INTEGRATED BIOSTRATIGRAPHY AND PALAEOENVIRONMENT OF THE MIDDLE JURASSIC SEDIMENTS AT KULDHAR (JAISALMER), WESTERN INDIA

SREEPAT JAIN

ABSTRACT

Stratigraphically controlled new ammonite collections from the Middle Jurassic sediments of Kuldhar (Jaisalmer, western India) indicate a Late Bathonian-early Late Callovian age. Previous records by different authors of *Dhosaites primus* and *Perisphinctes* (Dichotomosphinctes) aff. *subbelenae* from the top of the section suggest an age straddling Early to early Middle Oxfordian. The present study, besides documenting a rich ammonite fauna from Kuldhar (66 specimens), also identifies seventeen lithologic beds recording 7 ammonite zones and 2 subzones. These biozones are correlated with those of the adjoining Kachchh basin (western India) and the standard ammonite zones of the European and Submediterranean provinces. Additionally, based on an integrated multi-proxy approach using occurrences of benthic foraminifers, ostracods, nannofossils, belemnites, and trace fossils, the palaeoenvironment of the Kuldhar section is inferred.

Keywords: Middle Jurassic, Ammonite biostratigraphy, Palaeoenvironment, Jaisalmer, India

INTRODUCTION

The Mesozoic sediments of the Jaisalmer Basin (Fig. 1) are characterized by the deposition of carbonate rocks of the Jaisalmer Formation that unconformably overly the sandstones of the Lathi Formation (Das Gupta, 1975; Garg and Singh, 1983; Jain, 2007) (Table 1). The Jaisalmer Basin witnessed transgression sometime in Late Bajocian as indicated by the presence of coral *Inastrea bernardiana* (Orbigny) occurring “100 m below beds yielding Early Callovian ammonites” (Pandey and Fürsich, 1994). These “Early Callovian ammonites” were recorded from the Kuldhar section (Fig. 1), exposed along the Masurdi River, near the ruined village of Kuldhar (Fig. 2).

The present contribution, based on new ammonite collections from Kuldhar (Fig. 2), records 7 ammonite zones and 2 subzones (Fig. 3). These are correlated with the biozones of the adjoining Kachchh Basin (western India) and the standard ammonite zones of the European and Submediterranean provinces (Table 2). Additionally, based on previously recorded occurrences of benthic foraminifers, nannofossils, ostracods, trace fossils and belemnites, palaeoenvironment of the Kuldhar section is inferred.

PREVIOUS STUDIES

Body fossil evidences from Kuldhar, until recently, have produced conflicting ages for the same sediments (Jain, 2007, 2008) with no illustrated record either of the ammonite fauna (except for Subfamily Reineckeanae; Cariou and Krishna, 1988) or of a detailed bed-by-bed stratigraphy. A comprehensive integrated faunal approach of co-occurring benthic foraminifers (Dave and Chatterjee, 1996), ostracods (Khosla et al., 2006), nannofossils (Rai and Garg, 2007), trace fossils (Fürsich et al., 1991) and ammonites is also lacking (Jain, 2007). Previous integrated approaches (foraminiferal-ammonite: Dave and Chatterjee, 1996; nannofossil-ammonite: Rai and Garg, 2007) are either anchored on alleged or misplaced age-diagnostic ammonite taxa or on sections that are studied only in part (for details see Jain, 2008) (Fig. 2). Even more, little consideration is given to the placement of important age-diagnostic ammonite taxa such as *Stivajiceras congner* [M] or *Macrocephalites triangularis* [M] (Dave and Chatterjee, 1996) which in the adjoinging Kachchh Basin (Fig. 1) are zonal indices indicating precise age (Callomon, 1993; Jain et al., 1996; Krishna and Ojha, 2000). Recently, Prasad (2006) studied the Kuldhar Member identifying 13 beds. However, except for his bottom 6 beds (beds 1-6), the remaining are hard to track. Additionally, Prasad’s contribution has large problems with its taxonomic work (Callomon, 2008) and consequently with its biostratigraphy. A critical analysis is done here.

Thus, this contribution attempts to identify, describe and illustrate a bed-by-bed collection of ammonites, and presents the first comprehensive multi-proxy approach in inferring the palaeoenvironment of the sediments exposed at the Kuldhar section (Fig. 2). Additionally, the erected ammonite biozones are correlated with the established biozones of the adjoining Kachchh Basin and globally with the standard Submediterranean and Subboreal ammonite biozones (Table 2).

THE STUDY AREA

The Kuldhar section (26° 52’ North 70° 47’ East), situated near the ruined village of Kuldhar (Fig. 2), along the Masurdi River (18 Km south-west of the city of Jaisalmer), has exposed 17 beds for a sediment thickness of 12.7 m (Fig. 3). These beds are divided into three broad lithologic units. The lower calcareous unit comprises beds 1-6 (3.1 m thick); middle argillaceous unit of beds 7-16 (7 m thick) with thin calcareous inter-beds of oolitic limestone, capped by a fine-grained sandstone body, and an upper gypsiferous unit with two thin micritic inter-beds (beds 17b and d), capped by 2.6 m of loose sediments (Fig. 3; Table 3).

The lower 3.1 m thick unit has a 0.5 m clean sandstone body followed by a 2.6 m thick fine grained calcareous bed comprising beds 2-6 (Fig. 3). Beds 3-5 are hardgrounds, heavily bioturbated and bioclastic in nature, forming a prominent platform-like relief next to the river bed (Fig. 2; Locality I). Beds 3 and 6 lack bioclastic elements and the former is conspicuous for its low angle cross bedding. Numerous bivalve borings characterize the top of beds 3 to 5. A horizontal fault runs at the top of bed 6 and possibly accounts for a few metres of stratigraphic gap (Fig. 2; Locality I).

The middle unit (beds 7-16) is made up of a 7 m thick argillaceous unit with thin oolitic and moderately bioturbated
Fig. 1. Middle Jurassic outcrops of western India. Geological map of Jurassic sediments exposed in and around Jaisalmer (A) and localities from the Kachchh basin (B).
micritic bands representing beds 9, 11 and 13. Bed 16 is a medium-grained sandstone body with its lower part cross-bedded, upper surface ripple-bedded and the middle part is shelly in nature with several prominent Zoophycos traces. Together, they form a +7 m physiographic high at Locality III (Fig. 2).

The upper unit (2.6 m thick) is composed of gypsiferous shales with thin inter-beds of fine-grained limestone beds, constituting bed 17, and capped by loose sediments (Locality IV, Fig. 3). Dave and Chatterjee (1996) noted 6 m of shales over this bed that contained *Dhosaites primus* at its top (from the top beds at Locality IV; Fig. 3). This is a significant find and extends the age of the Kuldhar Member to at least earliest Oxfordian. Prasad (2006) from an unknown locality in Kuldhar recorded the association of *Perisphinctes* (*Dichotomosphinctes*) aff. *subhelenae*, *Mayaites* (*Mayaites*) aff. *maya* and *Dhosaites elephantoides* from the top of the section and dated the sediments as Late Oxfordian (Fig. 3). In Kachchh and elsewhere, this association is dated as Early to early Middle Oxfordian. Prasad (2006) from an unknown locality in Kuldhar recorded the association of *Perisphinctes* (*Dichotomosphinctes*) aff. *subhelenae*, *Mayaites* (*Mayaites*) aff. *maya* and *Dhosaites elephantoides* from the top of the section and dated the sediments as Late Oxfordian (Fig. 3). In Kachchh and elsewhere, this association is dated as Early to early Middle Oxfordian (Krishna et al., 1996). Interestingly, the present study recorded a stratigraphically loose example of early Late Callovian *Collotia fraasi* (Oppel) [M] that has the same lithology and color (dirty yellow) as of the loose sediments overlying bed 17. However, due to its loose nature, its age reliability is low and based on previous studies mentioned above; an age straddling Early to early Middle Oxfordian is preferred for the top of the Kuldhar section. Pending, better constrained collections, a more refined age for these top sediments might be possible.

**EXISTING LITHO- AND BIOSTRATIGRAPHIC PROBLEMS**

The sections measured for the Kuldhar Member are as wide-ranging in their lithology as they are in their inferred ages (Fig. 2). Hence, an attempt was recently made to streamline the age of the lower sediments of this Member (Jain, 2007, 2008). This contribution attempts to streamline both the litho-and biostratigraphy of the middle and upper parts of this member. The stratigraphic framework is modified after Jain (2007) (Table 1).

Kalia and Chowdhury (1983), while describing their foraminiferal fauna from Kuldhar, provided the most comprehensive and accurate stratigraphic column of the Kuldhar Member. They measured seven sections (A-G) along the Masudri River (see top panel in Fig. 2 for their section localities). Section A is the only section that straddles the Bathonian-Callovian boundary beds (Jain, 2007, 2008; see top panel in Fig. 2) and at its lower part is overlain by non-fossiliferous coarse-grained calcareous sandstone bed of the Badabag Member (now part of the Jaisalmer Formation; Table 1). Later authors (Cariou and Krishna, 1988; Dave and Chatterjee, 1996; Khosla et al., 2006; Rai and Garg, 2007; Rai, 2009) only measured either one or a small combination of the sections given by Kalia and Chowdhury (1983; sections B-G; Fig. 2). Hence, their inferred ages remained Callovian (Cariou and Krishna, 1988; Dave and Chatterjee, 1996; Khosla et al., 2006; Rai and Garg, 2007). Fürsich et al. (1991), while describing the occurrence of hardgrounds in the Jurassic of Kachchh, were the only startigraphers who have accurately re-measured Section A (of Kalia and

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**Table 1:** Lithostratigraphy of the Jurassic sediments exposed in and around Jaisalmer area.

