory of the victor fauna that could be correlated with the vanquished fauna, which would therefore inevitably be considered older.

Such considerations as these seem to be overlooked by those palaeontologists who insist on the universality of all ammonite assemblages and on unlimited incompleteness of the geological record and still hope to find that, for instance, the Upper Volgian faunas of Russia mark a time interval distinct from the Tithonian and Purbeckian.

The marine realms and provinces of the Jurassic and Lower Cretaceous were exhaustively discussed by Uhlig (1911) in one of the most inspiring and masterly contributions ever made to Mesozoic stratigraphy. In this work, completed a few days before his death and embodying a lifetime’s experience of stratigraphy and fossil faunas, Uhlig revised previous schemes put forward by Neumayr, Nikitin, Haug and others, and set out his results on a map of the world. He recognized four realms, which he subdivided into provinces, and a separate province (Japan) not attached to any realm. They were as follows:

1. Boreal realm, with its subdivision the ‘North-Andine’ province. The latter was unhappily named, since it comprised western North America with the whole of Alaska and reached no farther south than the
head of the Gulf of California. We should say, nowadays, 'North Cordilleran province'.

2. Mediterranean-Caucasian realm (for short, Mediterranean realm), including on its north side the central European and south Russian province as a 'neritic marginal zone'.

3. Himalayan realm, combining the Himalayan and Malayan provinces and the isolated Maorian (New Zealand) and Ethiopian provinces.

4. South Andine realm, including the Middle and South American outcrops from Mexico to Cape Horn and, for the Neocomian, including the Uitenhage beds of South Africa.

Innumerable facts subsequently accumulated are incompatible with this scheme and demand extensive modifications. For instance, as was shown above, the Kimeridgian faunas of Mexico (realm 4) show marked affinity with those of New Zealand (realm 3) and essential elements have also been found in Indonesia and Japan. The Bajocian faunas of southern Alaska and western Canada (realm 1) are not boreal; they connect with those of Western Australia (realm 3) and western Europe (realm 2). Such instances could be multiplied at length.

It is clear that the time factor was not given sufficient weight by Neumayr (1883) or Uhlig (1911). No map can show faunal provinces for the whole Jurassic, for the entire situation was constantly changing. The key to the problem is the sporadic but progressive differentiation of marine faunas during the Jurassic. Oppel and Waagen already realized this. Waagen wrote (1864, p. 98): 'The higher we climb in the Jurassic series the greater become the difficulties, either of recognizing or separating individual beds, or of correlating.' The climax is reached in the uppermost Jurassic with the situation which still to this day requires a threefold use of stage names—Tithonian, Volgian and Portlandian-Purbeckian, according to the part of the world.

During the Lower Jurassic (Lias) ammonite faunas seem to have been universal (fig. 97). The Hettangian and Sinemurian ammonites of western Canada, northern Alaska, Indonesia and Peru agree at specific level with those of western Europe, and European genera have been recognized in New Zealand, New Caledonia and the Himalayas. Of European Pliensbachian genera, Uptonia occurs in Greenland, Amaltheus, Lytoceras and ? Crucilobiceras in northern Alaska, Amaltheus and Phylloceras on the north coast of Siberia. Recent work reviewed in this book proves that in Japan there is a succession of Pliensbachian, Toarcian and Lower Bajocian faunas essentially the same as that in Europe, including some genera especially characteristic of the Mediterranean countries. In addition, however, there are some endemic forms which have not yet been matched elsewhere. Typical European Toarcian Pseudolioceras faunas, usually with Dactylioceras, occur in Transbaikal, Spitsbergen, Greenland and northern Alaska, and probably also in the Canadian Arctic Archipelago. The Lower Bajocian faunas may have a similar distribution, for a Ludwigia murchisonae assemblage is known near the Arctic Circle in the basin of

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Fig. 97.—Map showing the world-wide distribution of Liassic ammonite faunas. H, Hettangian; S, Sinemurian; P, Pliensbachian; T, Toarcian; TB, basal Toarcian with *Bouleiceras* fauna (Ethiopian province).

Fig. 98.—Map showing the distribution of Bathonian ammonite faunas. L, Lower; M, Middle; U, Upper Bathonian ammonites. The maximum regression was in the Middle Bathonian. Black bricks denote transgressive Upper Bathonian in shallow pelecypod facies, sometimes brackish.
the River Lena, and \textit{Tmetoceras} and \textit{Erycites} are recorded from northern Alaska.

No Middle or Upper Bajocian faunas, however, are known from Arctic regions. It seems that after the Lower Bajocian there was a withdrawal of ammonite population from the periarctic regions now accessible, presumably as a result of epeirogenic uplift, which is reflected in the Deltaic Series in northern Britain and the Baltic.

In the Middle Bajocian a Pacific realm is first clearly differentiated, though there is a suggestion in the peculiar endemic forms in the Japanese Toarcian that it may have already existed before the end of the Lias period. It was in the Middle Bajocian, however, that the peculiar Pacific genera \textit{Pseudotoites} and \textit{Zemistephanus} appeared in force in Australia and Indonesia and in the western cordilleras of both North and South America: genera which have so far been found nowhere else (Arkell & Playford, 1954).*

In the Bathonian (fig. 98) the contraction of ammonite populations already noticed in the Bajocian was carried further. If \textit{Oxycerites} found in the Canadian Middle Fernie (p. 542) are Lower Bathonian, like the \textit{Zigzagiceras} fauna of Mexico (p. 564), Middle and Upper Bathonian faunas, so far as known at present, are confined to the Tethys and north-western and central Europe. They have been found from central England to Morocco and from Cracow to Arabia, and in Madagascar, Baluchistan, the Pamirs, Indonesia and New Guinea, but nowhere else. This great contraction of the area of occurrence is associated with diminution in numbers and evolutionary stagnation or regression of the ammonites (Arkell, 1951, pp. 3-4, 15). Another strange feature of the Upper Bathonian, which will be discussed in Chapter 31, is that in places as widely separated as Tunisia, East Africa, Madagascar, Attock, Cutch and Burma the beds are transgressive but in regressive facies: that is, they show brackish tendencies and were evidently deposited in very shallow water (fig. 98). This is indicated by absence of cephalopods and abundance of small pelecypods such as \textit{Corbula}, \textit{Eomiodon}, \textit{Protocardia}, \textit{Pseudotrapezium} and \textit{Eligmus}. In England and France, moreover, the resemblance to the Purbeck Beds is increased by thin freshwater intercalations with non-marine gastropods and ostracods.

The inference is that in about the middle of the Bathonian there was a regression of the sea from most of the known world now land (perhaps due to a deepening of the Pacific?: see p. 641). For the rest only NW. Europe and the Tethys were left still inhabited by ammonites, while in some places was introduced a land or swamp regime comparable with that realized more completely in NW. Europe in the Purbeckian. Probably it was during this Bajocian and Bathonian regression that the Arctic Ocean was cut off from the seas of the rest of the world and the special Boreal fauna began to evolve. The prototypes probably lie entombed under the Arctic Ocean and will never be known.

* Uhlig (1911, p. 417) anticipated that a Pacific realm might be recognized one day and that Japan might be found to belong to it.
It is with the beginning of the Callovian that peculiar endemic Boreal faunas first appear, brought south over the surrounding lands by transgression spreading from the Arctic Ocean (fig. 99). The first Boreal elements are specialized Stephanocerataceae, Cranocephalites and Arctocephalites, soon followed by other peculiar Cadoceratinaceae and Kosmoceratidae such as Seymourites. While these were taking possession of northern Alaska, northern Canada, Greenland and Siberia, and sending out pioneers perhaps as far south as Japan, there were also synchronous transgressions taking place in the temperate and tropical world which caused a great equatorial expansion of the true Macrocephalitidae. These last are not of Arctic origin as sometimes supposed, for they are not found in the extreme north except perhaps in Arctic North America, whereas they abound throughout the temperate and tropical world and are obviously at home in the Tethys from western Europe to Indonesia and Madagascar, and round the Pacific. They were gradually replaced by the Reineckeiidites, which have a similar distribution and dominate the Middle Callovian in regions as far apart as Argentina, Mexico, south Germany and Cutch, but reached as far north as southern Alaska and Yorkshire only as rarities.

The Callovian, Lower Oxfordian and Lower Kimeridgian were characterized by great expansion, enrichment and spread of Boreal genera such as Kosmoceras, Cadoceras and its derivatives (Quenstedtoceras, Cardioceras, Amoeboceras), Rasenia and Aulacostephanus. These genera spread from the north across European Russia and Britain, but stopped short south of the Caspian and Caucasus and only reached south of the Alps as occasional stragglers—though Cardioceras went in some strength down the lower Rhone valley and a single species even reached Portugal. There was at this time considerable mingling of the Boreal and Pacific realms, for Kosmoceratids arrived in Peru; and the pelecypod family Buchiidae was equally abundant in the Boreal and Pacific Oceans, abounding in California and New Zealand and in Europe reaching south to Dorset and the Boulonnais in the Kimeridgian (Dutertre, 1926).

This fundamental fact in Jurassic history, the northward spread of temperate and equatorial faunas in the Lower Jurassic and Bajocian, and the southward spread of northern faunas in the Callovian and early Upper Jurassic, has been rightly emphasized by Termier & Termier in their brilliant review of historical geology (1952). They designate the first phase as the Tethyan transgression, the second as the Arctic transgression, and they point out that during the Oxfordian and Kimeridgian coral reefs were driven southward across Europe by the progressively cooling waters.

In order to keep distinct two separate phenomena, marine transgression and faunal migration, the process under discussion, namely the southward migration and colonization of boreal faunas, will here be referred to as the Boreal spread. The Boreal spread was not a continuous process. It is true that by the Kimeridgian coral reefs had retreated south to central

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FIG. 99.—Map showing the distribution (B) of the Boreal family Cardioceratidae (Cadoceras, Pseudocadoceras, Quenstedtoceras, Cardioceras) in the Callovian and Lower Oxfordian, at the time of the maximum Boreal spread.

FIG. 100.—Map showing the distribution of the Tethyan Perispinctes fauna (T) in the Upper Oxfordian, at the time of the Boreal retreat. M, Mayaitidae of the eastern Tethys.
Europe, but in the Upper Oxfordian they extended in force northwards to Yorkshire where none had been before, and perhaps even to northern Scotland.* This was long after the first and greatest southward spread of Boreal ammonites, which had reached the fringe of the present Mediterranean in the Callovian and Lower Oxfordian. The Upper Oxfordian in fact represents a temporary reversal of the Boreal spread and a return of Tethyan faunas; for the abundant large Perisphinctidae of the English Upper Oxfordian are a Tethyan race which does not occur in the Arctic; some are identical at specific level with those in equatorial East Africa and also closely related to forms that lived on and even south of the equator in Indonesia and northern Chile. In Europe they are common in the Mediterranean area, south of the southern limit of Cardioceratidae (fig. 100).

In the Lower Kimeridgian the Boreal spread was renewed, but in the Middle Kimeridgian it stopped. Thereafter in northern Europe and Russia old stocks became extinct, no fresh ones appeared, and specialization of the single surviving stock, the Perisphinctaceae, set in. In England, the Boulognais and Arctic America (Greenland and Canada) these gave rise to the Dorsoplanitinae which culminated in the giant Portlandian Perisphinctids, the largest Jurassic ammonites. There is still difference of opinion whether these are to be correlated with the similar giants of the Blakei Zone of the Moscow basin, and until that fauna has been monographed the last word cannot be said. In any case, during the Lower Portlandian there was still free communication across Pomerania and Poland between England and Russia, but in the Moscow basin a highly specialized and peculiar form of Perisphinctids, the Virgatitinae, had already reached its acme in Virgatites (pl. 45, figs. 1, 2). With the end of the Portlandian (assuming that to coincide with the end of the Lower Volgian) ammonites became extinct in NW. Europe, Greenland and North America, while another specialized, smooth, degenerate stock, the Craspeditidae, was evolved in the Moscow basin and adjoining Arctic regions (pl. 46). These presumably lived at the time of the Purbeckian. Their descendants (Subcraspedites fauna) returned to colonize Yorkshire and Greenland with the early Cretaceous transgression.

During this closing phase of regression and specialization in the north, the Tethyan fauna continued to thrive and evolve actively over all the rest of the world. From the Beckeri Zone of the Middle Kimeridgian onwards there were produced many and varied experiments in a number of ammonite stocks. The Perisphinctids evolved on separate and productive lines, producing the world-wide Berriasellidae with their numerous offshoots such as the Himalayitinae and Neocomitinae; the Simoceratids and Aspidoceratids also produced further novelties; and the Oppeliiaceae abounded in vast numbers and infinite variety, augmented by fresh developments from the Haploceratids. There is no basis for comparison

* If the reef-building corals in the Lower Kimeridgian boulder beds (Arkell, 1933, p. 476) are derived from erosion of Oxfordian beds on the upthrown side of the fault.

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with the Boreal realm, and until some area has been discovered where any
of the faunas of the three realms overlap (perhaps this may occur in the
region of the Caucasus), it is necessary to continue using the separate
stage name Tithonian, introduced for this purpose by Oppel, for all the
Jurassic above the Beckeri Zone over the whole Tethyan and Pacific
parts of the world.