<table>
<thead>
<tr>
<th></th>
<th><strong>DAS GUPTA, 1975</strong></th>
<th><strong>GARG AND SINGH, 1983</strong></th>
<th><strong>JAIN, 2007</strong></th>
<th><strong>THIS STUDY</strong></th>
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<tr>
<td><strong>Tithonian</strong></td>
<td>BHADASAR FORMATION</td>
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<td>Mokal Mb.</td>
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<td><strong>Kimmeridgian</strong></td>
<td>BAISAKHI FORMATION</td>
<td>Rupsi Shale Member</td>
<td>Earliest Tithonian-Latest Oxfordian</td>
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<td>Rupsi Mb.</td>
<td>Baisakhi Mb.</td>
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<td><strong>Callovian-Oxfordian</strong></td>
<td>JAISALKER FORMATION</td>
<td>Kuldhar Member</td>
<td>Middle-Early Callovian</td>
<td>Middle Callovian-Late Bathonian</td>
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<td>Kulankar Member</td>
<td>Middle-Early Callovian</td>
<td>Middle Callovian-Late Bathonian</td>
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<td></td>
<td>Badabag Mb.</td>
<td>Amarsagar Member</td>
<td>Late-Middle Bathonian</td>
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<td>Fort Mb.</td>
<td>Limestone Member</td>
<td>Late-Middle Bathonian</td>
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<td>Joyan Mb.</td>
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<td>Hamira Mb.</td>
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<td><strong>Lias-Bathonian</strong></td>
<td>LATHI FORMATION</td>
<td>Thiat Mb.</td>
<td>Early-Middle Jurassic (in part)</td>
<td>Early-Middle Jurassic (in part)</td>
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<td>Odania Mb.</td>
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<td>Subboreal Province</td>
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<td>Subboreal Province</td>
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<td>Callovienae</td>
<td>Enodatum</td>
<td>Rota</td>
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<td>Cornutum</td>
<td>Grossouvre</td>
<td>Pseudopteroceras</td>
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<td>Waageni</td>
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<td>Terebratulina</td>
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Fig. 2. Correlation of the Kuldhar Member beds. The upper part shows the locality map of beds exposed along the Masuri River. Kuldhar village and the lower panel shows the correlation of sections identified by different authors from various localities. Kalia and Chowdhury (1981), along the Masuri River measured seven sections (A-G in bold). Also marked in the top panel are the present localities (I to IV) where ammonites were collected. Localities I at A. All redrawn sections in the lower panel have the same scale of 1 cm. A is modified after Dave and Chatterjee (1976). B is a composite section after Kalia and Chowdhury (1981). C: after Fursich et al. (2001). D: after Jain, 2007 and 2008 and E: section by Rai and Garg (2007) with their ammonoid sampling levels. Note that they did not measure the entire Kuldhar Member, but measured a section only from a vertical scarp on the western flank of the river bed from Locality I at B (left side of the fault) that overlies beds 5-6 of present work. Part of this section is well exposed further south and west of present Locality IV. Note that for Section E the ages assigned at the right hand side are from present study. Bold arrows in 2C indicate hardgrounds. Note that this figure illustrates yet another aspect of complexity generated by partial sections measured by different workers from diverse locations (localities) but referred to as their “Kuldhar section” areas. Also note that section A is most likely a combination of sections from localities I and IV, B of I and III, C of I and D of I and III. The Bathonian-Callovian boundary sediments lie only at locality I and on the eastern flank of the river bed marked by an elliptical area with hatched symbols (timestring) (A at Locality I).
Chowdhury, 1983) where the actual Bathonian-Callovian boundary lies (as demonstrated by Jain, 2007, 2008).

A more generalized and largely hard to trace (though often cited) lithosection is given by Cariou and Krishna (1988) documenting an important fauna of subfamily Reinekeinae Hyatt. This section could not be traced or correlated with any of the sections discussed here. It will not be discussed henceforth, though the importance of the fossil finds cannot be negated. Ephemeral floods could have wiped out these low-lying beds that were possibly once exposed at Localities II and III (Fig. 2). However, an attempt is made to correlate their (Cariou and Krishna, 1988) beds based on the contained fauna with those of the present work (Table 2). The lithosection by Dave and Chatterjee (1996) used for describing their foraminiferal fauna is based on a combination of sections B and C of Kalia and Chowdhury (exposed along the western flank of the river from Locality IV in Fig. 2). Although they measured only a part of the section, they inferred a Callovian age for the entire Kuldhar Member (Fig. 2). Similarly, Khosla et al. (2006), who only measured Section C, and Rai and Garg (2007) and Rai (2009) who measured only the sediments exposed on a vertical scrap south-west of Locality IV (Fig. 2E), erroneously considered the entire Kuldhar Member as Callovian resulting in large age discrepancy (Jain, 2008).

Recently, Prasad (2006) studied the Kuldhar Member in somewhat more detail and identified 13 beds spanning Early Callovian to Late Oxfordian (Fig. 3). Except for the bottom 6 beds (beds 1-6), the remaining beds are hard to track. Additionally, there are serious problems with his biostratigraphic and taxonomic work (Callamon, 2008). Overall,
EXPLANATION OF PLATE I

a-b. *Collotia fraasi* (Oppel) [M], bed 18, Locality IV, Fraasi Zone.
a. sample no. SJK/18/1, Lateral view;  
b. sample no. SJK/18/2, lateral view. Bar represents 1 cm. Specimens belong to the Kuldhar section.
this contribution (Prasad, 2006) lacks (a) a proper arrangement of the taxonomic description of species, (b) identification of phragmocone and body chamber stages, that are otherwise quite clear at places, and more importantly (c) most newly erected species are based on fragmented and moderate to poorly preserved specimens that lack comprehensive and updated taxonomic comparisons with co-occurring and coeval species from within (India) and outside the basin (global). A case in point is the total absence of comparison with coeval and similar species extensively described by Jana et al. (2005) from the adjoining Kachchh basin. The problems with taxonomic identification and subsequent age assignment for the fauna from beds 7 and 12 (Prasad, 2006) are particularly acute and are briefly discussed.

Prasad’s (2006) bed 7 (Fig. 3), dated as mid Early Callovian, has otherwise yielded a mixed fauna of Late Early to early Middle Callovian age including Macrocephalites formosus, M. subcompressus, M. flexuosus, Indosphinctes errans, I. rasticus, Subkossmatia obscura, Subgrossouvria morley-daviesi, S. sparsibullata, S. gudjinsiriensis (= S. gudjinsiriensis) and a new species of Eucycloceras, E. durgakoti.

The M. formosus specimen illustrated by Prasad (2006, p. 17, pl. 1, fig. 3; whorl section in pl. 19, fig. 5) from his bed 3 (= present beds 5-6) as mentioned in the text, is shown to have come from his bed 1 in his Fig. 3, and is quite intriguing also. Besides being poorly preserved, it shows negative allometry (U/D = 0.18 at 34 mm to 0.11 at 107 mm) whereas “typical” M. formosus displays the reverse; strong uncoiling of the umbilical seam with increasing shell diameter (Bhaumik et al., 1993, p. 170, fig. 5d). Prasad’s specimen may well be an intermediate form closely resembling the “inflated (so called chariensis) variant” of M. formosus (see Bhaumik et al., 1993, pl. 1, fig. 5). Such morphological variability in the formosus - chariensis group is well documented from the adjoining Kachchh basin (Bhaumik et al., 1993).

The Macrocephalites (Dolikephalites) flexuosus Spath (Prasad, 2006, p. 20, pl. 1, fig. 5) (= M. flexuosus Spath) is most likely a variant of the late Early Callovian Indonesian Macrocephalites keeuwensis Boehm [m] (Westermann and Callomon, 1988, pl. 12, figs. 1-5, non fig. 4). This Kuldhar specimen, on one hand, is an intermediate form between the sparsely ribbed Madagascan M. flexuosus (Collignon, 1958, pl. 18, fig. 77) and, on the other hand, with Spath’s (1928, pl. 8, fig. 3) and Subkossmatia obscura Spath (=Eucycloceras obscura var. obscura of Jana et al., 2005) illustrated by Prasad (2006, pl. 2, fig. 3), in the adjoining Kachchh basin (Spath, 1928-33; Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000) occurs with “typical” early Middle Callovian Sivajiceras kleidios (Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000).

Subgrossouvria morly-daveisi Spath is a “typical” early Middle Callovian form that succeeds both Reineckeia (Reineckeia) ances [M] and Sivajiceras kleidios [M] in the adjoining Kachchh basin and does not co-occur with any of the Macrocephalitids, known so far; the latter had already disappeared by this time (Spath, 1928-33; Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000).

Thus, based on the occurrence of several taxa and common faunal elements with the adjoining Kachchh basin and elsewhere (Westermann and Callomon, 1988; Bhaumik et al., 1993; Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000; Jana et al., 2006), it is safe to conclude that Prasad’s (2006) bed 7 yields a mixed assemblage of late Early to early Middle Callovian age and not of Early Callovian age as suggested (Prasad, 2006).

The next bed (bed 12 of Prasad, 2006) is similarly problematic. The bed is marked by the co-occurrence of otherwise “typical” Early Callovian Macrocephalites lamellosus morph aureus (Sowerby), “typical” early Middle Callovian Subkossmatia ramosa Spath, a late Early-Middle Callovian Subkossmatia cf. opis Sowerby and Subkossmatia flexicosta, a new species. However, Prasad (2006), assigned this bed a Late Callovian age. Interestingly, Macrocephalitids do not reach even the middle part of Middle Callovian and Subkossmatia has yet to be recorded from the later parts of

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**EXPLANATION OF PLATE II**

Specimens a-f, i are from the latest Bathonian bed 4, Locality I, Triangularis Zone.

**a-c. Macrocephalites triangularis** Spath [M], sample no. SJK/4/1,
   a. Lateral view;
   b. Apertural view;
   c. Lateral view (sample no. SJK/4/2);

**d-f. Macrocephalites formosus** (Sowerby) [M], sample no. SJK/4/3;
   d. Lateral view;
   e. Opposite Lateral view;
   f. Apertural view;
   i. Sivajiceras congener (Waagen) [M], sample no. SJK/4/6, Lateral view and

**g. Macrocephalites lamellosus** (Waagen) [m], sample no. SJK/4/4, Lateral view.

**h and j are from bed 5, Locality I, Madagascariensis Zone.**

**h. Macrocephalites cf. madagascariensis** (Sowerby) [M], sample no. SJK/5/1, Lateral view;

**j. Macrocephalites subcompressus** (Waagen) [m], sample no. SJK/5/2, Lateral view;

**g. Macrocephalites dimerus** (Waagen) [m], sample no. SJK/7/1, bed 7, slightly north (~70 m) Locality III, Dimerus-Transitorius-Opis Zone. Lateral view. Bar represents 1 cm. All specimens unless mentioned belong to the Kuldhar section.
Plate II

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Middle Callovian (Waagen, 1875; Spath, 1927-1933; Krishna and Westermann, 1985, 1987; Westermann and Callomon, 1988; Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000; Roy et al., 2006; Jain et al., 1996; Jain, 2007, 2008), let alone Late Callovian, as suggested by Prasad (2006). This suggests that similar to bed 7, the assemblage from bed 12 is also mixed up. Thus, based on the above discussion, it becomes imperative that an updated biostratigraphic and taxonomic work is urgently needed for the rich ammonite fauna yielded by the Kuldhar sediments. It is also equally important to address the implications of excessive splitting of species based on old taxonomic comparisons and subsequent erection of new ones on incomplete or badly preserved specimens (Prasad, 2006). These not only pose immense problems for evolutionary systematics but renders the otherwise well constrained and often age-diagnostic ammonite species and its distribution (used for global correlation) useless.

THIS STUDY

The present study is divided into three sections:

Section 1 erects biozones based on the present distribution of the ammonite fauna recorded from the Kuldhar section and correlates these with those of the adjoining Kachchh basin and the standard zones of the European and Submediterranean provinces.

Section 2 attempts to put forward the likely depositional palaeoenvironment for the Kuldhar sediments based on previous and present observations of the recorded macro- and microfauna including that of benthic foraminifers, ostracods, nannofossils, belemnites, and trace fossils.

Section 3 deals with a brief taxonomy of the present recorded specimens. Some common species that were also recorded by Prasad (2006) are reviewed.

Additionally, marker intervals in both the Jaisalmer and Kachchh basins are briefly mentioned to get a sense of the depositional realm of these two Jurassic basins within the western part of the Indian Subcontinent. Furthermore, this contribution also attempts to demonstrate that large morphological variability exists within a species (best demonstrated by the Jana et al., 2005 study based on Kadhchh samples) and that such variability does not necessarily require the erection of new species. Excessive splitting can undermine the otherwise excellent quality of the ammonite fauna and thus, complicate any meaningful biostratigraphic inter- and intra-basinal and provincial correlation.

SECTION 1

Biostratigraphic Correlation

The present study identifies 7 Zones and 2 subzones for the 17 beds (bed 2-18) exposed at the Kuldhar section, along the Masurdi River (Fig. 3). Bed 1 is unsiluriferous and belongs to the lower Badabag Member, now part of the Amarsagar Limestone Member of the Jaisalmer Formation (Table 1). This unit has already been dated as Late Bathonian based on the characteristic presence of genus Clydoniceras (Prasad et al., 2007). The succeeding beds (2-17) belong to the Kuldhar Member discussed herein. Beds 2-4 form the Triangularis Zone of Late Bathonian age and beds 5-6 belong to the Early Callovian Madagascariensis Zone. Both these zones, their fauna and the placement of the Bathonian-Callovian boundary have previously been discussed in detail (Jain, 2007, 2008) and will not be discussed here any further. For sake of brevity, the fauna is illustrated in Plate 2. Beds 7-10 constitute the Dimerus-Transitorius-Opis Zone of mid-to-late Early Callovian age and beds 11-13 form the larger Anceps Zone that includes the lower Anceps subzone (beds 10-12) and the upper Eucyclum subzone (bed 13) of early Middle Callovian age. This is succeeded by the Giganthea Zone (beds 14-16) of mid Middle Callovian age and the topmost Paramorphum Zone of latest Middle Callovian age. A loose sample of Collotia fraasi (Plate 1) from the top of the section indicates early Late Callovian age. Based on the presence of this form from this bed, it is tentatively assigned to represent the informal Fraasi Zone (Fig. 3).

Triangularis Zone

Beds 2-3 are devoid of ammonites and bed 4 has yielded Sivajiceras congener [M], Macrocephalites triangularis [M], M. formosus [M], L. lamellus [m], M. subcompressus [m] and Eutrephoceras sp. (Locality I in Fig. 2; for details see Jain, 2007, 2008).


Recently, the presence of M. formosus [M] from the same beds was reaffirmed by Prasad (2006) suggesting that this species is also long ranging as previously indicated by Prasad (1998; Jara; Fig. 1B) and Jain and Pandey (2000; Jumara; Fig. 1B) from Kachchh. Interestingly, M. formosus [M] has also been recorded from the late Early Callovian Gracilis Zone in France (Krishna and Cariou, 1990) (Table 2).

Prasad (2006) from his bed 1 (beds 1-3 of present work; Fig. 2) recorded three fragmentary and poorly preserved specimens of Macrocephalites aff. transitorius Spath (his Indoceratites aff. transitorius: 2006, p. 24, pl. 3, fig. 7 and pl. 4, figs. 2-3). However, these forms are considerably more compressed and evolve than the species they are assigned to; their fragmentary nature can at best merit their identification as a depressed species of Macrocephalites only. Similar forms are quite common in the Late Bathonian Patcham Formation of Jumara (Kachchh; Krishna and Westermann, 1987; Callomon, 1993; Jain and Pandey, 2000). Hence, pending more complete specimens, any species identification and subsequent reliable age assignment based on these fragmentary specimens should be considered with caution.

Madagascariensis Zone

Bed 5 has yielded Paracenoceras sp., Macrocephalites cf. madagascariensis [M] and M. subcompressus [m]. Cariou and Krishna (1988) recorded M. madagascariensis [M] and M. transitorius [M] from the same sediments. The succeeding bed 6, a thin 0.30 m thick oolitic limestone, is devoid of ammonites.

M. madagascariensis is widespread in the adjoining Kachchh basin occurring both in the Mainland (Jumara, Jara, Keera and Habo Domes; Fig. 1) as well as in the Island belt (Pachchhim Island) and assumes a zonal status within the Indo-Madagascaran province (Krishna and Westermann, 1987; Krishna and Cariou, 1990; Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000). In Kachchh, M. madagascariensis ranges from the subjacent Triangularis Zone to the succeeding Dimerus-Diadematus Zone at Jumara (Jain and Pandey, 2000 = Chrysoolithicus Zone of Krishna and Ojha, 1996 at Keera), but
its acme is within the intermediate Madagascariensis Zone (Krishna and Westermann 1985, 1987) of earliest Early Callovian age. M. madagascariensis has also been recorded from the Early Callovian sediments of Central Nepal (Gradstein et al., 1989) and France (Cariou 1980, 1984, Krishna and Cariou 1990, 1993). In England (Callomon 1988), M. verus Buckman (= M. macrophalus Zittel non Schlotheim), a form morphologically close to M. madagascariensis [M], ranges from the Verus Horizon (Keppleri subzone) to the Terebratus Horizon (Terebratus subzone) of the Herveyi Zone of Early Callovian age also (Table 2). Solitary Late Bathonian records of M. madagascariensis are also noted from Indonesia (Westermann and Cariou, 1988) and from the Triangularis Zone of Madagascar (Collignon, 1958).

Thus, in the present study, both beds 5-6 are included within the Madagascariensis Zone and dated as earliest Early Callovian (Jain, 2007, 2008). The strata above bed 6 are horizontally displaced and the contact between beds 6 and 7 is not clear and is depicted by a “Gap” (Fig. 3). Incidentally, a similar hiatus is also noted at Jumara (Kachchh) that represents the most expanded Callovian section in western India (Biswas, 1991; Jain and Pandey, 2000).

Dimerus-Transitorius-Opis Zone

This zone spans from beds 7 to 9 (Fig. 3) and is equivalent to beds 4 to 6 of Prasad (2006). The lower part of the calcareous shale facies of bed 7 has yielded Macrocephalites dimerus, Hecticoceras proximum, Collotia oxyptycha and Hecticoceratoideas cf. suborientalis and in the upper part Subkossmatia opis, Eucycloceras eucyclum and Choffatia transitoria (Locality II; Fig. 2).

M. dimerus [M] in Kachchh has a long range from late Bathonian to mid-Early Callovian and hence, is stratigraphically not very valuable (Krishna and Ojha, 1996; Jain and Pandey, 2000). However, the association of C. oxyptycha [m and H. proximum [M] is well-constrained and indicates a latest Early Callovian age (Krishna and Ojha, 1996; Jain and Pandey, 2000).

In Kachchh (at both Keera and Jumara Domes; Fig. 1) Subkossmatia opis [m] transgresses the Early/Middle Callovian boundary (Krishna and Ojha, 1996; Jain and Pandey, 2000). At Jara (Fig. 1), S. opis occurs in early Middle Callovian sediments and ranges the entire Anceps Zone of Middle Callovian age (from the Anceps to the Singulare subzones of the Anceps Zone; Prasad, 1998). Kanjilal (1974) from the Habo Dome (Kachchh; Fig. 1) recorded S. cf. opis from his bed 7 (Anceps Zone) of the Jhikhadi Member in association with Idiocycloceras sp., Reineckeia sp., Choffatia sp. and Eucycloceras eucyclum [M] and dated the assemblage as Middle Callovian. S. opis has yet to be recorded from the Island belt outcrops of the Kachchh basin and beyond the mid of Middle Callovian time period.