Termier & Termier state that in the Upper Portlandian [recte Upper ?
or Middle? Tithonian] there was a third period of major marine trans­
gression and faunal spread around the Pacific, which they call the circum-
Pacific transgression, and they liken this to nine similar circum-Pacific
transgressions which they discern following Tethyan and Arctic transgres­
sions in the same order repeatedly throughout geological history (1952a,
p. 35). In the Jurassic instance the evidence for a final circum-Pacific
phase is much weaker than for the two preceding, Tethyan and Arctic
phases, which may be regarded as established facts. It is true that parts
of the Tithonian were transgressive in Argentina and California, after
the Nevadan orogeny, but there is nothing to suggest a Pacific transgression
on the Asiatic side. There is in fact no evidence for an appreciable Pacific
spread of faunas at this time, in any way comparable with the Tethyan
and Boreal spreads. If there was ever a Pacific spread it occurred in the
Lower Kimeridgian, when the Mexican Idoceras fauna, with its peculiarly-
ribbed race of Idoceras, and specialized Rasenian genera Epicephalites and

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Subneumayria invaded New Zealand, and the same forms of Idoceras reached Indonesia and Japan. However, as has been remarked above, the Pacific realm was already differentiated in the Middle Bajocian, and so this spread of the Idoceras fauna in the western Pacific was only a reclamation of territory.

The great southern bay off the central Tethys, which extended across the Arabian sea and down the east side of Africa to Madagascar, developed several peculiar faunas which warrant the recognition of an Ethiopian province, though in a wider sense than used by Uhlig and including Cutch, Baluchistan and Arabia (p. 336). That Uhlig was nevertheless right to classify this region as a province rather than a realm has been shown by the discovery of isolated stragglers of nearly all these endemic Ethiopian genera in other parts of the Tethys as distant as Portugal (Bouleiceras), Algeria (Ermoceras) and Indonesia (Mayaitidae).

In the eastern Tethys, from Spiti to Indonesia and New Guinea, another special fauna appeared at the very end of the Jurassic, but it is not yet certain which of its elements are Tithonian and which Lower Cretaceous. The collection of these faunas on rigid stratigraphical principles is one of the most important tasks still waiting to be done.

Summarizing, it appears that during the Jurassic there were only three faunal realms, which may be most simply named the Tethyan, Pacific and Boreal. None of the three was differentiated at the time of the Lias, when one fauna was universal. By progressive differentiation and spread of the Pacific and Boreal realms during the Middle and Upper Jurassic the remainder became the Tethyan realm. During Upper Jurassic times the three realms changed their frontiers considerably in certain regions at the expense of each other’s territory.

The Pacific realm began to be differentiated perhaps in the Toarcian, but certainly in the Middle Bajocian, at which time there began a general retreat of ammonites from the periarctic regions. This retreat culminated in the Middle Bathonian. In the Upper Oxfordian Mexico, Cuba, California and Indonesia belonged to the Tethyan realm, but in the Lower Kimeridgian the Pacific realm asserted itself anew and incorporated Mexico, Japan, Indonesia and New Zealand.

The first indications of the Boreal realm appear in the Lower Callovian, and during the rest of the Callovian and Lower Oxfordian it spread south over Europe to the borders of the present Mediterranean and Caspian seas. It was thrown back during the Upper Oxfordian by a temporary re-advance of the Tethyan realm, which took equatorial Perisphinctids and coral reefs to the north of England and Scotland but not into the Arctic regions. In the Lower Kimeridgian the Boreal spread was renewed and all the old territory was regained.

Finally, from the Middle Kimeridgian onwards the Boreal realm shrunk and its marginal areas were subdivided by regional uplifts into the Portlandian and Volgian provinces. Meanwhile the Tethyan realm continued to exist and locally to extend, as shown by Tithonian

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transgressions in many parts of the world, and it probably merged with the Pacific, but the Tithonian faunas became more sharply differentiated than ever from those in the Boreal realm.

CLIMATE

The foregoing summary of the distribution of faunal realms is based on fact, but questions of climate involve much inference and speculation. They might accordingly with justification be omitted from this book. However, the climatic consequences of much that has been stated are so drastically at variance with Neumayr's scheme of climatic zones (1883) and with what might be expected, especially in the north polar regions, that some remarks on the present state of the evidence and its implications seem called for. One day it may be possible to take actual measurements of past temperatures (Urey & others, 1951).

Uhlig again (1911, pp. 440 ff.) ably reviewed the evidence as it presented itself nearly thirty years after Neumayr's paper and stated in summary: 'Hence we may draw the conclusion that although climatic zones existed in the Jurassic, in general and at higher latitudes the climate was somewhat warmer than in later times.' Seward (1933, p. 335) also concluded from a study of the Jurassic vegetation that 'the available evidence indicates much less difference between the floras from different zones of latitude than our knowledge of plant-distribution at the present day might lead us to expect.' He qualified this by suggesting that the apparent monotony of the flora might be increased by inadvertent confusing of assemblages of different ages, and by the fact that the assemblages preserved as fossils would tend to be always from a similar biotype—the vegetation of coastal lowlands, river basins and estuaries. Moreover, in eastern Asia Kobayashi (1942, p. 162) has noticed that cycads and ferns are commoner towards the south and conifers and ginkgos towards the north. However, nothing can seriously detract from the fact that during some part of the Jurassic a fairly rich flora of temperate facies flourished within or near both the Arctic and Antarctic circles, in East Greenland and Grahamland. Even if we postulate, with Termier & Termier (1952a, p. 47), that monsoons reached Greenland, Uhlig's conclusion seems fully justified.

For the Upper Jurassic at least, the evidence of the vegetation is supported by the distribution of coral reefs in Europe. In the Upper Oxfordian the main coral belt runs through south-central Europe, and the coral reefs in Yorkshire are fully 20° of latitude farther north than the most northerly existing at the present day, in the Gulf of Suez, the Bermudas and Japan. The reef-building corals with their calcareous skeletons have certain physical and chemical requirements which presumably were much the same at all times and so they are in a class apart as the most valuable climatic indicators (Arkell, 1935).

Inferences drawn from the present-day distribution of the nearest allies of Jurassic animals in other classes may be misleading. For instance, three particularly common fossil pelecypod genera in Jurassic rocks,
especially in Europe, are *Trigonia*, *Astarte* and *Pholadomya*, and all three survive to the present day. In the Jurassic they are closely associated in the commonest, shallow-water biotype. But at the present day *Astarte* is boreal, *Trigonia* lives only in the warm waters around Australia, and *Pholadomya* is abyssal.

A more reliable guide than the descendants of a fossil mollusc or arthropod is probably its size. At the present day the largest forms of arthropods, snails and all shells, that is, animals with external skeleton, are found in equatorial or tropical regions. By analogy it is difficult not to believe that the immense Portlandian ammonites lived in much warmer water than anything possible in similar latitudes at the present day. This was contested by Neumayr (1883, p. 279), who pointed to the giant squids which live at present in the North Atlantic; but these have no shells and so are not relevant.

If the large marine shells (ammonites, pelecypods and gastropods) and occasional corals of the Portland Stone be accepted as of subtropical aspect, there is a puzzling contrast with the dwarf freshwater fauna of the Purbeckian, which conformably overlies it. The freshwater snails of the Purbeckian, though belonging largely to common surviving genera such as *Viviparus*, *Lymnaea*, *Physa*, *Valvata*, are smaller than many of their living English counterparts. The insects too are small and have always been considered to be of temperate facies. Unless there was a cooling of the climate between the Portlandian and Purbeckian, the only explanation seems to be a warm current in the sea and cooler air-temperature on land. This would be the opposite of what Termier & Termier (1952, pp. 506, 510) postulate for North America to explain the warm continental climate suggested to them by the Morrison fauna in the midst of what to them was a cold Kimeridgian sea. The Morrison molluscan fauna, however, is of just as temperate appearance as the Purbeck, and except that the North American Kimeridgian marine fauna is called 'Boreal' there is nothing to suggest that the sea was particularly cold. *Buchia*, as we have seen, crosses the equator in the Pacific realm.

That the Boreal sea was cooler than that farther south is indicated by the absence or rarity of limestones in its deposits. On the other hand indications of glaciation are also lacking from all Arctic regions. Moreover, the giant Portlandian ammonites are part of the Boreal fauna. Their most southerly known place of occurrence is northern France and they extend, as already mentioned, to Greenland and Canada. Nor are any of the other marine faunas of the Boreal realm stunted, impoverished, or in any way indicative of a specially cold habitat. It is impossible to imagine the Arctic Ocean under its present polar regime as the cradle of the so-called Boreal faunas. The conclusion is inescapable that the Arctic Ocean in the Jurassic had no ice cap and that its waters were at least as warm as those of the present temperate zones.

It has been argued (for references see Dacqué, 1915, p. 422) that the

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general temperature of the sea was lower at the time of the Lias than during the Upper Jurassic. This is suggested by the general scarcity of limestones and of coral reefs before the Middle Jurassic and by an increase in the average size of fossil insects during the period. It should not be overlooked however, that the Greenland flora about which so much has been said lived in early Lias times.

The existence of seasonal changes in what are now temperate and Arctic regions seems indicated by growth-rings in fossil wood, dissepiment rings in certain fossil corals and by ledging or ringing of the growth-lines of certain pelecypods. (For references see Arkell, 1935, p. 102.)

When we speak of the waters of the whole earth being warmer in the Jurassic than at present, there are two areas about which there must be reservations, since at present there is no evidence, namely, the middle of the Pacific and the middle of the South Atlantic. If some theory of geophysics were to demand that the poles were situated in these areas in the Jurassic, and that in consequence of the poles lying in great oceans (the Arctic Ocean is a diminutive land-locked sea in comparison) there were no permanent (or greatly reduced) ice caps, there would not seem to be any positive evidence against this. But to be sufficiently far from the rich Jurassic faunas of the Alaska peninsula and from the corals in the Torinosu Limestone of Japan, the Pacific pole would have to be not more than 20° or 30° north of the present equator if on such a meridian as would bring the other pole reasonably central to the South Atlantic. In that case the Jurassic equator would have lain on about latitude 60°-70° on the European side, namely north of the Orkneys and through Iceland and Scandinavia, which is too far north to suit the facts. The ideal position for the Jurassic equator, assuming displaced poles, would be through southern Europe, which would bring the north pole up to latitude 40°-50° in the Pacific, too near Alaska and Japan. Any less drastic displacement of the north pole, which would locate it over any of the lands surrounding the Arctic Ocean, must be ruled out unless the climate was in general much warmer, owing to the ring of Jurassic faunas which encircles that ocean and to the absence of any signs of glaciation.

All things considered, therefore, the most probable explanation of the warm temperature of the Jurassic is that which depends on receipt of more solar radiation, as already postulated by Dubois (1895).* His theory has the special advantage that the effects of increased solar radiation would have a disproportionately great effect in high latitudes, owing to the efficiency of the distributary mechanism of currents and winds. Therefore, in order to melt the ice caps and render the Arctic Ocean inhabitable by a large and varied fauna, it is not necessary for the sun to heat the equatorial zone to inconveniently high temperatures. Moreover, in middle and high latitudes currents are said to have a greater warming effect than winds, so that the sea would tend to be warmer than

* 'Continental submergence' (Berry, 1929) does not seem a suitable or adequate explanation for the Jurassic, at least.
the air; this may explain the contrast between the giant marine Portland and the dwarf Purbeck freshwater shells.

If there was a general warming of the earth’s surface by increased radiation received from the sun, there would be nothing to show where the poles were situated. Provided the general temperature was such that no ice caps were formed, geophysicists are at liberty to postulate almost any wanderings of the poles that may be convenient. They may do this for most of geological history, for ice ages seem to have been infrequent events; and their geological remains are so awkwardly arranged that some wandering of the poles may be welcome as an aid to accounting for their distribution.

The infrequency of glacial episodes and especially the rarity of fossil tills in Arctic regions indicate that if, in fact, the poles have always been approximately where they are now, the warm state of the earth in the Jurassic was normal and our present condition, with polar ice caps, is exceptional. In that case it rests with the astronomers to decide whether the output of radiation from the sun has fluctuated enough and at the required times, or whether part of the radiation has been intercepted on occasion by interstellar dust or gas.
CHAPTER 29

SHIELDS, SHELVES, MOBILE BELTS AND GEOSYNCLINES

For many geological purposes it is useful to classify the land areas of the earth into (1) shields, or ancient continental nuclei, composed of pre-Cambrian crystalline complexes, which have been relatively stable and received little sediment all through post-Archaean time; (2) shelves, or moderately rigid platforms, surrounding the shields, often with the crystalline basement not far below or protruding as large horsts, but the surface beneath the Mesozoic cover composed of either flat-lying or (farther from the shields) often highly folded, consolidated and eroded Palaeozoic sediments which are relics of older mountain chains; and (3) mobile belts, in which stand the youthful Tertiary mountain chains of the present day and which display in their Mesozoic and Tertiary sedimentation a high degree of mobility, often with geosynclinal deposition, volcanic extrusions and batholithic intrusions. The shields and stable parts of the shelves together form the rigid elements of the earth's surface, the kratogens; the mobile belts and mobile parts of the shelves form the unstable elements or orogens.

In general the principal shields conspicuous at the present day (North America, South America, Antarctica, Scandinavia, Africa with western Arabia, peninsular India, Angaria, Sinia, Western Australia) were already in existence in Jurassic times. So also were the shelves; indeed, our concept of the shelves is conditioned largely by the development of the Mesozoic epicontinental deposits left upon them. The mobile belts, however, were by no means always the same in the Jurassic as in the Tertiary and at present, although for the most part distributed along the same general lines, namely: in a ring round the Pacific, and as a connecting band east-west across Asia and the Mediterranean and Alpine region.