In Keera, E. eucyclum, S. opis and C. oxyptycha occur together in the latest Early Callovian subzones (Opis / Eucyclum; SIII Horizon; beds 120-131; Krishna and Ojha, 1996). This horizon (SIII) has also yielded Hecticoceras proximum and based on it, the subzone was correlated with the Proximum Horizon of the Submediterranean province (Table 2). H. proximum is an index of the Patina (Oxyptyca / Proximum) subzone of the Gracilis Zone of the Submediterranean province (Cariou, 1984; Krishna and Ojha, 1996; Table 2).

At Kuldhar, C. oxyptycha is restricted to bed 9 and is also associated with the first appearance of genus Indosphinctes (I. errans). In the Submediterranean province and in Kachchh (Cariou and Krishna, 1988), Indosphinctes occurs slightly early in the Laugieri subzone of the Gracilis Zone (Cariou and Krishna, 1988) (Table 2).

Thus, in Europe (Austrian Alps and France) as in Kachchh, Collotia oxyptycha is strictly localized at the top of Early Callovian sediments (Cariou, 1984; Cariou and Krishna, 1988; Jain and Pandey, 2000). The association of C. oxyptycha with H. proximum at Kuldhar, Jaisalmer further attests its localized nature. Hence, beds 7 to 9 are dated as latest Early Callovian.

The beds 7 to 9 of present work are equivalent to beds 4 to 6 of Prasad (2006) that have also yielded Macrocephalites chariensis and M. formosus. Both species in Kachchh span from the earliest Callovian Madagascariensis Zone to its nominal Formosus Zone of mid Early Callovian age (Bhaumik et al., 1995; Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000).

Anceps Zone

This zone includes beds 10 to 13 (Fig. 3). Two subzones are identified within these beds, the lower Anceps (beds 10-12) and the upper Eucyclum (bed 13). Bed 10 is devoid of ammonites. Bed no. 11 has yielded Reineckeia (R.) aniceps [M] in association with R. (R.) stuebeli [m], Subkossmatia opis [m], Indosphinctes urbanus [M] and Eucycloceras eucyclum [M] (Locality III; Fig. 2). In bed 12 Sindetes madagascariensis [M], E. eucyclum [M], Subkossmatia opis [m], S. cogni-browni [m], S. obscura [m] and S. ramosa [m] are recorded. Bed 13 has yielded Rehmannia (Locyceras) balusseaui [M], R. (R.) stuebeli [m and M], R. (R.) tyranniformis [M], S. opis [m], E. eucyclum [M], Idiocycloceras perispincoides [M] and I. dubium [m] (Locality III; Fig. 2).

Anceps subzone

This subzone spans from beds 10-12. Reineckeia (Reineckeia) stuebeli [M] is restricted to the base of Middle Callovian and Reineckeia (R.) aniceps [M] is an index of the Anceps Zone in the Submediterranean province (Cariou, 1984; Cariou and Krishna, 1988). Hence, beds 11-12 are correlated with the Stuebeli subzone, Anceps Zone of the Submediterranean province (Table 2). In Kachchh, at Jumara, R. (R.) stuebeli [M] also marks the base of Middle Callovian (Jain and Pandey, 2000) and at Keera, the Ramsosa subzone (Al horizon; beds 131 - 163), the lowest subzone of the Anceps Zone, is also defined by the first occurrence of R. (R.) aniceps [M] occurring in association with Subkossmatia ramosa [m] and Chanasia hartmanni (Krishna and Ojha, 1996).

Eucyclum subzone

Rehmannia (L.) balusseaui [M] in Europe is common in the upper part of the Anceps Zone as also Reineckeia (R.) tyranniformis [M] and hence, bed 13 has been correlated with the Tyranniformis subzone of the Anceps Zone of the Submediterranean province (Fig. 3; Table 2). Sindetes madagascariensis [M] is recorded for the first time from the Indian subcontinent. This species has also been recorded from Middle Callovian sediments of Madagascar (Collignon, 1958). Owing to the dominance of E. eucyclum [M] from this bed, it is assigned a subzonal status here.

Gigantea Zone

This Zone spans from beds 14 to 16 (Fig. 3). Bed 14 has yielded Collotia gigantea [M], E. eucyclum [M], Hecticoceras cf. hecticum Reinecke [M] and Idiocycloceras singularare [M] (Locality III; Fig. 3). C. gigantea is restricted to the upper part of the Coronatum Zone of the Submediterranean province (Cariou, 1984; Cariou and Krishna, 1988) (Table 2). Rehmannia (Locyceras) radis [M] which succeeds C. gigantea at the
Kuldhar section has also been recorded from bed 15. Bed 16 has yielded *R. (R.) tyranniformis* [M], thus, the pair of *Collotia gigantea* [M] and *Rehmannia* (L) *rudis* [M] helps in correlating beds 14-16 with the Baylei subzone, upper part of the Coronatum Zone of the Submediterranean province (Table 2). Bed 16 records the last appearance of *R. (R.) tyranniformis* [M]. However, this species, in Europe, disappears at the base of the Coronatum Zone. Its absence further up attests its similar European and Kachchh occurrences (Jain and Pandey, 2000).

**Paramorphum Zone**

Bed 17a has yielded *Paralcidia* sp.; bed 17c - *Hecticoceras* sp. and *Hecticoceras ignoble* Waagen [M]; bed 17d - *Sivajiceras paramorphum* [M] and *Putealiceras bisulcatum* [M] and bed 17e has yielded *Hubertioceras ophalodes* [M] and *Subgrossouvria* sp. [M] from Locality IV (Fig. 2).

At Keera (Krishna and Ojha, 1996) *Idiocycloceras* is also succeeded by *Sivajiceras* (S. *paramorphum* and S. *kleidos*). In the present work, bed 17, which follows after the *Collotia gigantea - Rehmannia* (L) *rudis* pair favors correlation of these beds with the Uehiardti subzone (Coronatum Zone) of the Submediterranean province (Table 2). This pair in Europe typifies the base of the Coronatum Zone (Cariou, 1980, Cariou and Krishna, 1988).

**Fraasi Zone**

A loose sample of *Collotia fraasi* [M] from the top of the Kuldhar section indicates early Late Callovian age. Based on the presence of this form from this bed, it is tentatively assigned to represent the informal Fraasi Zone here (Fig. 3).

Interestingly, in Kachchh (Jamura), *C. fraasi* [M] occurs with *Pelloceras* (P.) *athleta* [M] and is correlated with the Collotiformis subzone, Athleta Zone of the Submediterranean province (Jain and Pandey, 2000; see Table 2). *C. fraasi* also persists at the same level in the adjoining Jara Dome (personal observation; Fig. 1) and is associated with *C. aff. kachchhense* and *C. aff. decorra* (Prasad 1998). In the Keera Dome (Fig. 1) also, *C. fraasi* co-occurs with *Pelloceras* (P. *metamorphicum* and P. *vijaya*) and species of *Binatisphinctes* and *Paralcidia* (Krishna and Ojha, 1996, 2000). In the Hobo Dome (Fig. 1), bed 4 of the Athleta beds (Kanjilal, 1974) has also yielded *Reineckeia* (R.) *kachchhense*, a possible synonymy for *C. fraasi*.

In fact, genus *Collotia* in Kachchh is widespread in the Athleta Subzone, Athleta Zone (Krishna and Ojha, 1996, 2000; Prasad 1998; Jain and Pandey, 2000). Thus, within the Kachchh basin, the common occurrence of genus *Collotia*, along *Pelloceras* (P.) *athleta* helps in correlating the Athleta Zone of these domes (Table 2).

Thus, the presence of *C. fraasi* (bed 18) and of *Paralcidia* from bed 17a at Kuldhar above the Middle Callovian fauna favors correlation of bed 18 with the Collotiformis Subzone, Athleta Zone of the Submediterranean province (Table 2). However, further up, a previous record of *Dhosaites primus*, 6 m above bed 17 (Chatterjee, 1990) suggests an Early Oxfordian age. But, a more recent record of *Perisphinctes* (*Dichotomosphinctes*) aff. *subhelenae* from the top of the section has been assigned an early Middle Oxfordian age (Prasad, 2006). Here, pending precise finds, an age straddling between Early to early Middle Oxfordian is favored for the top of the section.

A distribution chart of the ammonite fauna (66 specimens) recorded from Kuldhar is given in Table 4.

**SECTION II**

**Palaeoenvironment of the Kuldhar Section Nannofossils**

Early Callovian low diversity nannofossil assemblage has recently been reported from the Kuldhar section (Rai and Garg, 2007; see Fig. 2 Section E for their sampling distance). The palaeoecological potential of this assemblage has not been inferred. It is done so here. This Callovian nannofossil assemblage of 21 species (Rai and Garg, 2007) is dominated by long-ranging taxa such as *Watznaueria barnesae*, *W. britannica*, *W. ovate*, *Cyclagelosphaera margerelii* and marked by variable-sized species of *Watznaueria*.

The placolith *Watznaueria barnesae* is generally regarded as a dissolution-resistant cosmopolitan taxon abundant in oligotrophic surface water settings (Roth and Krumbach, 1986; Premoli-Silva et al., 1989; Williams and Bralower, 1995; Burns and Bralower, 1998; Herrle, 2003; Ebra and Tremolada, 2004). However, blooms of this taxon are also considered to indicate eutrophic environments (Lees et al., 2004). This species is also considered to have an opportunistic mode of life, able to thrive under extreme conditions and is better adapted than any of its counterparts (Thomsen, 1989; Mutterlose, 1991). High abundances of *W. barnesae* have also been observed in other restricted, shallow-water settings where samples show a high diversity/low diversity nannoflora (Mutterlose, 1989), as noted at Kuldhar (Rai and Garg, 2007).

*Watznaueria manivitae* is prolific in low-latitude nannofloral assemblages and its distribution is controlled by temperature. Pittet and Mattioli (2002) and Olivier et al. (2004) proposed that this species proliferates under oligotrophic conditions. However, *W. britannica* has been suggested both as a mesotrophic (Lees et al., 2004) or a eutrophic taxon (Busson et al., 1992; 1993).

The ecological affinities of *Cyclagelosphaera margerelii*, another cosmopolitan species, is still unclear. Pittet and Mattioli (2002) and Olivier et al. (2004) suggest that it occupies an intermediate position within the trophic continuum between *W. manivitae* (more oligotrophic) and small-sized *W. britannica* (more eutrophic). Several authors (Busson et al., 1992; 1993; Tribovillard et al., 1992) described extremely high abundance of *C. margerelii* in lagoonal environments characterized by low-diversity nannofloral assemblages with marked salinity variations. Interestingly, this taxon also survived the Cretaceous/Tertiary boundary extinction and hence, has been interpreted as a neritic species (Street and Bown, 2000; Bown et al., 2004). However, it is unclear if the small fluctuations in abundance of this taxon are driven by increases and decreases of other taxa or by salinity variations.

Thus, overall, a warm, humid and moderately oligotrophic condition at shallow shelf depths (~50 m) is inferred for the entire Early Callovian section studied at Kuldhar.

**Benthic foraminifers**

Thick-walled lenticulinitids dominate between beds 2~7 (samples nos. R-34/3-13 of Dave and Chatterjee, 1996) and deep-dwelling epistominids between beds 9-13 (samples nos. R-34/15-19 of Dave and Chatterjee, 1996). *Epistomina mosquensis* dominates within the Epistominids and *Lenticulina muensteri* and *L. bulla* for Lenticulinitids (Dave and Chatterjee, 1996). *E. mosquensis* (and in general species of *Epistomina*) prefer relatively deep waters from ~200 to 250 m, whereas *L. muensteri* (and in general species of *Lenticulina, Nodosaria* or *Dentalina*) fill the depth niche between ~50 to 150 m (Murray,
Table 4: Distribution of species and genera identified from Kolhar (Jaisalmer).

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<th>Zone</th>
<th>Family</th>
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<td>MIDDLE</td>
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MIDDLE JURASSIC AMMONOIDS FROM JAISALMER, WESTERN INDIA
2001). Low diversity of benthic foraminifers (maximum species diversity is 8; and a range of 6-8 is noted for beds 2-4; data of Dave and Chatterjee, 1996) may also indicate a somewhat stressed environment.

However, Kalia and Chowdhury (1983) from the same section recorded a rich benthic foraminifer fauna of 47 species indicating a healthy bottom environment with well-oxygenated conditions. Additionally, in this study (Kalia and Chowdhury, 1983), the placement of dominant taxa are also opposite in occurrence as compared to that by Dave and Chatterjee (1996).

Kalia and Chowdhury (1983), for the same sediments, identified three foraminiferal assemblages:

a. The Gubkinella-Epistominia ghoshi assemblage marked by the abundance of epistominids, planktonic foraminifers and arenaceous benthic forms. This assemblage extends from sandy limestone to oolitic beds (beds 1-6 of present work; Fig. 3).

b. The Litharina rhomboidea-Lenticulina brueckmanni assemblage is characterized by the abundance of nodosariids (especially lenticulinids). This assemblage extends from clay limestone intercalations to grayish clay beds (beds 7-13 of present work; Fig. 3) and

c. The Barren zone includes the top gypsicretary clay horizon, devoid of microfossils (beds 14-17 of present work; Figs. 3).

Thus, interestingly, according to Dave and Chatterjee (1996) lenticulinids dominate between beds 2-7 (their samples nos. R-34/3-13), whereas according to Kalia and Chowdhury (1983), Epistominids dominate. Additionally, up section, according to Dave and Chatterjee (1996), the Epistominids have an abundant but restricted occurrence (their samples nos. R-34/15-19) but according to Kalia and Chowdhury (1983), Nodosariids (especially lenticulinids) dominate at this level.

Thus, if the data of Dave and Chatterjee (1996) are considered, the Kulhar section experienced a stressed environment marked by low abundances and low species diversity. Additionally, beds 2-7 experienced less deep settings (50 to 150 m) as compared to beds 9-13 (200 to 250 m). This depth estimation, species diversity and paleoenvironment are reversed if the dataset of Kalia and Chowdhury (1983) is considered.

Although benthic foraminifers are excellent indicators of the marine environment, the dataset from the Kulhar section due to their contrasting distribution are surprisingly of little use in interpreting the prevailing environment, except for suggesting that the depth of deposition was less than 100 m (van Morkhoven et al., 1986) and the high diversity of ammonites would suggest some open marine connection. A more comprehensive and well-constrained benthic foraminiferal data is urgently needed for these excellently preserved beds at Kulhar to infer its palaeoenvironment.

Ostracods

Khosla et al. (2006) described the ostracod assemblage from Kulhar (Fig. 3). Their section includes beds 5-17 of present work with possible omissions of beds 9-13 (Fig. 3). They (Khosla et al., 2006) identified three ostracod assemblages (= concurrent range zones) dominated by genus Majungaella. Majungaella in the Mesozoic was widely distributed in shallow, warm seas and but in the Jurassic was restricted to the southern Hemisphere (India, Africa and Madagascar). Thus, only broad conclusions can be arrived at for the Kulhar section and the available data indicate that for bed 4 upwards, a shallow (<30 m) warm water environment was present.

Trace fossils

The presence of Rhizocorallium in bed 4 along with Chondrites and Thalassinoides (Fig. 3; see also Fürsich, 1998; Jain, 2007) in association with oolites and shell debris indicates deposition of the bed in a storm-influenced ramp setting. Higher up, bed 5 has yielded abundant traces of Thalassinoides and Planolites (Fig. 3), suggesting relatively calmer conditions. However, presence of bored concretions, hardgrounds, and shell debris also indicates long periods of non-deposition (hiatus) and intermittent episodes of storm influenced below fair-weather wave base. Up section, the presence of well-preserved and large traces of Zoophycos and Thalassinoides in beds 9 and 16 (Fig. 3) suggests ramp environments of low to intermediate energy (Fürsich, 1998).

Fürsich (1998) noted that high energy/near shore areas and submarine shoals are represented by members of the Skolithos ichnofacies such as Ophiomorpha and Rhizocorallium and that the storm-influenced ramp contains both members of the Cruziana ichnofacies (Rhizocorallium, Thalassinoides and Chondrites) and the Skolithos ichnofacies (in particular Ophiomorpha). The Cruziana ichnofacies were produced during interstorm phases, the Skolithos ichnofacies are of post-storm origin. Carbonate ramp environments of low to intermediate energy also contain members of the Cruziana ichnofacies, whilst equivalent siliciclastic environments are characterized by a low-diversity Zoophycos ichnofacies. Low energy basinal environments of fine-grained substrates contain an impoverished Cruziana ichnofacies consisting of Chondrites and Thalassinoides.

Though, a much more detailed analysis and close bed-by-bed examination of trace fossils distribution is needed for any accurate inference for the Kulhar Member, the preliminary data indicate that bathymetrically, bed 3 is deposited at a shallow ramp setting (Thalassinoides and Planolites), followed by sudden deepening (Chondrites with Thalassinoides and Planolites) for bed 4 and again shallowing to bed 3 levels for beds 5-6. However, beds 4-6 had much lower energy levels marked by the absence of cross-bedded ripple marks present at the top of bed 3.

Bored concretions and growth of serpulids over oyster shells in beds 3-6 suggest periods of break in sedimentation. Presence of hardgrounds at this level has already been well documented by Fürsich et al. (1991). Presence of well-preserved and large traces of Zoophycos and Thalassinoides in bed 9 and of Thalassinoides and Planolites in bed 13 suggests calmer and deeper conditions for beds 9-13.

Presence of cross bedding in the lower part of bed 16 (sandstone) indicates shallowing and high energy conditions of deposition. The upper part of this bed has however well-preserved and large traces of Zoophycos suggesting calmer and slightly deeper conditions which prevailed thereafter until bed 17, which is indicatively marked by thick calcareous marls (Fig. 3).

Belemnites

Abundant belemnites have been noted in beds 3-6 (Fig. 3). The construction of the belemnite phragmocone imposes a habitat depth limit due to the possibility of implosion from hydrostatic pressure. For two species of Hibolites (that proliferate the Kulhar section and in the adjoining Kachchh basin), the habitat depth limit is calculated at around 215 m (Wierzbowksi, 2004). According to him, other belemnites should
EXPLANATION OF PLATE III

a-g. *Collotia oxyptycha* (Neumayr) [M] from beds 8 and 9, Dimerus-Transitorius-Opis Zone, Locality III, a-c, f and g are from bed 8, sample nos. SJK/7/2-4 respectively; d-e from bed 9, sample nos. SJK/9/1-2 respectively. All are septate specimens with lateral views except for b (ventral view) c (apertural view). Bar represent 1 cm. All specimens unless mentioned belong to the Kuldhar section.
have had a lower depth limit averaging 150 m, similar to the depth limit of a majority of ammonites. A differentiation of depth limit is, however, possibly recognized within the Middle Jurassic genus *Cylindroteuthis* (Westermann, 1973). Similarly, the large differentiation of depth limit is also observed for modern *Sepia*; particular *Sepia* species differing in shell size and septal thickness inhabit either shallow or deep waters, but rarely exceeding depths of 200 mts (Rexford and Mutterlose, 2006). For these reasons the calculations of the depth habitat of belemnites seem not to be very exact but based on the above discussion, a lower depth limit of 150-200 mts would be safe to assume, confirming their necto-benthic mode of life in the Jurassic. Thus, the presence of belemnites indicates a conservative depth not exceeding 150 mts.