In this chapter will be brought together salient facts bearing on the distribution and condition of the shields, shelf-seas, mobile belts and geosynclines during the Jurassic. Finally, in the last two chapters (30, 31) are critically summarized the volcanic activity and diastrophic movements that occurred during the Jurassic in the mobile belts.

It must be emphasized how arbitrary is the division between shields, shelves, and mobile belts: all grade into one another. Like all attempts to classify natural phenomena, this is to some extent an artificial scheme; but it has its uses.

SHIELDS

The absence of marine fossils from the greater part of the shields makes dating of their deposits extremely uncertain, and it is consequently
seldom that we yet have accurate knowledge of their histories. As will be seen from the brief remarks on the South African and South American shields (pp. 343, 588), it is impossible to be sure whether any of the continental deposits thereon are Jurassic, but the indications are that the latest are all Triassic. The same applies to the Antarctic shield. The North American, North African and Scandinavian shields definitely carry no Jurassic deposits. The Indian shield has usually been supposed to carry thick Jurassic deposits of continental facies, with plant-beds, but on examination they all appear to be Cretaceous (like the Nubian Sandstone of North Africa), and the Jurassic is left represented only by a disconformity between Triassic Middle and Cretaceous Upper Gondwanas (p. 384).

It appears, therefore, that all these shields were above sea-level and the scene of erosion during the Jurassic. They are recognizable only by the sediments they supplied to surrounding shelf-seas and geosynclines. For instance, on the south side of the Tethys in Barbary there are immense wedges of clastic sediments which thin out northwards and were evidently derived from erosion of the Saharan shield; in NE. England and Scotland the Bajocian and Bathonian comprise unusual thicknesses of deltaic deposits which can only have been derived from the Scandinavian shield; and in Scania, close to the edge of the crystallines, similar clastics are interbedded with and make up the greater part of the Lower Lias. In America similar wedges of clastics, coarsening north towards the shield, underlie the Gulf coastal plain, and in the Western Interior most of the colossal pile of sandstones (p. 545) was presumably derived from the shield—though here and in the south largely from Palaeozoic rocks rather than direct from the crystallines. (The same secondary derivation was independently inferred for the Nubian Sandstone.) From interfingering of the clastics with marine faunas round the edges of the shields something can be inferred of the periods of maximum erosion, and therefore differential elevation, of the shields, and the picture gained is consistent with the absence of deposits on the shield surface.

The shields of NE. Asia are less well defined and the region is hardly known with sufficient geological detail to enable a clear picture to be obtained. Angaria and Sinia were and are certainly covered to some extent by continental deposits of Jurassic age, but a large part of the outcrops of these deposits lies rather on folded, consolidated and eroded Palaeozoic basement which should be classified with the shelves. Authors disagree as to the number of shields that should be recognized at the present day. Some are better classed as horsts in labile shelf areas, like those in NW. Europe. It is not legitimate to admit existence of Jurassic continental deposits as evidence of a shield, for, as just remarked, such deposits are by no means characteristic of shields and hardly exist at all on most of them.

There remains Australia. Only the western part of the continent is a shield. The eastern part consists of Caledonian and Variscan fold ranges

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(Palaeo- and Meso-Australia in fig. 102). Some lacustrine continental deposits occur as outliers on the western and northern parts of the shield, but only those in the south-west are dated by plants as Jurassic. The main outcrops of the Jurassic lacustrine beds are all in the east, where most rest on the folded Palaeozoic shelf. Australia is therefore no exception to the general rule that the major pre-Cambrian shields of the earth were upstanding in the Jurassic and mainly the scene of erosion rather than deposition.

**FIG. 102.—Sketch-map to show the structural evolution of Australia. After R. W. Fairbridge, 1950.**

**SHELVES**

Surrounding the shields are usually more or less broad shelves ('aires d'ennoyage' of Haug, 1900, 1910), which are neither shields nor true mobile belts, but were covered or partly covered in the Jurassic by epeiric seas, the deposits of which are varied, seldom very thick, and often highly fossiliferous.

The shelves were described and defined with reference to Europe by von Bubnoff (1931), who divided them into stable shelves and labile shelves. The typical stable shelf is European Russia. Over enormous areas horizontal, thin but palaeontologically almost complete Upper Jurassic sediments spread transgressively over little-disturbed Palaeozoics. The
whole area has been protected by the rigid foundations of a pre-Devonian platform which lies not far beneath. Long but very gentle anticlinal ripples alone break the monotonous plains, in which dips are hardly perceptible.

The labile shelves are typified on the other hand by NW. Europe. Here the Jurassic facies is similar and there are often also condensed beds, but the formations tend to swell out into thicker lenses, there has been considerable tectonic disturbance of a minor order (Stille's Germano-type tectonics), and a number of ancient horsts break through the sedimentary cover—such as the Black Forest, Bohemian Forest, Ardennes Island and Scottish Highlands. There is evidence that in the Jurassic most of these horsts were already upstanding or else began to rise. The foundations of the labile shelves are the worn-down mountain chains thrown up by the Variscan and Caledonian orogenies. Such a foundation is a mosaic of structures and varying rock-types. Although solidified and welded together by earlier orogenies, these tracts were still unstable during the Mesozoic, and the nature of the foundations is sufficient explanation of the contrast in their histories in comparison with the stable shelves.

On the labile shelf of Europe there was in Jurassic times a complex network of subsiding troughs of sedimentation of various shapes and sizes. These grade imperceptibly into geosynclines (Arkell, 1933, p. 616), but it is preferable not to stretch this term to cover them, for they seldom contain more than 1000 m. of Jurassic sediments, they were not the seat of volcanic activity or greywacke-type sedimentation, and they have not been converted into folded mountains.

Troughs of subsidence and sedimentation on the labile shelves are called cuvettes by Wills (1929, 1951), parageosynclines by Stille (but this term was preoccupied in another sense by Schuchert: see Glaessner & Teichert, 1947, p. 588), and intracratonal geosynclines by Kay (1951, p. 107), who subdivides them into three types, each with a formidable new name, according to shape, setting and filling. Here they will be called by their English name, troughs, or troughs of deposition. The nature, extent, subsidence and contemporaneous tectonics of the troughs, with their cyclic sedimentation and its causes, have already been discussed at length in relation to the British Jurassic, and all this need not be repeated here (Arkell, 1933, chapter iii).

For data on some of the largest shelf regions in the Jurassic outside Europe, the reader should refer to the Trans-Erythraean trough (p. 298) and the Western Interior of the United States (p. 544). The American example has been admirably monographed from this point of view by Imlay (1949) without the use of any daunting terminology. It also illustrates how a shelf trough can pass imperceptibly into a geosyncline.

The continental-lacustrine Jurassics of eastern Australia accumulated in a broad trough which is tectonically analogous to the Rocky Mountain trough of the Western Interior of the United States. The
MOBILE BELTS AND GEOSYNCLINES

Australian deposits reach 2500 m. in thickness in parts of Queensland and so are of geosynclinal magnitude. It appears that the sea was at all times excluded in the Jurassic (p. 461), whereas in the American analogue several marine transgressions occurred in the Middle and early Upper Jurassic (p. 545). In the Lower Jurassic and from the beginning of the Kimeridgian onward (Morrison formation), however, when the sea was shut out from the American trough also, the analogy was complete.

The Rocky Mountain trough in Jurassic time was separated (though not completely and permanently) from the Pacific by the cordilleran geanticline, which was part of the circum-Pacific mobile belt and supplied clastic sediments to the trough on the east. If the analogy with eastern Australia holds, there was in Jurassic times, between the present Australian coast and the Papuan geosyncline, a geanticline which performed the dual role of excluding the Pacific Ocean from the Australian lakes and supplying sediment to them and to the geosyncline to the east. Possibly a sunken remnant of the barrier survives in the New Zealand ridge (fig. 102).

The thickness of the Australian continental Jurassic is about the same as that of the Jurassic system in much of the Elburz Mountains of Persia (p. 368), where the Lower Jurassic is in the same facies, but the Middle and Upper Jurassic are marine. The Elburz Jurassics, however, were laid down in an elongated trough on the mobile belt and have more claims to be called geosynclinal. Such examples, nevertheless, serve to show the transitions that exist and emphasize the artificiality of all attempts at rigid classification.

MOBILE BELTS AND GEOSYNCLINES

The mobile belts which appear in all the textbooks and are best defined and described under this name by Bucher (1933, chapters 3 and 4) are belts of high young mountain chains, volcanic and seismic activity, gravity anomalies, long linear or arcuate strike-lines, island festoons and narrow deeps. The belts are easy enough to define at the present day: as stated above, one forms a ring round the Pacific and another branches off from it in Indonesia and passes through the Himalayas, Persia and the Alps and Mediterranean, beyond which it is usually shown with a hypothetical extension across the Atlantic to the Caribbean region. The pattern of the mobile belts has been described as 'just what we might expect on a contraction theory' (Jeffreys, 1952, p. 310).

Since virtually the only constant character for recognizing these belts in past geological systems is their high degree of diversity, which is an expression of a high degree of mobility, the term mobile belts is the most appropriate. They are called orogens by Kober (1928) and Staub (1928), a name that emphasizes their role as the source of mountain systems. Haug (1900, 1910) called them geosynclines, but this was a misuse of Dana's term (for the history of which see reviews by Glaessner & Teichert, 1947, and Knopf, 1948); and Stille calls them orthogeosynclines.

The circum-Pacific mobile belt of the Jurassic coincides largely with

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GENERAL SURVEY

that of the present day; in fact the volcanic rocks, batholiths and fold-
structures of the Pacific border of North America are largely of Jurassic
origin, as appears in the next two chapters. Batholiths such as characterize
the mobile belt in North America were not intruded in the Jurassic
period in any other part of the world. Active volcanicity is found also in
South America, in the Caucasus and Crimea, and on a smaller scale in
the Mediterranean. Jurassic orogenies occurred in North America but
not South America, and also in the Caucasus and Crimea.

Over the rest of the mobile belts, down most of the east side of Asia
(except NE. Siberia) and thence to New Zealand, the only feature distin-
guishing the Jurassic deposits from those on the labile shelves, besides
occasional volcanicity, is the great thicknesses of sediment, and even that
criterion fails in the Himalayas, in SE. Asia and over much of the Medi-
terranean area. Geosynclines certainly existed in the Jurassic in NE.
Siberia, where thicknesses of 4000 to 6000 m. are recorded, and (the
Papuan geosyncline) from New Guinea, through New Caledonia to New
Zealand, where the thickness of the Jurassic approaches 5000 m. Something
like such thicknesses are reached in the Alps where, as Deecke (1912)
showed, small deeps and shallows and emergent islands and mobile ridges
existed side by side.

In the Himalayas and Tibet the Jurassic system shows signs of mobility,
such as disconformities, condensed formations and contrasting facies,
but there is no indication of a geosyncline between Western Yunnan and
the Pamirs. As has been pointed out before, the celebrated Spiti Shales
are similar in facies to the English Upper Lias and Kimeridge Clay,
but they are thinner, more heterogeneous, and indicative of less continuous
subsidence than the Kimeridge Clay of Kimeridge. The Spiti Shales
extend over an enormous area in Tibet (p. 413) without radical change of
facies. The Callovian in the Spiti area and the Bajocian in Tibet (Lungma
Limestone) are condensed and highly fossiliferous ironshot oolites, and in
the exotic blocks of the Kiogars are samples of red Adnet Limestone of
Hettangian and Sinemurian age and Upper Tithonian Calpionella oolite,
both matching their counterparts in southern Europe. Except for 200-
300 m. of possibly Lower Tithonian limestone (Kiogar Limestone), all
the formations, though varied, are thin; and there are no conglomerates,
unconformities, or Jurassic igneous rocks. The Jurassic features of this
part of the greatest Tertiary mobile belt on earth, therefore, are those of a
labile shelf. Here the Tethys was merely a shelf-sea comparable with that
of north-western Europe.

In the Mediterranean area outside the Alps (where acute tectonic
defORMATION in the Tertiary orogenies makes reconstructions difficult
and hazardous), North Africa (Barbary) provides the most detailed
information over the largest area, thanks to the work of many French
geologists in Algeria and Morocco, and especially to the brilliant analyses
and syntheses of G. Lucas (1942, 1952). Barbary forms the southern part
of the mobile belt of Tethys, adjoining the north margin of the African

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shield. Here any attempt at classification into labile or stable shelves breaks down when the region as a whole is considered: almost every imaginable type of terrane is represented. The High and Middle Atlas if they alone survived would be considered a shelf area; but the Saharan and Tellian Atlas provide lines of horsts active in the Jurassic and elongated troughs of truly geosynclinal dimensions, containing up to 3900 m. of Jurassic sediments (Cornet, 1952, p. 12), which have been converted in the Tertiary into true fold-mountains, with locally complete overturning (as in the Ouarsenis: Calembert, 1952). Volcanic activity alone is lacking. North Africa must be considered to have been part of a mobile belt in the Jurassic period; it included at least one geosyncline, but also large tracts occupied by shelf-seas.

Over the rest of the Mediterranean region too much has sunk beneath the sea to enable safe generalizations to be made about the isolated fragments that remain accessible. The Pyrenees and most of the Iberian peninsula had shelf-seas in the Jurassic. So did Sardinia and Sicily, where the sequence from Bajocian to Oxfordian is usually not more than 10-15 m. thick. But Sicily had volcanic activity during the Bajocian, whereas the Atlas geosynclines with their thousands of metres of sediments did not.

The peculiar lithology and fauna of the Kimeridgian and Tithonian (fausse brèche, Knollenkalk) is not distinctively geosynclinal but rather Tethyan. It is surely to be ascribed to climatic, chemical and environmental influences, not tectonic; though the origin of the peculiar breccias is probably seismic (p. 147).

Except in the Alps and the Atlas there is nothing in the Mediterranean region comparable to the great geosynclines of western North America. In Oregon, for instance, the Middle Bajocian alone, with ammonites throughout, is 1300 m. thick (more than the whole Jurassic at any one locality in Britain). In California the Tithonian is 7500 m. thick. Parallel to these rapidly subsiding geosynclines were long volcanic geanticlinal ridges or island festoons, which suffered rapid erosion and kept the geosynclines filled with sediments and volcanic material. These geanticlines form an integral part of the Pacific mobile belt. Spasms of exceptional uplift or movement were marked by the deposition of hundreds of metres of conglomerate. Such conglomerates within the Jurassic are commonest in North and South America, but occur also in New Zealand, the Caucasus and Crimea.

**Summary**

The main shields recognized at the present day were in existence in the Jurassic and were essentially land areas, undergoing erosion. The edges of some of them, and more especially the surface of minor shields already covered by sea in Upper Palaeozoic times, were stable shelves, on which thin and uniform Jurassic were deposited (e.g. Russian platform). Regions which had been the site of geosynclinal deposition in Palaeozoic times
and of mountain-building in the Caledonian and Variscan orogenies were in part above water in the Jurassic and formed extensions of the shields (e.g. Ural Mountains, Kuen Lun), but in part were submerged and formed labile shelves, on which varied Jurassic were formed in troughs, often interspersed with horsts (e.g. extra-Alpine Europe).

The mobile belts so conspicuous at the present day are a heritage from the Tertiary orogeny and do not coincide entirely with any easily recognized combination of features in the Jurassic. The circum-Pacific mobile belt was the most actively mobile in Jurassic times and provides the

<table>
<thead>
<tr>
<th>Mountain ranges in the Tertiary mobile belt</th>
<th>Continental facies &gt; 1/2</th>
<th>Continental facies &lt; 1/2</th>
<th>Thick conglomerates</th>
<th>Thickness 2000-5000 m. or more</th>
<th>Diorphism</th>
<th>Volcanism</th>
<th>Plutonism</th>
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<tbody>
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<td>Canadian coast ranges</td>
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<td>Californian coast ranges</td>
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<td>Rockies</td>
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<td>New Zealand</td>
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<td>[Eastern Australia]</td>
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<td>Himalayas</td>
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<td>Elburz</td>
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<td>Caucasus</td>
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<td>Crimea</td>
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<td>Alps</td>
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<td>Pyrenees</td>
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The greatest number of special characters. In North America it was the scene of active volcanism, geosynclinal subsidence and sedimentation, orogeny and batholith intrusion, all in Jurassic times. The Tertiary mobile belt, however, takes in the Rocky Mountains, which was a non-volcanic, non-orogenic, shelf-sea during the Jurassic. In eastern Australia the analogue was not incorporated in the Tertiary mobile belt, which coincided with the Jurassic geosyncline (New Guinea—New Caledonia—New Zealand). This geosyncline qualifies as such and as a mobile belt by its great thickness of Jurassic greywacke and flysch-type sediments (approaching 5000 m.) and conglomerates, but it shows only feeble Jurassic volcanism, no plutonism and no folding.

The east-west mobile belt across southern Asia and Europe coincides approximately with the Tethys sea of the Jurassic. On the whole it was mainly a mobile belt in the Jurassic, but it embraced within it many areas of stable shelf and rising horsts, and many of its mobile parts would, by themselves, be classed only as labile shelves. The Himalayas do not
coincide with any geosyncline in the circum-Pacific sense; the Himalayan Jurassic sea-bed was mobile at first and later became stable; there was in Jurassic times no thick geosynclinal deposition, no volcanism, no folding, not even conglomerate-formation. Geosynclines with some of these features in various combinations do occur within the Tethys, however, notably in the Pamirs, Elburz, Zagros, Caucasus, Crimea, Alps and Atlas. The Caucasus and Crimea come nearest to the North American geosyncline in showing all the requisite characters except plutonism, as will appear in the next two chapters.

A complicated terminology (Kay, 1951) for different kinds of troughs and geosynclines does not seem to serve any purpose and tends to create a false impression of clear-cut divisions where in reality there is gradation (see table 25).
CHAPTER 30

VOLCANICITY

The Jurassic period was no exception to the rule that volcanic rocks tend to reach their maximum development in the 'girdle of fire' round the Pacific Ocean. They are, however, unevenly distributed, being far more conspicuous on the American side than on the Asiatic, except in the extreme north-east of Asia, where it approaches nearest to America.

Owing to the size of the area, the mountainous terrane and the complicated tectonics, and to the fact that volcanic rocks can be dated only by reference to fossils above or below them, hardly ever interbedded, it is often difficult or impossible to determine accurately the age of enormous masses of effusives and pyroclastics along the Pacific coast of the Americas. The dating becomes most difficult where the volcanics are thickest, that is usually westward, towards their source of origin, for there fossil-beds become scarcest.

Many occurrences are described in Geological Survey memoirs and papers on parts of Alaska, British Columbia, Oregon and California, but too often with unavoidable vagueness of date. A number of references have been collected together by Kay (1951, pp. 45-6), and Taliaferro (quoted in Chapter 23) has dealt in masterly fashion with the stratigraphy of the igneous rocks of California, while those of South America are well summarized by Gerth (1935). The present account concentrates on the stratigraphical dating of igneous episodes, as a contribution towards understanding a large subject outside the scope of this book and the competence of its author.

Starting in the north, in Alaska, records show the comparatively modest thickness of about 300 m. of submarine lavas and tuffs of Lower Jurassic date, ending in the Lower Toarcian. Minor tuffs also occur in the Kimeridgian or Tithonian, or both.

In British Columbia the volcanic series becomes enormously thick, totalling in some places up to 5400 m. and resting on a like thickness of volcanics assigned to the Upper Triassic. In the Harrison Lake area, the volcanic series is overlain by fossiliferous Lower Callovian and embraces the Lower and Middle Jurassic; the thickness below the Callovian and above the Trias here is about 2700 m. Volcanic activity continued, however, well into the Callovian, in which there are 540 m. of tuffs.

In Oregon and, still more, California, the date of the chief volcanic activity is later. Here some 870 m. of lavas and tuffs are found in the stages Toarcian to Callovian. There follow some more lavas and tuffs in the Lower (and probably Middle) Kimeridgian; and finally, after the
Nevadan orogeny, thousands of metres of varied volcanics in the Franciscan and Knoxville formations, largely of Tithonian age.

In Mexico no volcanic activity seems to have occurred until the Oxfordian, when there was an outpouring of andesitic lavas during a brief continental episode. Tuffs and bentonite occur also in the Tithonian.

For South America the picture is less clear; much more work needs to be done. A volcanic island festoon probably existed off-shore along much of the Andes in Lower and Middle Jurassic times. In Peru volcanic rocks 900 m. thick of probably Liassic age rest directly on ancient gneiss, and in both Peru and Chile further eruptions of submarine lava occurred in the Callovian. The climax of activity was reached in west-central Argentina at the end of the Oxfordian, with the building up of 1000 m. of basic lavas and pyroclastics. This episode may correspond to any or all of the Kimeridgian. Finally, in Patagonia the Tithonian shales are underlain, overlain and interfingered with porphyritic lavas and contain thick beds of tuff.

For NE. Asia information is too sketchy for dating the extensive volcanics that occur supposedly at the top of the Jurassic of NE. Siberia and in

Table 26.—VOLCANIC ROCKS OF JURASSIC AGE IN AMERICA, AND THEIR DATES

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<th>SOUTH AMERICA</th>
<th>MEXICO</th>
<th>OREGON AND CALIFORNIA</th>
<th>BRITISH COLUMBIA (HARRISON LAKE)</th>
<th>ALASKA</th>
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<tbody>
<tr>
<td>Tithonian and Portlandian</td>
<td>Lava and tuffs, Patagonia</td>
<td>Tuffs and bentonite</td>
<td>Interbedded volcanics several 1000 m.</td>
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<tr>
<td>Kimeridgian</td>
<td>Volcanics 1000 m. Argentina (?)</td>
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<td>Some lavas and tuffs</td>
<td>Some tuffs</td>
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<tr>
<td>Oxfordian</td>
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<td>Lavas 150-300 m.</td>
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<td>Tuffs 540 m.</td>
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<tr>
<td>Callovian</td>
<td>Lavas in Peru and Chile</td>
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<td>Bathonian</td>
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<td>Bajocian</td>
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<td>Toarcian</td>
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http://jurassic.ru/
Sikhota Alin and northern China (p. 509). In Japan volcanic activity in the Jurassic was slight, being represented only by tuffs in thin lenticles in the early-Upper Jurassic of Rikuzen and the Hida plateau (Honshu).

In Indonesia water-laid tuffs and lapillae on Buru and Misol are accurately dated to the Upper Oxfordian. Probably of the same date are thick volcanic breccias and eruptive igneous rocks on Buru. In New Zealand tuffs occur in the Jurassic of both islands but volcanic signs are inconspicuous, perhaps because volcanoes were not close to surviving outcrops. In Australia a variety of lavas and pyroclastics are interbedded near the bottom of the Jurassic lake-beds in Queensland, and olivine basalts occur in the upper part of the series in New South Wales (p. 462).

The Tethys of Eurasia and North Africa can show little on the scale of the volcanic activity on the east and north sides of the Pacific ring. The eastern half, from Indonesia to the frontier of Persia, shows no volcanic rocks at all. Although it now contains the highest mountains in the world, this tract, as already remarked (p. 624) displays few geosynclinal characters in the Jurassic. In the Zagros Mountains radiolarites in the zone of overthrusting are associated with basic igneous rocks, both extrusive and intrusive, as in the ophiolite zone of the Alps. Volcanic rocks also occur in the Mekran hinterland (p. 380).

The only focus of Jurassic volcanism in the Old World comparable with the Pacific seaboard of the Americas was in the Caucasus ranges, the Little Caucasus, Azerbaijan and Crimea. Here the activity was mainly of Bajocian date, though in the Araxes valley (p. 365) it came to an end before the Middle Bajocian. In the southern Caucasus and Little Caucasus thick porphyritic lavas and tuffs, with tuff breccias, are interbedded over wide areas among sandstones and shales with Middle Bajocian ammonites (p. 357). In Georgia the thickness reaches 2000 m. (Vassoyevich & others, 1937, p. 12); even 3000 m. has been estimated here (Mokrinski, 1939, p. 509) and also in the Little Caucasus (Leontyey, 1950). In some places activity is said to have begun in the Lower Bajocian. Three petrographic zones are recognized: a central zone mainly basaltic, a northern zone andesitic-dacitic, a southern zone essentially andesitic (Lebedev, 1947). The volcanic series may go up into the Bathonian and in some places probably spans the Middle Jurassic less Callovian.

In Sicily widespread marine tuffs occur in the Middle Jurassic and in at least one place Upper Bajocian ammonites have been obtained from them (p. 209).

In the Crimea there was a longer history of volcanic activity. Following intrusions after the Pliensbachian and probably also after the Toarcian, there were three successive periods of eruption of submarine andesites, agglomerates and tuffs during the Middle Jurassic with Callovian. In the Balaclava area there is also a tuff bed of Tithonian or Lower Cretaceous date. The Middle and Upper Jurassic eruptions are of both fissure and central type and there are indications of at least five volcanoes (Federovitch, 1927).
In Anatolia, around Bayburt, two separate masses of andesitic lavas and tuffs, each 300 m. thick, are interbedded in the Sinemurian, and some thinner volcanic rocks also occur in the Upper Pliensbachian (p. 350). In the coast range south of the Sea of Marmara a bed of red tuff occurs in the supposed Middle Jurassic.

The ‘ophiolites’ of the Alps and north Italy are generally very difficult to date and may be of widely different ages. They consist of basic submarine lavas, usually basalt, accompanied by intrusive gabbro and peridotite and often much mixed up by later tectonic deformation and metamorphism. Extrusive and intrusive rocks are difficult to separate and some of the serpentines may be lavas (Bailey & McCallien, 1953). These igneous rocks are generally associated with cherts, with or without radiolaria. In the northern Apennines the earliest may be late Tithonian. There are effusions in the Lower Tithonian near Belgrade and some of the ophiolites in the Dinaric Alps may be Jurassic (p. 192).

On the shields the time of transition from Triassic to Jurassic witnessed colossal outpourings of basalt. Most of these probably occurred during the Rhaetian, but close dating is generally difficult if not impossible. The Stormberg lavas in South Africa, the Sera Geral lavas in South America and the plateau basalts in Angaraland belong to this category, but all need not be of exactly the same age. The scant evidence is, in fact, opposed to the idea of contemporaneity; for the Angara basalts were eroded before deposition of the Jurassic, whereas those in Morocco are said to be in part interbedded with marine Lower Lias (p. 260) and so are probably contemporary with the Lower Hettangian basalts and tuffs of the Pyrenees (p. 224).
CHAPTER 31

DIASTROPHISM

OROGENIC PHASES OF THE JURASSIC

European geologists interested in the dynamic aspects of their subject think little of the Jurassic period. In most of the Old World it was a time of quiet, given over to moderate deposition, guided and on occasion modified by epeirogenic movements. Only in parts of a narrow belt through the Alps, Anatolia, the Crimea and Caucasus are there signs of unusual dynamic (and igneous) activity.