In summary, the sediments at Kuldhar indicate deposition in a warm, humid and moderately oligotrophic condition at shallow shelf depths (<100 m) with an intermittent open marine connection. The distribution of trace fossils better indicates the fluctuations both in sea and energy levels. The beds are deposited at shallow ramp settings, a sudden deepening for bed 4, shallowing for beds 5-6, with calmer and deeper conditions until bed 13. Cross-bedding in the lower part of bed 16 indicates shallowing and high energy conditions of deposition followed by calmer and slightly deeper conditions until bed 17. Sudden deepening possibly brought in Subboreal and Submediterranean ammonites as exemplified by numerous common species of Family Reinekeiidae Hyatt, Grossouvirianae Spath and Hecticoceratinae Spath. A summary of the palaeoenvironment discussed above in given in Fig. 4.

**Interbasinal marker intervals**

Pandey *et al.* (2009a, b) identified four marker intervals in both Jaisalmer and Kachchh basins:

1. the pebbly rudstone unit with *Iasstrea bernardiana* and *Leptocephinextes* of the Kaladongar Formation (Kachchh Basin) and the *Iasstrea bernardiana*-bearing rudstone of the Jaisalmer Formation (Jaisalmer Basin) both represent transgressive systems tract (TST) deposits dated as Late Bajocian;

2. bioturbated micrites with anomalodesmatan bivalves within the Goradongar Yellow Flagstone Member (Kachchh Basin) and bioturbated units in the Fort Member (Jaisalmer Basin) represent maximum flooding zone (MFZ) deposits of the Middle to Late Bathonian;

3. trough-crossbedded, sandy pack-to grainstones of the Raimaloro Limestone Member (Kachchh Basin) and the basal limestone-sandstone unit of the Kuldhara section of the Jaisalmer Formation (Jaisalmer Basin) correspond to Late Bathonian TST deposits; and

4. ferruginous ooid-bearing carbonates with hardgrounds of the Dhosa Osolite member (Kachchh Basin) and the middle part of the Jaijya Member (Jaisalmer Basin) are Oxfordian TST deposits.

Pandey *et al.* (2009a, b) further noted that the fact that in both basins similar biofacies prevailed during certain time intervals, a common control of their depositional history is plausible. However, as the two basins represent different tectonic settings, the most likely controlling factors are likely to be (a) relative sea-level changes produced by eustatic processes, (b) common subsidence history of the northwestern margin of the Indian craton, and (c) similar paleoclimate.

**SECTION III**

**Systematic Palaeontology**

In this section only those specimens are described in detail that have stratigraphic relevance or form an important element of an assemblage. Dimorphism in *Rehmannia* (*Locyceras*) *rudis* (Bourquin), *Reinekeia* (*Reineckeia*) *stuebeli* Steinmann, *R. (R.)* *anceps* (Reinecke) and *Idiocycloceras dubium* Spath are documented. Microconchs (male) of *Rehmannia* (*L.*) *reissi* (Steinmann) and *R. (L.)* *rudis* (Bourquin) and macroconchs (female) of *Collotia oxyptycha* (Neumayr) [M] and *C. gigantea* (Bourquin) are also described.

Both microconchs of *R. (L.)* *rudis* (Bourquin) [m] and *R. (R.)* *anceps* (Reinecke) are described from Jumara (Kachchh) and *R. (L.)* *reissi* (Steinmann) [m], *R. (R.)* *stuebeli* Steinmann [M and m] are common to Kuldhara (Jaisalmer) and Jumara (Kachchh) sections. A comparative age-range chart for these species is provided (Fig. 5).

Both Spath's genus *Eucycloceras* and *Subkossmatia* from Kachchh have recently been investigated and integrated into one genus *Eucycloceras* Spath (Jana *et al.*, 2005). However, in the present study (based on both morphological and statistical data), the traditional taxonomic classification of Spath (1924-1928) and Callomon (in Donovan *et al.*, 1981) is preferred. Brief comparison with the new classification of Jana *et al.* (2005) is also done (Table 5).

Additionally, only new data on species description with an emphasis on family Reinekeiidae is given, since, much of the species description is well documented by works of Waagen (1875), Spath (1927-33) and Jana *et al.* (2005). Other specimens are, thus, only recorded and illustrated for future species comparisons.

All measurements are given in Appendix-1. D, shell diameter; U, umbilical diameter; T, thickness of the shell; H, height of the shell; all measurements are in millimetres; M, macroconch; m, microconch. The notation SJK used for Kuldhara specimens is based on Sreepat Jain Kuldhara and is followed by bed number and specimen number. So, for example a specimen from bed 9 will have the notation as SJK/9/1. Those from Jumara (Kachchh) have the first initials as Ju. All specimens are reposited at the Invertebrate Paleontology Laboratory of the Geology Department, University of Rajasthan, Jaipur, India. At places, the old inventory numbers (like the one illustrated on Plate 6, fig. c: Ju/12/7) is now replaced by the newer one (Ju/B35/10). Collections for 1993-1994 were broad based and were later refined in 1999. Hence, the two numbering systems.

The principle for differentiation of dimorphism is the co-occurrence of two groups of ammonites differing in shell size, ornamentation of outer whorl(s), type of peristomial modifications and displaying identical or practically indistinguishable inner whorls (Makowski, 1962; Callomon, 1963, 1969). Dimorphism was interpreted as sexual in nature. Smaller forms with more complex peristome as males, and larger - as females (Makowski, 1962). Thus, in general, the microconchs are smaller, lappeted and strongly ornamented, with strong primary ribs. However, it must also be pointed out that “the question of which of a dimorphic pair should be identified with a particular sex...can never rise above speculation” (Callomon, 1963, p. 47).

**Family Reinekeiidae** Hyatt, 1900

**Subfamily Reinekiinae** Hyatt, 1900

Cariou (1980, p. 35) recognized two distinct subfamilies -
Fig. 4 A summary of paleoenvironmental conditions inferred from various micro- and macrofauna identified from Kuldhar (Jaisalmer). The cosmopolitan and endemic species of ammonites recorded at Kuldhar are also marked along with the gross lithology of co-occurring beds.
the Late Bathonian-Early Callovian East Pacific Neuquenciceratinae recorded from the Andes (Riccardi and Westermann, 1991) with rare occurrences from Japan (Westermann and Callomon, 1988). The Japanese specimens have now been assigned to a new genus - *Pesedoneuqueniceras* (Riccardi and Westermann, 1991). The other subfamily - the cosmopolitan late Early Callovian - early Middle Callovian western Tethyan *Reineckeiinae* is widely distributed in the Mediterranean, Submediterranean, Subboreal, Indo-Malagache as well as in the Andes, Mexico (Cariou and Krishna, 1988).

Recently, the age of the western Tethyan *Reineckeiinae* was revised and lowered down to an age bracketed to lie between latest Late Bathonian and Middle Bathonian (Jain et al., 1996; Jain, 2000) which incidentally, also coincides with the extension of the upper age limit of this family in the Andes into the Early Oxfordian (Gröschke, 1994). In Kachchh, Spath (1932, p. 252), on purely nomenclatural grounds, had earlier assigned Bathonian age to the earliest *Reinekeidae* (Epimorphoceras decorum), recorded by Waagen (1875, p. 208, pl. 57, figs. 3a-c) from the “highest beds of the Putchum group of Jumara” (Sponge beds; Jain et al., 1996). The recent Bathonian discovery of *Reineckeia* sp. indet. A and B [M] from the Yellow bed of the Jumara Dome (bed A4) has made “the supposed centre of evolution…to be moved eastwards…into the Pacific” (Jain et al., 1996). This Bathonian discovery from the same level at Jumara as also the strong resemblance of the asymmetrical lateral lobe of *Reineckeia* sp. A (Jain et al., 1996) with that of *E. decorum* (Waagen), favors the much debated placement of the latter in the *Reineckeidae* firmly.

**Genus Collotia** (De Grossouvre, 1917)

*Collotia oxyptycha* (Neumayr, 1870) [M]  
(Pl. III, figs. a-g, Text-fig. 6a)

*Collotia oxyptycha* (Neumayr) - Cariou, 1980, p. 503, pl. 43, figs. 1-4, pl. 44, figs. 1-4-5, pl. 45, figs. 1-2, text-figs. 162-163, 168, 175-177 and 201 - Cariou and Krishna, 1988, p. 164, pl. 4, figs. 2, 3a-b and 4a-b; Text-fig. 4.

**Material:** 5 specimens (SJK/9/2-4 and SJK/9/1-2).

**Horizon:** Bed 7, Patina subzone and bed 9, Anceps Zone, Locality II (Fig. 2), Kulsar.

**Description:** All specimens are fragmentary but preserved well enough to enable correct identification at the species level. Shell is large, evolute and compressed with missing inner
whorls. In the middle whorls, ribbing is dense and sharp. At this stage, primaries arise rursiradiately from below the rounded umbilical margin and divide at varying flank heights into 2 to rarely 3 sharp, dense and strongly prorsiradiate secondaries with a single intercalatory. Secondaries at the rounded ventrolateral margin show a slight backward bend. Venter is distinctly grooved more so on the earlier whorls. There are 12 to 16 primaries with 30 to 34 secondaries per half whorl. Maximum estimated shell diameter is between 150-160 mm.

Remarks: Ribbing is present in all the specimens. Ribs either bifurcate or rarely trifurcate with a single intercalatory. This character is restricted to the middle whorls; outer whorls display quadrifurcate ribbing (Cariou and Krishna, 1988). Hence, all fragmentary specimens belong to the middle whorl. Another character is the varying heights of ribfurcation, ranging from lower to the outer third of the flank height.

Occurrence and Age: late Early Callovian (beds 7 and 9; Locality II). The species is strictly localised at the top of Early Callovian (Patina subzone, Gracilis Zone; Table 2) in the Submediterranean province (Cariou, 1984). In Kachchh, it spans from the Semilaevi to the Opis Zones of latest early Callovian age. Both at Kuldhar (Jaisalmer) and Jamara (Kachchh), this species disappears before the beginning of the Middle Callovian Anceps Zone (Fig. 5).

Collotia gigantea (Bourquin) [M]
(Pl. IV , figs. a-b; Text-fig. 6b)
Collotia gigantea (Bourquin) - Cariou, 1980, p. 550, pl. 49, figs. 1-4; pl. 50, figs 1, 3 and 5; text figs. 170-171, 187-188, 190 and 204. - Cariou and Krishna, 1988, p. 165, pl. 5, figs. 1 a-b, 2 and 3.

Material: 2 specimens (SJK/14/1-2).
Horizon: Bed 14, Gigantea Zone, Locality III (Fig. 2), Kuldhar.

Description: Phragmocone is large (270 mm) with a maximum estimated shell diameter of at least 400 mm. Primaries arise slightly rursiradiately from the broadly rounded umbilical margin and show typical subrectiliiniear arrangement until 200 mm; thereafter, they assume a somewhat straighter pattern. Primaries divide at the middle to the lower third of the flank height. Until 120 mm, the primaries divide into 3 prorsiradiate secondaries with a single intercalatory. At around 170-180 mm each primary rib divides into 5-6 prorsiradiate secondaries. Ribbing until 150-170 mm is dense and moderately fine. Thereafter secondaries become somewhat coarse and faint at the body chamber. Fine spines are present at the rib furcation points until 50 mm; thereafter they are absent. At around 170-180 mm, faint tubercles appear at the point of branching. Throughout the phragmocone stage the flanks are moderately flat, but near the body chamber become slightly arched. In early whorls venter bears a distinct groove which at the body chamber reduces in prominence. Venter until 200 mm is well rounded but thereafter becomes narrow and somewhat arched.

Remark: It differs from Collotia oxyptycha (Neumayr) in its pattern of the branching of ribs and in being considerably larger and slightly more evolute.

Occurrence and Age: late Middle Callovian (bed 14; Locality III). C. gigantea (Bourquin), a European species, is restricted to the upper part of the Coronatum Zone (Baylei subzone) of the Submediterranean province (Table 2).

Genus Rehnmannia Schirardin, 1956
Subgenus Loczyceeras Bourquin, 1881
Type species: Loczyceeras sequanicum (Bourquin)

Table 5: A comparative morphological categorization based on the classification given by Spath (1928), followed by Callomon in Donovan et al. (1981) and used here with the one given by Jana et al. (2005).

<table>
<thead>
<tr>
<th>Classification followed here is of Spath (1927-33) and Donovan et al. (1981)</th>
<th>Modern classification after Jana et al. (2005)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eucycloceras encyclan (Waagen) [M]</td>
<td>Eucycloceras opis (Sowerby) [M]</td>
</tr>
<tr>
<td>Subkossenia opis (Sowerby) [M]</td>
<td>Eucycloceras opis (Sowerby) [M]</td>
</tr>
<tr>
<td>Subkossenia cogn-browni Spath [M]</td>
<td></td>
</tr>
<tr>
<td>Subkossenia dissoidea Spath [M]</td>
<td></td>
</tr>
<tr>
<td>Subkossenia ranosa Spath [M]</td>
<td>Idicycloceras perispinicofoides Spath [M]</td>
</tr>
<tr>
<td>Idicycloceras dubium Spath [M]</td>
<td>Idicycloceras perispinicofoides Spath [M]</td>
</tr>
<tr>
<td>Idicycloceras perispinicofoides Spath [M]</td>
<td>Idicycloceras perispinicofoides Spath [M]</td>
</tr>
<tr>
<td>Idicycloceras dubium Spath [M]</td>
<td>Idicycloceras perispinicofoides Spath [M]</td>
</tr>
<tr>
<td>Idicycloceras sanguinare Spath [M]</td>
<td>Idicycloceras sanguinare Spath [M]</td>
</tr>
</tbody>
</table>

Fig. 6. Whorl sections. (a): Collotia oxyptycha (Neumayr) [M]; (b): Collotia gigantea (Bourquin) [M]; (c): Rehnmannia (L.) helvovirens Cariou [M]; (d): Rehnmannia (K.) stuchihi Steinmann [M].

MIDDLE JURASSIC AMMONOIDS FROM JAISALMER, WESTERN INDIA

Table 5: A comparative morphological categorization based on the classification given by Spath (1928), followed by Callomon in Donovan et al. (1981) and used here with the one given by Jana et al. (2005).
EXPLANATION OF PLATE IV

a-b. Collotia gigantea (Bourquin) [M], bed 14, Gigantea Zone, sample no. SJK/14/1-2 respectively, septate specimens. Lateral views. Bar represent 1 cm. All specimens unless mentioned belong to the Kulhar section.
EXPLANATION OF PLATE V

a. Rehmannia (Locyceras) rudis (Bourquin) [M], bed 15, Gigantea Zone, Locality III, Kuldhar section, sample no. SJK/15/4. Lateral view.

b-c. Microconch [m], Bed C13, Jamara (Kachchh) sample no. Ju/C13/12, Obtusicostites Zone, Jamara (Kachchh). Bar represents 1 cm.

EXPLANATION OF PLATE VI

a-d. Rehmannia (Locyceras) reissi (Steinmann) [m], Bed B35, sample no. Ju/B35/10, Opis Zone, Jamara (Kachchh). a: Lateral view, b: Opposite lateral view, c: Apertural view, d: Ventral view. Bar represents 1 cm.
Rehmannia (Loczyceeras) rudis (Bourquin)

Macroconch [M]

(Pl. V, fig. a)

Rehmannia (Loczyceeras) rudis (Bourquin) - Cariou, 1984, p. 210, pl. 17, figs. 2a-b, 3 and 4 a-b; text-figs. 71-72.

Material: One specimen (SJK/15/4).

Horizon: Bed 15, Locality III, Gigantea Zone (Fig. 2), Kuldhara.

Description: Maximum estimated shell diameter of ~120 mm. In the inner whorls, the primaries are fine, radially arranged with concealed tubercles, due to overlapping by the succeeding whorls. Near the end of the phragmocone, primaries are slightly rursiradiate at the rounded umbilical shoulder and branch into three fine and strongly prorsiradiate secondaries with a single intercalary. At the point of division, which is at the upper third of the flank height, a tubercle is present. Venter bears a mid-ventral groove. Whorl section subquadratic due to almost flat to slightly converging flanks, being more pronounced at the body chamber, where the venter is narrow but remains rounded. Primaries arise from the umbilical seam rursiradiately. At the end of the phragmocone or at the beginning of the body chamber, ribbing is finer and evenly spaced. The tubercles which are still at the third of the whorl height begin to fade after the end of the phragmocone, being ultimately replaced by a crest. Constrictions are wide, prominent, deeply incised and more forwardly inclined than the ribbing.

Occurrence and Age: late Middle Callovian (bed 15; Locality III).

Microconch [m]

(Pl. V, figs. b-c)

Rehmannia (Loczyceeras) rudis (Bourquin) - Cariou, 1980, p. 210, pl. 17, figs. 2a-b, 3 and 4 a-b; text-figs. 71-72.

Material: 2 specimens (Ju/C13/12-13).

Horizon: Bed C13, Obtusicostites Zone (Jain and Pandey, 2000), Jumara, Kachchh (Table 2).

Description: Shell evolves and reaching a T/H ratio of 1. The maximum estimated shell diameter is ~90 mm. The primaries are fine, sharp, evenly spaced and slightly rursiradiate at the umbilical area, becoming more pronounced at the end of the body chamber. Primaries bear a sharp tubercle at the point of branching in the lower third of the flank height, whence they divide into 3 fine sharp and prorsiradiate secondaries, which cross the narrow but rounded venter with a slight forward sinus. Sometimes one of the secondaries detaches and forms a single intercalary. Primaries originate rursiradiately from just below the rounded umbilical shoulder. Whorl section is rounded just at the end of the phragmocone but changes to subtrapezoidal at the body chamber. There are 2 constrictions per half whorl, which are distinct, forwardly inclined, deep and well marked.

Remarks: Pattern of ornamentation matches with its Macroconch that are considerably larger in size (for details see Cariou, 1984, p. 210, pl. 17).

Occurrence and Age: late Middle Callovian. This species is restricted to the Obtusicostites Zone at Jumara (Kachchh) (for details see Jain and Pandey, 2000) (Table 2).

Rehmannia (Loczyceeras) reissi (Steinmann) [m]

(Pl. VI, figs. a-d)

Rehmannia (Loczyceeras) reissi (Steinmann) - Cariou, 1980, p. 480, figs. 2a-b, p. 482, pl. 11, figs. 2 and 5a-b.

Material: One specimen (Ju/B35/10).

Horizon: Bed B35, Opis Zone, Jumara (Kachchh).

Description: Shell is small, evolute and compressed. The cariniform stage persists until 10 mm. Minute tubercles present at the point of branching of the primary ribs. The primaries arise from the umbilical edge, and branch into 3 fine and prorsiradiate secondaries with an occasional single intercalary until 30 mm. A single intercalary precedes the constrictions also. After the 30 mm stage, and until 50 mm, the primaries branch into 4-5 prorsiradiate secondaries with a single intercalary. Thus, the Anceps stage persists until 30 mm which is followed by a Reissi stage. Tubercles of the Anceps stage are pyramidal which after 40 mm (Reissi stage) become spinose and die out at 50 mm, replaced by very faint and sharp crests only. This demonstrates degeneration of the tubercles, instead of the normal course of regeneration. Primaries at the body chamber branch into 2 or 3 blunt secondaries with a single intercalary. Primaries at the body chamber remain crested but the secondaries become somewhat coarse or blunt, being pronouncedly prorsiradiate at the end of the body chamber. 4 forwardly inclined and deep constrictions are present per whorl. Venter bears a strong and distinct mid-ventral groove.

Occurrence and Age: This species has been recorded from the Anceps Zone (Stuebeli Subzone) of the Submediterranean province (Cariou, 1984). In the present record the species has been recorded from the subjacent Semiavis/Opis Zone from Jumara (Table 2) of latest Early Callovian age. This is the earliest record for this species from Kachchh, western India.