On the west side of North America the story is very different. There, where volcanic action was greatest and sedimentation often extremely rapid, full-scale mountain-building took place in the Jurassic. To some extent, like the volcanism, these events spread over into NE. Asia. It was the western cordillera of North America, however, that was in Jurassic times the seat of by far the most important earth-movements in the world. Accordingly it is from North America that any study of Jurassic diastrophism should start, and from which it should take its nomenclature if a separate nomenclature for tectonic events is considered necessary.

The chief focus of activity was the Sierra Nevada, after which is named the Nevadan orogeny. (This name, however, conveys nothing until one knows that its date was immediately pre-Tithonian; it can, therefore, more usefully be known as the pre-Tithonian orogeny.* The same applies a fortiori to less important orogenies or phases). The pre-Tithonian or Nevadan was a major ‘revolution’, and besides causing isoclinal folding and thrusting, and being both preceded and followed by intense volcanism and geosynclinal deposition, it culminated with the intrusion of the great Sierra Nevada batholith.

In America there is no reliable evidence that the Triassic and Jurassic were separated by an orogenic phase or important movements of any sort. In western Nevada has been found that stratigraphical rarity, marine Rhaetian deposits with ammonites, and they lie conformably between marine Norian and marine Hettangian (p. 556). In British Columbia both Upper Trias and Lower Jurassic are mainly represented by thick volcanics which together build a conformable column. The first movements seem to have occurred in the Pliensbachian, for in Oregon it is the Upper Pliensbachian that oversteps unconformably across acutely folded Upper Trias and unfossiliferous beds which may represent earlier parts of the Lias here folded with the Trias. In the Sierra Nevada the Pliensbachian contains thick conglomerates and displays folding of the lower beds and incipient thrusting. This was the Dunlap orogeny.

* Even this must be qualified as pre 'local Tithonian'.

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In Alaska an unconformity occurs somewhat later than the Dunlap, apparently in the middle of the Toarcian, though more information is required. The indications consist of unconformable relations of the Tuxedni sandstone, which contains conglomerates and Upper Toarcian ammonites, to the underlying volcanic series, said to include stages up to Lower Toarcian (pp. 535, 538). It seems that the Dunlap may have been a minor orogeny that shifted northward along the Pacific coast during the Pliensbachian and Toarcian.

In the late Callovian or at the boundary between Callovian and Lower Oxfordian another orogeny took place in Canada, where it is represented in the Harrison Lake area by the Kent conglomerate (900 m.), resting on folded Jurassic which include Callovian with Cadoceras, and in Alaska by the Chisik conglomerate (90 m.), which rests on beds dated as Upper Callovian. This episode was named by Crickmay the Agassiz, because he believed that during it the Agassiz Mountains of Canada were folded, upheaved and eroded, all within the time taken to deposit perhaps a single zone (pp. 539, 560). This startling deduction has received support from subsequent work on other orogenic phases, more especially the Nevadan. The course of events in British Columbia at this time recalls those in a French Upper Palaeozoic geosyncline illuminatingly described and discussed by Pruvost (1939).

The Nevadan orogeny was on a much larger scale than the earlier ones in the western United States at least, but in Canada and Alaska its effects are less conspicuous. In its type area it caused isoclinal folding and at least partial metamorphism of the underlying Jurassic, extensive thrusting and migration of the geosyncline outwards, to the Pacific coast ranges. The precise date of emplacement of batholiths is proverbially difficult to determine, but there seems general agreement that arrival of the mighty Sierra Nevada and Canadian Coast Range batholiths was the culmination of this orogeny, though other west coast batholiths came later, at various times in the Cretaceous. The new geosyncline formed after the orogeny was the seat of volcanism (Franciscan/Knoxville) as intense as any that went before, and of extremely rapid sedimentation. This might, however, be reconciled with theory by assuming it to be the pre-orogenic volcanism leading up to the next orogeny, which took place in the Berriasian in the same general region (Diablan orogeny).

The greatest surprise that has resulted from detailed stratigraphical work by Taliaferro and Anderson is the discovery that the whole Nevadan orogeny occupied a span of time probably no greater than the Upper Kimeridgian. The folded rocks include fossils of Lower and probably Middle Kimeridgian date, while the post-orogenic suite is Tithonian, with Middle Tithonian ammonites thousands of feet above the base (pp. 551-4).

It is natural to suppose that in the Rocky Mountains and Western Interior trough these orogenies might be expressed in some way in the stratigraphy. No convincing correspondence, however, is apparent.
The principal marine transgressions or ingressions there occurred in the Middle Bajocian, Lower Callovian, Lower Oxfordian and probably Lower Kimeridgian (Morrison formation). Of these only the Lower Oxfordian coincides in any way with a western orogeny; it might be considered to echo the end of the Agassiz. The Nevadan orogeny, however, may well be expressed in a negative way by the cessation of deposition at the end of the

<table>
<thead>
<tr>
<th>South America</th>
<th>Western Interior</th>
<th>Pacific Border and Texas</th>
<th>Canada</th>
<th>Alaska</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berriasian</td>
<td></td>
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<tr>
<td>Tithonian and Portlandian</td>
<td>. . . .</td>
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<tr>
<td>Kimeridgian</td>
<td>. . . . regional uplift</td>
<td>\textit{Diablan Orogeny}</td>
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<tr>
<td>Oxfordian</td>
<td>. . . . pre-Morrison</td>
<td>\textit{Nevadan Orogeny}</td>
<td></td>
<td></td>
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<tr>
<td>Callovian</td>
<td></td>
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<td>Agassiz Orogeny</td>
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</tr>
<tr>
<td>Bathonian</td>
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<tr>
<td>Bajocian</td>
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<tr>
<td>Toarcian</td>
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<tr>
<td>Pliensbachian</td>
<td></td>
<td>\textit{Dunlap Orogeny}</td>
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<tr>
<td>Sinemurian</td>
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<tr>
<td>Hettangian</td>
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</tbody>
</table>

Morrison. This latter event was presumably due to a very wide regional uplift, but it cannot be dated with precision. In Canada the basal Kootenay transgression probably coincides with the end of the Nevadan orogeny.

In Trans-Pecos Texas and under the Gulf coastal plain the Lower Kimeridgian is transgressive, and in the latter area the most important uplift deducible from the borings occurred at or near the end of the Kimeridgian, namely at the same time as the Nevadan orogeny. There is also a big gap, which undoubtedly corresponds to the Nevadan orogeny, in Trans-Pecos Texas (Upper Kimeridgian and ? Lower Tithonian missing; p. 567) and in Cuba (whole Kimeridgian and Lower Tithonian missing; p. 570). Where the gap is so big one must beware of jumping to the

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conclusion that it was necessarily caused by the latest tectonic phase when more than one is possible, as Gilluly (1949) has emphasized; but unless two phases were superimposed, the lowest member of the transgressive, post-orogenic suite may generally be relied on to give an approximate date to the significant movements.

In the Mexican trough there seem to be only indirect and inconspicuous repercussions of the orogenies in the cordilleran geosynclines. This fact puts the trough in the Jurassic tectonically with the Rocky Mountain trough, as might be expected, and despite the single episode of Oxfordian volcanism.

The South American Andes present an altogether different pattern. Despite the intense volcanic activity down the west side of the geosyncline, no authenticated Jurassic folding can be recorded. Instead there are successive transgressions acting as markers in a varied but essentially conformable series of extremely thick deposits. In the north, in Equador, marine Upper Trias passes up into marine Lower Lias, but in the south, in Patagonia, the Rhaetian is continental and the Lower Lias (Hettangian?) is transgressive and overlaps it on to Palaeozoic and pre-Cambrian rocks (p. 588). The four main transgressions thereafter in the Andes are Middle Bajocian, Lower Callovian, Lower Kimeridgian and Lower to Middle Tithonian; and all four coincide with transgressions in the Western Interior of the United States and Canada. Tectonically, therefore, the Andean geosyncline of the Jurassic resembles the Rocky Mountain trough, but in its heavy sedimentation and intense volcanicity it belongs with the Pacific cordilleran geosyncline. Its hybrid character is still further brought out by the fact that its principal orogenic deformation (Andean or Subhercynian) took place in the mid-Upper Cretaceous (pre-Senonian), a time intermediate between the Nevadan and Diablan orogenies of the Pacific coast geosyncline of North America and the Laramide orogeny of the Rocky Mountains.

In NE. Asia, including China, precise data are so scarce, chiefly owing to the predominantly continental facies of the formations, which have so far defeated attempts at zoning, that no firm conclusions are yet possible.* Orogenies certainly took place at various times approximately datable to the Jurassic. Some of the later movements have been called the Yenshan orogeny (term introduced by Wong, 1926), but while numerous phases have been separated, none is satisfactorily integrated with the universal time-scale (Lee, 1945, pp. 25-7). For these reasons the term Yenshanian is quite unsuitable for use outside NE. Asia.

Along the remainder of the west side of the Pacific, from Japan to New Zealand, no orogenic movements can definitely be assigned to the Jurassic, but conglomerates at two horizons in the late-Lower and the ?Middle or ?early-Upper Jurassic of New Zealand suggest that such movements did occur.

* From data available it does not seem to me that we are yet in a position to warrant a map such as that shown, for instance, by Umbgrove (1947, pl. 3).
GENERAL SURVEY

In the Tethys, knowledge of stratigraphical detail is so uneven, so thin for the eastern half and so concentrated for the western half, that a balanced summary is impossible. No true orogenic movements have been proved in the eastern part until the Caucasus, though evidence may well exist.

The Caucasus seems to rank next to North America for the intensity of its sedimentation, volcanism and orogeny during the Jurassic. The enormously thick Toarcian rests in places with a basal conglomerate on pre-Cambrian gneisses, while in others it cuts unconformably across an immense thickness of isoclinally folded slates and phyllites, in the upper part of which Upper Pliensbachian ammonites are recorded (p. 357); but this record was doubted by Renz. There is here a possible equivalent of the 'late Dunlap' orogeny of Canada and Alaska. Tectonic movements and faulting are also reported 'at the end of the Middle Jurassic' and called the Adyghe phase (Robinson, 1937, p. 35), but the age is not clear. The Nevadan orogeny is recognizable by the behaviour of the Tithonian, which in places has a basal conglomerate and in the North Caucasus oversteps unconformably on lower stages down to the crystallines (p. 358).

The Crimea is probably the most interesting part of the Old World from the point of view of Jurassic earth-movements, for in it three Middle and Upper Jurassic orogenies are demonstrable by thick conglomerates and unconformities, as well as in each of the Neocomian and possibly another above or below the problematic Rhaetian. It also deserves special attention as the type locality of the 'Cimmerian movements' of Suess (see p. 353).

The term Cimmerian (from the semi-mythical Crimean people of that name) has led to confusion, because in the German language, in which it has chiefly been used, it is spelt with a 'K' and in the common adjectival form as 'Kimmerische Faltung' it has been mistaken for 'Kimmeridgian' by both British and Asiatic authors. Moisseiev (1937, p. 13) has replaced the term by 'Chersonian orogeny'. But in any case it was first introduced for two widely separated orogenies, supposed to have occurred at the base of the Lias and at top of the Tithonian; whereas it has since been shown that the pre-Lias phase is at least extremely doubtful and more likely pre-Rhaetian (therefore intra-Triassic) and that the second phase, which was supposed to have ended the Jurassic, in reality preceded most of the Tithonian and so is the Nevadan orogeny. Two intervening phases have since been shown to be equally important. The term Cimmerian movements is therefore now too vague to have any meaning or value, being synonymous with 'Mid-Mesozoic'.

According to Moisseiev (1937, p. 13) movements between Rhaetian and Lias were 'quite possible' and he calls them 'hypothetical Salghir subphase'.

The Bajocian or Donetz phase seems to have been important in the Crimea; it is marked by coarse conglomerates up to 1000 m. thick, resting

unconformably on folded Lias shales and limestones which contain Pliensbachian and Toarcian ammonites. The precise dating, however, is none too certain owing to scarcity of ammonites—the lower limit of time rests in fact on one record of a Lytoceras jurensense. This may therefore turn out to be the 'retarded Dunlap' orogeny of Alaska.

The Lower Oxfordian orogeny is marked by conglomerates, up to 150 m. thick, which rest on Upper Callovian and pass up into Upper Oxfordian, and in places transgress on to Lias and Trias. This (the Yaila phase of Moisseiev) is clearly the Agassiz orogeny of Canada and Alaska.

Finally, the pre-Tithonian unconformity, already familiar in the Caucasus, can again be linked with the Nevadan orogeny.

In view of the remarkable correspondences at all these levels with western Canada and Alaska it is worth noticing that along a polar great circle the Canadian-Alaskan boundary at the Pacific coast is no farther from the Crimea than from the northern Andes on the frontier between Equador and Peru.

Some of the appearances of unconformity below the Crimean conglomerates, where they rest on tightly folded shales, may be exaggerated by disharmonic movements between the shales and more competent conglomerates (Weber in Moisseiev, 1937, p. 71).

In the Donetz, type locality of the Donetz phase of earth-movements, there is a feeble conglomerate containing Middle Bajocian ammonites, which rests on Upper Toarcian; so the gap is slight. The Lower Toarcian is transgressive on Trias, but without angular unconformity (pp. 484, 487). In the High Atlas of Midelt, Morocco, the Donetz phase is double, gentle folding having taken place twice: pre-Lower Bajocian and pre-Middle Bajocian, with local transgression of Middle Bajocian on to Lower Lias (p. 265).

In Europe pre-Lias and pre-Tithonian unconformities are recorded from many places in the Balkans and elsewhere, but the latter is hardly perceptible in the Alps. No attempt need be made here to recapitulate the mass of information available and so ably summarized already by Stille (1924, pp. 133 ff.). Of special interest, however, are the gentle foldings of pre-Middle and pre-Upper Bajocian age in the Cotswolds detected by Buckman (summarized in Arkell, 1933, pp. 198-9), and three minor phases in the Upper Jurassic and Neocomian of NW. Germany described by Schöndorf (1914), Dahlgrön, and others (Stille, 1924, p. 141). Limestone-conglomerates occur there at the base of the Gigas Zone of the Middle Kimeridgian (Deister phase), and in the Serpulite, which is Middle Purbeckian (Osterwald phase), and again in the Valanginian (Hils phase) (see p. 133).

Purbeckian folding also took place in the Swiss Jura, where the effects are registered in changes of facies, corresponding with anticlinal folds of the Tertiary orogeny that caused the structures existing at the present day (Carozzi, 1948, p. 123). The similar alignment of the Upper Oxfordian

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and Lower Kimeridgian coral reefs parallel to the present structural grain of the Jura, long ago observed by Bourgeat, suggests that preliminary foldings of the Alpine orogeny occurred even earlier in the Jurassic.

In North Africa the only intra-Jurassic folding, of approximately Upper Oxfordian date, is described from western Algeria and is localized and associated with faulting (Lucas, 1952, p. 66). Something of the same sort may perhaps explain localized intra-Jurassic folding reported at one point in Tanganyika (p. 333), and also seismic (?) breccias in the Toarcian of the Ain Sefra region in the Saharan Atlas (p. 265).

**The Time-Factor in Diastrophism**

One of the principal objects that have been borne in mind when assembling and sifting the stratigraphical data has been the perfection of a time scale by which to measure earth-movements. Only when a reasonably detailed and reliable stratigraphy of world-wide scope has been established can we hope for progress along many fascinating lines of enquiry into the mysteries of mountain-building and dynamic geological history in general; in fact, into the fundamental problems of geology.

The starting-point of all such enquiries in modern times is Professor H. Stille’s monumental book, ‘Grundfragen der vergleichenden Tektonik’ (1924). If the conclusions of such a work could be summed up in a few lines without impropriety or loss of sense, they would read somewhat as follows:—

1. Orogenic movements are episodic, world-wide and synchronous.
2. Epeirogenic movements have these same attributes.
3. Orogenies synchronize with regressions outside the mobile belts (opposite of Haug’s ‘law’).

All of these propositions have been debated in an interesting symposium (‘Struktur und Zeit’, Geol. Rundschau, 1950, vol. xxxviii, Heft 2), and since a diagram from my ‘Jurassic System in Great Britain’ (1933) is reproduced on the front page and the book is often quoted, it is appropriate to enquire what contribution the Jurassic system has to make to these fundamental problems, in the light of the data now available.

Those interested can go through the foregoing chapters for themselves, collecting and resifting the innumerable instances of unconformities, disconformities, pebble-beds, conglomerates, transgressions and regressions. To marshal and appraise them all here would unduly lengthen the book. The most important orogenic data have, however, been reviewed in the preceding section of this chapter. No one appraising these data with an unbiased mind can fail to be struck by the remarkably short duration of the orogenic phases: Crickmay’s first announcement of this in 1931 for the Agassiz orogeny has been confirmed for the Nevadan and is likely to be confirmed also for the Dunlap; it is also true for the Diablan and Donetz. Just as striking is the correspondence in date between orogenic episodes in western North America and the Crimea, on the same polar great circle on opposite sides of the world. Here the
two principal American orogenies, Nevadan and Agassiz, turn out to be recognizable on exactly the same horizons. Hence, despite the flat contradiction by Krejci-Graf (1950, p. 120), the first of Stille’s three propositions, as enumerated above, seems valid for the Jurassic.

To preclude the implication that an orogeny called ‘world-wide’ should have occurred everywhere, it would be as well to rephrase proposition 1 to read: ‘Orogenies are episodic and tend to occur at the same time in widely-separated parts of the world’.

As to proposition 2: inspection of the table on p. 634 shows another remarkable correspondence between the three main transgressions in North and South America, the Middle Bajocian, Lower Callovian, and Lower Kimeridgian. Correspondence between these two regions could be greater than appears from the table, because the Hettangian and Tithonian transgressions of South America could not be recorded in the Western Interior of the United States for the good reason that the region had been put out of reach of the sea by uplifts.

Transgressions at the same periods certainly took place in many parts of the Old World also: notable examples are Middle Bajocian transgression in Western Australia; Lower Callovian transgressions in Russia and Arctic regions; Lower Kimeridgian transgressions in Algeria, Arabia, the Middle East, and many parts of Europe. Synchronism is much less striking, however, because there were so many more epeiric than orogenic movements. It appears as though almost every stage, or even substage, is transgressive somewhere; though in some places it is difficult to make the needful distinction (pointed out by Stille) between a true marginal transgression and a discordance or mere disconformity due to immediately preceding localized movements. Nevertheless, proposition 2 can fairly be stated as follows: 2. ‘Epeiric movements were more numerous than orogenic, but the principal transgressions can be recognized at the same horizons in many widely separated parts of the world’.

The third proposition, dealing with the relations between orogenic and epeiric movements, was discussed at length by Stille, and his conclusions as to the invalidity of Haug’s ‘law’ are irrefutable. Owing to the advocacy of Dacqué in two authoritative papers (1910, 1911), in which he made Lemuria (the eastern half of Gondwanaland) the test case to prove Haug right, I have examined the evidence of the Middle Jurassic transgressions surrounding the Indian and Pacific Oceans with particular care and it seems worth stating the results, since they emphatically support Stille’s rejection of Haug’s ‘law’.

Dacqué, in confirmation of Haug’s ideas, after marshalling all the evidence then available, stated that ‘the greater part of the geosyncline surrounding Lemuria experienced a regression or shallowing of the sea at the end of the Lias or beginning of the Bajocian; and corresponding to this there was a simultaneous transgression over the continental margins’ (1910, p. 166). The same result was arrived at for the circum-Pacific geosynclines and their borderlands (1911, p. 494).
Certainly the Bajocian and Bathonian faunas seem to be absent from the Papuan geosyncline in central and SE. New Guinea, New Caledonia and New Zealand, and also (with minor exceptions) in Japan, but there is plenty of sediment in which they may yet be found, and the faunas are present where these geosynclines meet the Tethys in Indonesia, which is nearest to the transgressive Middle Bajocian of Western Australia. For the rest of the vast length of these western Pacific geosynclines there is no bordering continent with marine marginal Jurassics now above sea, so it is impossible to say whether or not there was a transgression at this time over adjoining continental land. At any rate none reached the enclosed basin of east Australia.

On the eastern side of the Pacific the position is clear. The Middle Bajocian transgression over vast areas in the Western Interior states and Canada, already often mentioned, synchronizes perfectly in the Pacific coast geosyncline with Middle Bajocian which is the thickest in the world. No other interpretation is possible than that transgression over the Western Interior was going on simultaneously with extremely rapid subsidence in the Pacific coast geosyncline. An eleven-page analysis of North American Jurassic stratigraphy in the state of knowledge in 1911 led Dacque to the conclusion that it confirms Haug's 'law': but in fact it contradicts it absolutely.

Similarly in the enormously thick geosynclinal series of the Caucasus, the Toarcian and Bajocian are particularly well represented, whereas according to Haug's 'law' they should be regressive there. The volcanic developments in the southern Caucasus merely denote geosynclinal mobility.

The single unit 'Middle Jurassic', used by Haug and Dacque, is, of course, much too crude. The transgressions over various continental areas within the Middle Jurassic were by no means simultaneous (as indeed Haug realized: 1900, p. 701). For instance, in Western Australia the transgression over lake beds and crystalline basement was Middle Bajocian, but in Transbaikal, on the edge of Angaraland, the Lias sea was there already, and although both Lower and Upper Bajocian are present, Middle Bajocian ammonites have so far not been reported. In Madagascar, East Africa and central Arabia the transgression over the African shield was early Toarcian (Bouleiceras beds) and marine Bajocian merely follows on. In Cutch, Tunisia, Egypt (Suez) and Burma, the transgression was Bathonian, and probably late Bathonian. These various transgressions, therefore, were not synchronous with an alleged regression in the geosynclines 'at the end of the Lias or beginning of the Bajocian'.

Regressions from continental margins being marked mainly by negative evidence (absence of expected faunas, which may be due to various causes), they are less satisfactory to deal with than transgressions. It is therefore preferable, indeed usually unavoidable, to proceed from the transgressions, and to enquire how they are integrated with the signs of orogenic movement within the mobile belts (table 27, p. 634). Accordingly, from the evidence
presented by the Jurassic system, the third proposition (p. 638) may be restated as follows: 3. 'Orogenies within the mobile belts do not synchronize with transgressions outside the mobile belts'. Rather, the transgressions tend to follow orogenies. Table 27 shows that the Callovian transgression is an exception, and this prompts enquiry whether there was not somewhere a Bathonian orogeny still to be discovered? Perhaps the 'Matmatian' folding in southern Tunisia (p. 282) may turn out to be of this age. The Bathonian is missing or peculiar in facies in many parts of the world, and even where it is physically transgressive it is lithologically and palaeontologically in 'regressive facies' (Cutch, Burma, Egypt, S. Tunisia). There is here a paradox requiring explanation. Perhaps the transgressive beds (probably all late Bathonian) are merely precursors of the Callovian transgression.

Haug strove to find in the transgressions over continental areas accommodation for water expelled from the geosynclines by orogenic compression and uplift. Stille's conclusion, that the main mountain-building periods in geologic history were periods of regression outside the mobile belts, while obviously true, aggravates the problem if too many of the oceans are supposed to be continents, as on Haug's maps. Stille postulated 'asylums' for the regressed waters in deeps within the mobile belts. If, however, as was shown in Chapter 27 to be probable, the Pacific was an ocean much as now, all the water drained from the continental margins could be taken care of by modest depression of parts of the Pacific floor. The volume of water in the Pacific (it has more than half the water surface of the earth) is so huge that comparatively small movements of its floor could account for all the observed transgressions and regressions. That movements took place in the Pacific hemisphere as in the other hemisphere there is no reason to doubt. Tertiary to recent movement over large areas is proved by the coral reefs.

So far as our knowledge goes at present, it does not point to any master plan of universal, periodic, or synchronized orogenic and epeirogenic movements. The events were episodic, sporadic, not periodic. There was no 'pulse of the earth'.

Different regions of the earth had different histories, but some spasms in the mobile belts were great enough to affect very large areas. Perhaps a strong spasm in one part of a mobile belt would touch off others at points of weakness or mounting unbalance in distant parts of the globe. Movements under the huge water reservoir of the Pacific could have repeatedly caused world-wide changes of sea-level, but the effects of these would vary according to the relief in different parts of the world and might often be modified by local land movements.

It appears that tectonic events were controlled by magmatic and compressional processes which went forward with ever-shifting emphasis in both time and place, as the crust of the earth gradually adapted itself to the shrinking interior.
### Table 28. — Dates of Named Diastrophic Episodes

<table>
<thead>
<tr>
<th>Epoch</th>
<th>Event</th>
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<tbody>
<tr>
<td>Upper Valanginian</td>
<td>Hils phase</td>
</tr>
<tr>
<td>Lower Valanginian</td>
<td>Diablan orogeny</td>
</tr>
<tr>
<td>Berriasian</td>
<td>Osterwald phase</td>
</tr>
<tr>
<td>Upper Tithonian/Purbeckian</td>
<td>Nevadan orogeny</td>
</tr>
<tr>
<td>Middle Tithonian/Portlandian</td>
<td>Late Cimmerian</td>
</tr>
<tr>
<td>Lower Tithonian/Upper Kimmeridgian</td>
<td>(= Yenshanian)</td>
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<td>Middle Kimmeridgian</td>
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EXPLANATIONS OF PLATES 31-46

Illustrations of the principal zonal index ammonites of the Jurassic, mainly from the type specimens.

Plates 31-41, Hettangian to Portlandian of the North-west European province.
Plate 42, Oxfordian and Kimeridgian of the Tethys.
Plates 43-44, Tithonian of the western Tethys.
Plates 45-46, Volgian of Russia.

(20 of the 95 species here figured are from photos reproduced from my Jurassic System in Great Britain, 1933, by kind permission of the Oxford University Press.)

The 'Opinions' referred to are decisions of the International Commission on Zoological Nomenclature, published during 1953-5 in their Bulletin, upon problems of nomenclature submitted to them by the author with the object of protecting and stabilizing the names of zonal index ammonites.
PLATE 31

HETTANGIAN AND SINEMURIAN

1. 

Euasteroceras turneri (Sowerby), lectotype designated by Buckman, 1898. (British Mus.). Alluvium ex Glacial Drift, Wymondham Abbey, Norfolk. Type species of the genus Euasteroceras Donovan, 1953. ×0·66.

2. Asteroceras obtusum (Sowerby), chorotype after Arkell (1933, pl. xxx, fig. 2). Charmouth, Dorset. The holotype is lost. (For the genus Asteroceras Hyatt, 1866, see Opinion 324.) ×0·8.

3. Arnioceras semicostatum (Young & Bird), ? holotype, after Buckman (1918, Type Am. ii, pl. CXII). Robin Hood's Bay, near Whitby, Yorks. (Whitby Mus.). Ventral view of another specimen after Hyatt. (For the genus Arnioceras Hyatt, 1867, see Opinion 307.) ×1·0.

4. Arietites bucklandi (Sowerby), chorotype after Arkell (1933, pl. xxx, fig. 5). Keynsham, Somerset. Type species of the genus Arietites Waagen, 1869. (Opinion 305). ×0·15.

5. Schlotheimia angulata (Schlotheim), lectotype designated by Lange, 1951, after Lange (1951, pl. i, fig. 2). Probably from Wellersen near Eimbeck, Saxony. (Schlotheim Coll., Geol. Inst. Berlin). Type species of the genus Schlotheimia Bayle, 1878 (objective synonym Scamnoceras Lange, 1924). (Opinion 323.) ×1·0.

6. Schlotheimia angulata (Schlotheim), chorotype after Lange (1951, pl. i, fig. 5). Oldentrup, Saxony. ×1·0.

7. Psiloceras planorbis (Sowerby), lectotype now designated, Watchet, Somerset. Crushed in a shale. (British Mus.). Type species of the genus Psiloceras Hyatt, 1867, designated by Spath, 1924. (Opinion 324.) ×1·0.

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1. *Pleuroceras spinatum* (Bruguière), after Arkell (1933, pl. xxxi, fig. 1). Stoke-sub-Hamdon, near Ilchester, Somerset. Type species of the genus *Pleuroceras* Hyatt, 1867, designated by Fischer, 1882. (Objective synonym *Palto­pleuroceras* Buckman, 1898.) (Opinion 324.) ×1·0.

2. *Amaltheus margaritatus* (Montfort?) auct., after Arkell (1933, pl. xxxi, fig. 2). South Petherton, Somerset. Type species of the genus *Amaltheus* Montfort, 1808. ×0·8.

3. *Prodactylioceras davoei* (Sowerby), topotype, Charmouth, Dorset, after Arkell (1933, pl. xxxi, fig. 3). The holotype is lost. Type species of the genus *Prodactylioceras* Spath, 1923. (Synonym *Paralytoceras* Frebold, 1922, non Frech, 1902.) ×0·8.

4. *Tragophylloceras ibex* (d'Orbigny), after Arkell (1933, pl. xxxi, fig. 4). Branch Huish, near Radstock, Somerset. ×1·0.

5. *Echioceras raricostatum* (Zieten), holotype after Zieten (1830, pl. xiii, fig. 4). ?Boll, Württemberg. Type species of the genus *Echioceras* Bayle, 1878. (Opinion 324.) ×1·0.

6. *Oxynoticeras oxynotum* (Quenstedt), after Arkell (1933, pl. xxx, fig. 1). Stone-house, near Stroud, Glos. Type species of the genus *Oxynoticeras* Hyatt, 1875. ×1·29.

7. *Uptonia jamesoni* (Sowerby), after Arkell (1933, pl. xxxi, fig. 6). Paulton, Somerset. The holotype is lost. Type species of the genus *Uptonia* Buckman, 1898. ×0·78.

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PLATE 33
TOARCIAN

1. Pleydellia aalensis (Zieten), holotype after Zieten (1830, pl. xxviii, fig. 3). Lias of Aalen, Württemberg. ×1.0.

2. Lytoceras (Pachylytoceras) jurense (Zieten), after Quenstedt (1885, pl. 47, fig. 2), copied from a drawing by Zieten. Probably from Uhrweiler, Alsace. ×0.90.

3. Hildoceras bifrons (Bruguière), topotype after Arkell (1933, pl. xxxii, fig. 3). Whitby, Yorks. (Neotype was figured by Buckman, 1918, Type Am. ii, pl. cxiv.) Type species of the genus Hildoceras Hyatt, 1867. ×1.0.

4. Dactylioceras commune (Sowerby), lectotype now designated, Whitby, Yorks. The aperture is carved as a snake’s head. (British Mus.). ×1.0.

5. Harpoceras falcifer (Sowerby), holotype, Ilminster, Somerset. (British Mus.) Type species of the genus Harpoceras Waagen, 1869. (Opinion 303.) ×1.0.

6. Dactylioceras tenuicostatum (Young & Bird), chorotype after Arkell (1933, pl. xxxii, fig. 6). Whitby, Yorks. ×0.8.
1. *Witchellia laeviuscula* (Sowerby), lectotype designated by Roman, 1938, Inferior Oolite, Dundry, Somerset. (British Mus.) Type species of the genus *Witchellia* Buckman, 1889. $\times 1.0$.

2. *Sonninia sowerbyi* (Sowerby), holotype, Inferior Oolite, Dundry, Somerset. (Bristol City Mus.) $\times 1.0$.

3. *Ludwigia murchisonae* (Sowerby), holotype, Inferior Oolite, Holme, near Portree, Isle of Skye. (British Mus.) Type species of the genus *Ludwigia* Bayle, 1878, designated by H. Douvillé, 1879. $\times 0.34$.

4. *Graphoceras concavum* (Sowerby), after Arkell (1933, pl. xxxiii, fig. 3). Inferior Oolite, near Sherborne, Dorset. The holotype (British Mus.) from the Inferior Oolite between Ilminster and Yeovil, Somerset, has been refigured by Buckman, 1887, Mon. Inf. Oolite Am., pl. ii, figs. 6, 7. $\times 0.8$.

5. *Tmetoceras scissum* (Benecke), holotype after Benecke (1865, pl. vi, fig. 4). Cape San Vigilio, Lake Garda, Southern Alps. Type species of the genus *Tmetoceras* Buckman, 1892. $\times 0.7$.

6. *Leioceras opalinum* (Reinecke?), after Quenstedt (1849, pl. vii, fig. 10). Reinecke's type is lost and his figure is unrecognizable. Quenstedt's fig. 10 is therefore 'regarded as the arbiter of what is *opalimus*' (Buckman, 1899, Mon. Inf. Oolite Am., Suppl., pp. xxxiv-v, xli). Teufelsloch, near Boll, Württemberg. Type species of the genus *Leioceras* Hyatt, 1867, designated by Buckman, 1887. See G. R. Lepsius, Beitr. Kenntniss Juraformation Unter-Elsass (Leipzig, 1875). $\times 1.0$. 

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MIDDLE AND UPPER BAJOCIAN

1. *Parkinsonia parkinsoni* (Sowerby), lectotype* designated Buckman, 1908, Inferior Oolite, near Yeovil, Somerset. (British Mus.) Type species of the genus *Parkinsonia* Bayle, 1878, designated by H. Douvillé, 1879. $\times 0.54$.

2. *Garantiana garantiana* (d'Orbigny), lectotype now designated, St Vigor, Calvados. (d'Orbigny Coll., Paris, no. 2149C; photos from plaster cast.) Type species of the genus *Garantiana* Masc, 1907. (Opinion 324.) $\times 0.68$.

3. *Stephanoceras humphriesianum* (Sowerby), lectotype* designated Buckman, 1908, Inferior Oolite, Sherborne, Dorset. (British Mus.) Type species of the genus *Stephanoceras* Waagen, 1869, designated by Buckman, 1898. (Opinion 324.) $\times 0.57$.

4. *Teloceras blagdeni* (Sowerby), holotype, Inferior Oolite, Sherborne, Dorset. (British Mus.) Type species of the genus *Teloceras* Mascke, 1907. $\times 0.40$.

5. *Otoites sauzei* (d'Orbigny), original figure from d'Orbigny (1846, pl. 139). France, locality not specified. There is no specimen agreeing with this in the d'Orbigny Collection. (Since this plate was printed a neotype has been chosen and figured by Westermann, 1954, p. 89.) Type species of the genus *Otoites* Mascke, 1907. $\times 0.70$.

6, 7. *Strenoceras subfurcatum* (Schlotheim), two syntypes in the Schlotheim Collection, Berlin, after Bentz (1928, pl. 14, figs. 1, 2b). Subfurcatus-Schichten, Auerbach, Bavaria. Fig. 6 now designated lectotype. $\times 1.0$

* The figuring of these specimens only, under the title 'Type specimens in the Sowerby Collection', is here regarded as tantamount to designation of lectotypes.
1. *Oppelia* (*Oxycerites*) *aspidoides* (Oppel), holotype after Oppel (1862, pl. 47, fig. 4). Nipf. near Bopfingen, Württemberg. Type species of the subgenus *Oxycerites* Rollier, 1909. (Opinion 324.) \( \times 0.50. \)

2. *Clydoniceras discus* (Sowerby), after Arkell (1933, pl. xxxv, fig. 2). Lower Cornbrash, South Brewham, Somerset. (Oxford Univ. Mus.) The holotype, figured Arkell, 1951, pl. ii, fig. 2 (Lower Cornbrash, Bedford) is worn and poorly preserved. Type species of the genus *Clydoniceras* Blake, 1905. \( \times 1.0. \)

3. *Tulites subcontractus* (Morris & Lycett), lectotype designated by Buckman, 1921. Great Oolite, Minchinhampton, Glos. (Geol. Survey Mus., London.) \( \times 0.72. \)

4. *Procerites* (*Gracilisphinctes*) *progracilis* Cox & Arkell, holotype. (*Am. gracilis* J. Buckman non Miinster). Stonesfield Slates, Minchinhampton Common, near Cheltenham. (Manchester Mus.) Type species of the subgenus *Gracilisphinctes* Buckman, 1920. \( \times 0.42. \)

5. *Oppelia* (*Oxycerites*) *fallax* (Guéranger) (=*fusca* auct.), after Arkell (1933, pl. xxxv, 5). Basal Fuller's Earth, Broad Windsor, Dorset. (Opinion 324.) \( \times 1.0. \)

6. *Zigzagiceras zigzag* (d'Orbigny), Zigzag Bed, north Dorset (probably Broad Windsor). (Oxford Univ. Mus.) Type species of the genus *Zigzagiceras* Buckman, 1902. \( \times 0.76. \)
PLATE 37

LOWER AND MIDDLE CALLOVIAN

1. Reinekeia anceps (Reinecke). Gammelshausen, Württemberg. Tübingen Geol. Inst. Type species of the genus Reinekeia Bayle, 1878. ×2·0.

2. Erymnoceras coronatum (Bruguière, d'Orbigny), as interpreted by Jeannet, 1951. Ironstone, Herznach, Switzerland, J. H. Callomon Coll., 1953, now Sedgwick Mus., Cambridge. Type species of the genus Erymnoceras Hyatt, 1900. ×0·37.

3. Sigaloceeras calloviense (Sowerby), lectotype designated Arkell, 1933, Kellaways Rock, Kellaways, Wilts. (British Mus.) Type species of the genus Sigaloceeras Hyatt, 1900. (Opinion 324.)

4. Proplanulites koenigi (Sowerby), lectotype designated Buckman, 1921, Kellaways Clay, [Rampisham?], Dorset. (British Mus.) (see Buckman, 1921, Type Am. iii, p. 36). ×1·0.

5. Kosmoceras (Gulielmites) jason (Reinecke), topotype, inner whorls, after Buckman (1924, Type Am. v, pl. DIII). Gammelshausen, Württemberg. (Alte Akademie, Munich.) (For the genus Kosmoceras see Opinion 303.)

PLATE 38

UPPER CALLOVIAN AND LOWER OXFORDIAN

1. Cardioceras cordatum (Sowerby), lectotype designated by the International Commission on Zoological Nomenclature, Opinion 235; after Arkell (1946, pl. xlviii, fig. 1). Lower Calcareous Grit, Seend district, Wilts. (British Mus.) Type species of the genus Cardioceras Neumayr & Uhlig, 1881. \( \times 1^{\circ} \).

2. Cardioceras (Scarburgiceras) praecordatum R. Douville, neotype designated by Arkell, 1941, after R. Douville (1913, pl. vii, fig. 7). Villers, Normandy. (Synonyms douvillei Maire, praemartini Spath.) \( \times 1^{\circ} \).

3. Cardioceras (Scarburgiceras) scarburgense (Young & Bird), holotype after Arkell (1939, pl. x, fig. 1). Oxford Clay, Scarborough, Yorks. (Whitby Mus.) Type species of the subgenus Scarburgiceras Buckman, 1924. \( \times 1^{\circ} \).

4. Quenstedtoceras (Pavloviceras) mariae (d'Orbigny), lectotype designated Buckman, 1913, after Arkell (1939, pl. xi, fig. 4). Villers, Normandy. D'Orbigny Coll., Paris. (From plaster cast.) (For the genus Quenstedtoceras see Opinion 324.) \( \times 1^{\circ} \).

5. Creniceras renggeri (Oppel). 'Renggeri marls', Oxford Clay, Woodham Pit, Bucks; after Arkell (1939, pl. ix, fig. 18). The holotype, figured by Sowerby from near Weymouth, is lost. Type species of the genus Creniceras Munier-Chalmas, 1892. \( \times 1^{\circ} \).

6. Quenstedtoceras (Lamberticeras) lamberti (Sowerby), topotype, Oxford Clay, Tidmoor Point, Weymouth. Author's Coll. Type species of the subgenus Lamberticeras Buckman, 1920. (Objective synonym Bourkelamberticeras Buckman, 1920.) (Opinion 324.) \( \times 1^{\circ} \).

7. Peltoceras athleta (Phillips), neotype, after Spath (1931, reproduced in Arkell, 1933, pl. xxxvii, fig. 7). Hackness Rock, Scarborough, Yorks. (British Mus.) Type species of the genus Peltoceras Waagen, 1871, designated by Schindewolf, 1925. \( \times 0.85 \).

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1. *Perisphinctes (Perisphinctes) cautisnigrae* Arkell, holotype, after Arkell (1935, pl. i, fig. 1). Trigonia clavellata Beds, Corallian Beds, near Osmington, Dorset. (British Mus.) \( \times 0.17 \).

2. *Ringsteadia pseudocordata* (Blake & Hudleston), holotype, after Buckman (1925, Type Am., v, pl. DXL). Ironstone, top of Corallian Beds, Westbury, Wilts. (Geol. Surv. Mus., London.) \( \times 0.23 \).

3. *Perisphinctes (Perisphinctes) variocostatus* (Buckland), holotype, after Arkell (1947, pl. lxxvi, fig. 3). Drift or Ampthill Clay, near Bedford. (Oxford Univ. Mus.) Type species of the genus *Perisphinctes* Waagen, 1869. (Opinion 303.) \( \times 0.25 \).

4. *Decipia decipiens* (Sowerby), holotype, after Arkell (1937, pl. F, fig. 2). Drift ex Ampthill Clay. (British Mus.) Type species of the genus *Decipia* Arkell, 1937. \( \times 0.59 \).

5. *Perisphinctes (Arisphinctes) plicatilis* (Sowerby), holotype, after Arkell (1939, pl. xxix, fig. 1). Berkshire Oolite Series, Corallian Beds, Dry Sandford or Marcham, Berkshire. (For the subgenus *Arisphinctes* see Opinion 306.) \( \times 0.45 \).
1. *Subplanites (Virgatosphinctoides) wheatleyensis* (Neaverson), holotype after Neaverson (1925, pl. i, fig. 1). Wheatley, near Oxford. (British Mus.) Type species of the subgenus *Virgatosphinctoides* Neaverson, 1925. ×0·57.

2. *Gravesia gravesiana* (d'Orb.), lectotype designated by Pavlow & Lamplugh, 1892, from Palaeontologia Universalis, no. 178. Near Auxerre, Yonne, France. Type species of the genus *Gravesia* Salfeld, 1913. ×0·68.

3. *Rasenia cymodoce* (d'Orb.), lectotype designated by Tornquist, 1896, the original figure from d'Orbigny (1850, pl. 202, fig. 3). ×1·0.

   (It is believed that, like so many of d'Orbigny's types, the original specimen is not in the collection and that the alleged lectotype figured in Palaeontologia Universalis, no. 55, and reproduced in my Jurassic System in Great Britain, pl. xxxix, fig. 4, belongs to another species; it appears to be a *Triozites* of the Baylei Zone.)

4. *Rasenia (Rasenioideae) mutabilis* (Sowerby), holotype, Horncastle, Lincolnshire. (British Mus.) ×1·0.

5. *Pictonia baylei* Salfeld, holotype, the original figure from Bayle (1878, pl. lxvi, fig. 1). Cap de la Hève, Le Havre. (Application has been made to stabilize *P. baylei* as type species of the genus *Pictonia* Bayle, 1878; Bull. Zool. Nomencl. 1951, vol. 2, parts 6/8, p. 178.) ×0·62.

6. *Aulacostephanus pseudomutabilis* (de Loriol), lectotype designated by Durand, 1932; the original figure from d'Orbigny (1850, pl. 214, figs. 1 and 2). No type specimen resembling these figures is in the d'Orbigny Collection. Type species of the genus *Aulacostephanus* Tornquist, 1896. (Opinion 302.) ×0·66.
KIMERIDGIAN AND PORTLANDIAN

1. *Titanites giganteus* (Sowerby), holotype after Sowerby (1816, vol. ii, pl. 126). Portland Stone, Chicksgrove Quarry, Tisbury, Wilts. The holotype was said to be 2 ft. 3 ins. in diameter and is lost. \( \times 0.96 \).

2. *Glaucolithites gorei* (Salfeld), holotype after de Loriot (1874, pl. ii, fig. 1). Wimille, Boulonnais. (Objective junior synonym *Perisphinctes pellati* Lewinski, 1923.) (The whorl-section is deceptive owing to crushing, and so is not reproduced here.) \( \times 0.38 \).

3. *Zaraiskites albani* (Arkell), holotype, Arkell Coll., Oxford University Museum (figd. Arkell, 1935, pl. 26, fig. 2). Emmet Hill Marls, Portland Sand, St Albans Head, Dorset. (Type species of the genus *Pro galbanites* Spath, 1936.) \( \times 1.0 \).

4. *Pavlovia pallasioides* (Neaverson), holotype after Neaverson (1925, pl. iii, fig. 5). Hartwell Clay, Hartwell, near Aylesbury, Bucks. (Geol. Survey Mus., London.) \( \times 0.76 \).

5. *Pavlovia rotunda* (Sowerby), topotype after Neaverson (1925, pl. i, fig. 6). Rotunda Nodules, Chapmans Pool, Dorset. (British Mus.) The holotype (in the British Museum) is a waterworn quarter-whorl, not worth figuring. \( \times 0.64 \).

6. *Pectinatites pectinatus* (Phillips), topotype, neotype, after Arkell (1933, pl. xi, fig. 5). Shotover Grit Sands, Sandy Upper Kimeridge, Shotover Hill, Oxford. (Oxford Univ. Mus.) The holotype is lost. Type species of the genus *Pectinattites* Buckman, 1922. \( \times 0.5 \).
TETHYAN OXFORDIAN AND KIMERIDGIAN

1. *Gravesia gigas* (Zieten), holotype after Zieten (1830, pl. xiii, fig. 1). Riedlingen on the Danube. $\times 0.14$.

2. *Hybonoticeras beckeri* (Neumayr), lectotype designated by Spath, 1925, after Neumayr (1873, pl. 38, fig. 3). Immendingen, Baden. $\times 0.62$.

3. *Streblites tenuilobatus* (Oppel), holotype after Quenstedt (1849, pl. ix, fig. 16). Weissensteiner Steige. Type species of the genus *Streblites* Hyatt, 1900. $\times 1.0$.

4. *Aspidoceras acanthicum* (Oppel), lectotype designated by Roman, 1938, after Neumayr (1873, pl. 41). Tenuilobatus Zone, Thalmässing, Franconia. (Oppel Coll., Munich Mus.) $\times 0.35$.

5. *Epipeltoceras bimammatum* (Quenstedt), holotype after Quenstedt (1858, pl. 76, fig. 9). Lochen, Württemberg. Type species of the genus *Epipeltoceras* Spath, 1924. $\times 1.0$.

(Haug, 1910, Traité, p. 1049, replaced *bimammatus* as zonal index by *bicristatus*, on the assumption that they are synonyms. *Am. bicristatus* Blainville (1840) was published without figure, dimensions or locality, and since the description is inadequate and a search of the collections at Paris has failed to produce any types, the name should lapse. *Am. eugeniobicristatus* Raspail (1842) was well figured and can be seen from the figures to be a different species: less tumid and less strongly and distantly ribbed than *bimammatus*. I am indebted to the Centre d'Études et de Documentation Paléontologiques, Paris, for kind help with this matter.)

6. *Gregoryceras transversarium* (Quenst.), holotype, after Salfeld (1906, pl. xi, fig. 6). Birmensdorf, Switzerland. (Tübingen Geol. Inst.) Type species of the genus *Gregoryceras* Spath, 1924. $\times 1.0$.

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1. *Semiformiceras semiforme* (Oppel), lectotype now designated, after Zittel (1879, pl. 28, fig. 8). Monte Catria, Italy. \( \times 0.69 \).

2. *Neochetoceras steraspis* (Oppel), lectotype now designated, after Oppel (1863, pl. 69, fig. 1). Lithographic slates, Solnhofen. Type species of the genus *Neochetoceras* Spath, 1925. \( \times o \cdot 60 \).


4. *Anavirgatites palmatus* (Schneid), holotype after Schneid (1914, pl. viii, fig. 5). Neuburg Beds, Neuburg. This was named by Schneid as alternative index to his Ciliata Zone and is figured here because of the doubtful generic position of *ciliata* and ease of misidentification. \( \times o \cdot 50 \).

5. *Taramelliceras lithographicum* (Oppel), holotype after Oppel (1863, pl. 68, fig. 1). Lithographic slates, Solnhofen. \( \times 1.0 \).

6. *Lithacoceras ulmense* (Oppel), neotype after Schneid (1914, pl. iv, fig. 3), designated by Arkell, 1937. Lithographic slates, Eichstätt. Type species of the genus *Lithacoceras* Hyatt, 1900. \( \times 0.46 \).
1. *Berriasella calisto* (d'Orbigny), toptype, after Mazenot (1939, pl. iv, fig. 12), Berriasian, Apremont. The species also occurs in the Upper Tithonian. ×1·0.

2. *Berriasella privasensis* (Pictet), lectotype designated by Mazenot, 1939, after Mazenot (1939, pl. ii, fig. 3), Berriasian, Berrias. The species also occurs in the Upper Tithonian. Type species of the genus *Berriasella* Uhlig, 1905, designated by Roman, 1938. ×1·0.

3. *Berriasella delphinensis* (Kilian), holotype, after Mazenot (1939, pl. vi, fig. 15). Upper Tithonian, Claps-de-Luc. ×1·0.

4. *Protacanthodiscus chaperi* (Pictet), lectotype designated by Mazenot, 1939, after Mazenot (1939, pl. viii, fig. 7). Upper Tithonian, Aizy. ×1·0.

5. *Virgatosphinctes transitorius* (Oppel), lectotype now designated, after Zittel, 1868, pl. 22, fig. 1. Upper Tithonian, Stramberg. ×0·55.
1. *Virgatites virgatus* (von Buch), holotype after von Buch (1830, pl. viii, fig. 1). Black shales at Karashovo (Koroshovo) on the River Moskva, 2 leagues above Moscow. Type species of the genus *Virgatites* Pavlow, 1892, designated by R. Douvillé, 1910. (Objective synonym *Euvirgatites* Lewinski, 1923.) ×2/3.

2. *Virgatites stschukinensis* (Michalski) (lectotype Michalski’s pl. vi, fig. 8, now designated), figured to show the virgatotome style of ribbing photographically, and also the suture. Moscow district. (Geol. Survey Mus., London.) ×1·0.

3. *Zaraiskites scythicus* (Vischniakoff), lectotype now designated, after Vischniakoff (1882, pl. iii, fig. 1), Mniovniki, near Moscow. Genus *Zaraiskites* Semenow, 1898 (objective synonym *Provirgatites* Lewinski, 1923). ×0·56.

4. *Dorsoplanites dorsoplanus* (Vischniakoff). Ventral view of imperfect lectotype now designated, after Vischniakoff (1883, pl. i, fig. 5), ×2/3, and side view of a more complete specimen after Michalski (1890, pl. xi, fig. 2). ×0·58.

The lectotype from Tatarovo. Type species of the genus *Dorsoplanites* Semenow, 1898, designated by Roman, 1938 (objective synonym *Polytosphinctes* Schindewolf, 1925).
PLATE 46

LOWER AND UPPER VOLGIAN

1. *Riasanites rjasanensis* (? Lahusen, 1883) Nitkin; the first figures, after Nitkin (1888, pl. i, fig. 1). Ryazan. Type species of the genus *Riasanites* Spath, 1923. $\times 1.0$.

2. *Craspedites (Kachpurites) fulgens* (? Trautschold, 1861), after Nikitin (1881, pl. vi, fig. 48). Kamenik on the Upper Volga. Type species of the subgenus *Kachpurites* Spath, 1923, designated by Spath, 1924. $\times 1.0$.

3. *Craspedites nodiger* (Eichwald, 1865-8), after Nikitin (1884, pl. v, fig. 19). Kotelniki, near Moscow. $\times 2/3$.

4. *Craspedites subditus* (Trautschold) (= *Am. koenigi* d'Orb. non Sow.), after d'Orbigny (1845, pl. 35, figs. 3, 4). Koroshovo, on the Moskva, above Moscow. $\times 1.0$.

5. *Lomonossovella [Titanites?] blakei* (Pavlow), holotype, after Pavlow (1889, pl. ii, fig. 4). Mnionviki, near Moscow. $\times 1.0$.

6. *Epivirgatites nikitini* (Michalski), lectotype now designated, after Michalski (1890, pl. xii, fig. 5). Kashpur on the Volga. Type species of the genus *Epivirgatites* Spath, 1923, designated by Spath, 1924. $\times 0.67$.

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The only authors indexed are the pioneers. Alphabetical lists of authors will be found in the bibliography, pp. 643-757.

Accepted zones are not indexed. For lists see tables 1-3, pp. 10-12.

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