Rehmannia (Loczyceeras) balusseiaui Cariou, 1984 [M]

(Pl. VII, figs. a-b, Text-fig. 5c)

Rehmannia (Loczyceeras) balusseiaui Cariou, 1984, p. 170, pl. 13, figs. 1a-b, 2 a-b, 3; pl. 14, fig. 1 a-c, text-figs. 39, 42, 62 and 63. - Cariou and Krishna, 1988, p. 157, pl. 11, figs. 3a-b; pl. 2, figs. 1 a-b.

Material: 2 specimens (SJK/13/1 and SJK/13/9).

Horizon: Bed 13, Locality III, Anceps Zone.

Description: Phragmocone is large (still septate at 245 mm; SJK/13/1), evolute and moderately compressed. Primaries arising from the umbilical shoulder are rursiradiate at the umbilical area, and then they become prorsiradiate, branching into 6 prorsiradiate and closely spaced secondaries with one to 2 intercalatories. The ribbing trajectory remains subrectilinear throughout shell growth. Early whorls until 70 mm bear pyramidal tubercles of varying height at the point of branching of the primaries in the upper third to middle of the whorl height. There are 7 primaries with 2-3 prorsiradiate constrictions per half whorl. The tubercles numbering 9 per half whorl are faint and sharp until 30-40 mm, become pyramidal at 70-80 mm and blunt at around 120-130 mm. The tubercles maintain varying heights throughout ontogeny.

Occurrence and Age: early Middle Callovian (bed 13; Locality III). R. (L.) balusseiaui Cariou occurs in the upper part of the Anceps Zone (Tyranniformis subzone) of the Submediterranean province (Cariou, 1984) (Table 2). Here also at Kuldhara (Jaisalmer), it defines the upper part of the Anceps Zone.

Genus Reineckeia Bayle, 1878

Type species: Nautilus anceps Reinecke, 1818.

Reineckeia (Reineckeia) stuebeli Steinmann

Macroconch [M]

(Pl. VIII, fig. b)

Reineckeia kiliani Parona and Bonarelli, 1897, p. 162, pl. 6, figs. 3, 3a-b, Reineckeia (R.) stuebeli Steinmann - Cariou, 1980, p. 445, pl. 40, figs. 1-5; pl. 41, figs. 2a-b, 3, 6a-b; Text-figs. 131, 147-149, 152,159. - Cariou and Krishna, 1988, p. 159, pl. 3, figs. 2a-b. - Prasad, 2006, p. 40, pl. 10, fig 3.
JAIN

EXPLANATION OF PLATE VII

a-b. Rehmannia (Locyceras) balusseaui Cariou [M], bed 13, Anceps Zone, Locality III, sample no. SJK/13/1, Septate specimen. a: Lateral view, b: Ventral view. Bar represents 1 cm. Specimen belongs to the Kuldhar section.
**Material:** Two specimens. Kuldhar: SJK/13/9 and Jamara: Ju/C13/3.

**Horizon:** Bed 13, Anceps Zone, Locality III (Kuldhar) and bed C13, Obustoscopicites Zone, Jamara (Kachchh).

**Description (Phragmocone):** Initial cartiform stage exists up to 15 mm. Until this stage, the ribbing in fine, lamellar and forwardly inclined with faint tubercles, at the point of branching of the primaries which bifurcate between the umbilical shoulder and the lower 1/3 of flank height. Umbilical edge remains rounded. It is only after 15 mm shell diameter that the primaries branch in 3 secondaries, and at the body chamber, sometimes into 4 secondaries. At this stage the tubercles are at the lower 1/3 of the flank height. The primaries arise from the umbilical seam and are slightly concave until the tubercle, whence branching into prorsiradiate secondaries which at the ventrolateral margin is slightly concave (retroflexive) and crosses the venter with a distinct groove. The tubercles are placed at the umbilical shoulder until 15 mm; shift higher to the lower third of the whorl height at the phragmocone. The tubercles at 15 - 20 mm are faint and spinose, sharp until 50 mm and then become mamilliform at later stages. Constrictions number 3 per whorl, are well marked and forwardly inclined. Whorl section is subquadratic and compressed with a distinct midventral groove.

**Remarks:** The present specimen with its compressed and subtrapezoidal whorl section matches with its European counterpart (Cariou, 1984). The present specimens also closely resemble Kachh Reineckeia (Reineckeia) crispus Spath (1933a, p. 679, pl. 128, figs. 9-12), R. (R.) torulosus Spath (1933a, p. 679, pl. 127, figs. 5, 6; pl. 128, fig. 1) and R. aff. torulosus Spath (1933a, p. 679, pl. 127, figs. 4, 11; pl. 128, fig. 8) in possessing similar ornamentation but differing only in the placement of the position of the tubercles, that are placed slightly away from the umbilical shoulder. Both R. (R.) torulosus Spath and R. (R.) crispus Spath could well be considered subspecies of R. (R.) stuebeli Steinmann which occur in stratigraphically coeval sediments.

**Occurrence and Age:** early Middle Callovian (Bed 13; Locality III from Kuldhar and Obustoscopicites Zone, Jamara, Kachchh).

**Microconch [m]** (Pl. VIII, figs. a-g, Text-fig. 6d)

Reineckeia stuebeli Steinmann – Enay et al., 1984, p. 230, pl. 41, figs. 1a-b, 4a-c and 5. - Enay et al., 1994, p. 150, pl. 61, figs. 4a-c and 5.

**Material:** 3 specimens. Kuldhar: SJK/11/1 and SJK/13/2; Jamara: Ju/C4/5.

**Horizon:** Kuldhar: Beds 11 and 13, Anceps Zone, Locality III (Fig. 2); Jamara: Bed C4, Anceps Zone, Kleidos subzone.

**Description:** Phragmocone measures 65 mm with a maximum estimated diameter of 95 mm. Shell compressed and evolute. Cartiform stage is until 15 mm. The European microconch [m] also has a cartiform stage until 12-13 mm. Primaries arise from the umbilical edge and are slightly prorsiradiate at the umbilical shoulder, whence become prorsiradiate, strictly bifurcating, at the upper part of the upper third of the whorl height. Sharp and spinose tubercles persist till 30 mm, placed at the point of branching of the primary rib. Rare single intercalatory is also present, which runs through the entire whorl height, always present next to the constriction. Each whorl has 2 prorsiradiate and deeply incised constrictions, which are slightly more prorsiradiate than the ribbing. Primaries at earlier stages (till 35 mm) are sharp, lamellar and subrectilinear, but with increasing shell diameter, become fine and crested. The whorl section changes from being slightly rounded at the end of phragmocone to compressed and subtrapezoidal at the end of the body chamber. Body chamber occupies 94% of the whorl. Near the end of the body chamber, the costation becomes more prorsiradiate and the secondaries form a slight forward sinus at the grooved venter. This groove is distinct and equal to the rib thickness. At the end of the body chamber a constriction precedes the lappet.

**Remarks:** The present specimens in their nature of growth, coiling, ornamentation and size are similar to the European lectotype of Reineckeia (R.) stuebeli figured by Enay et al. (1994), but differs in possessing sharper ornamentation, being slightly more evolute and moderately compressed. The Jaisalmer specimens are closer to forme type (Enay et al., 1984, pl. 41, figs. 1a-b) (Fig. 7), than with forme waageni (Enay et al., 1984, pl. 41, figs. 4a-c and 5) (Fig. 7). The Jamara specimen (Pl. 8, figs. d-f) is much more compressed and less evolute and are more close to the lectotype (Fig. 7). Collection of more specimens is likely to bridge this dimensional gap.

**Occurrence and Age:** early Middle Callovian (Beds 11 and 13; Locality III from Kuldhar and Anceps Zone, Kleidos subzone from Jamara, Kachchh). Cariou (in Enay et al., 1994) recorded the microconch [m] from the Middle Callovian, Anceps Zone of Europe. He considered this species to be an index of the upper part (Stuebeli subzone) of the Anceps Zone of the Submediterranean province (Table 2). Its occurrence in the adjoining basin (at Jamara, Kachchh; Fig. 1) also comes from a coeval horizon (Anceps Zone, Kleidos subzone).

Reineckeia (Reineckeia) aniceps (Reineckeia) - Cariou, 1980, p. 375; pl. 33, figs. 4-5; pl. 34, figs. 1, 2 and 5; pl. 35, figs. 1, 4 and 5; Text figs. 123, 126, 137, 155-156. - Cariou and Krishna, 1988, p. 160, pl. 2, fig. 2a-b; pl. 3, fig. 1 a-b. - Prasad, 2006, p. 38, p. 160, pl. 10, fig. 5.

**Material:** 4 fragmentary specimens (SJK/11/2-5).

**Horizon:** Bed 11, Anceps Zone, Locality III.

**Description:** All the specimens are septate and fragmentary but preserved well enough to merit species level identification.

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**EXPLANATION OF PLATE VIII**

- **a-g.** Reineckeia (Reineckeia) stuebeli Steinmann [m].
  - a-c. bed 11, Anceps subzone, Anceps Zone, Locality III, sample no. SJK/11/1.
  - d. sample no. SJK/13/2, bed 13, Anceps subzone, Anceps Zone, Locality III.

- **e-g.** bed C4, Anceps Zone, Kleidos subzone, Jamara (Kachchh), sample no. Ju/C4/5.
  - e. Lateral view.
  - f. Opposite lateral view.
  - g. Ventral view.
  - h. Macroconch [M], bed 11, Anceps subzone, Anceps Zone, Locality III, sample no. SJK/13/9. Bar represents 1 cm. All specimens unless mentioned belong to the Kuldhar section.
  - i. Reineckeia (Reineckeia) stuebeli Steinmann [M], bed 13, Anceps Zone, Locality III, Sample no. SJK/13/9.
Simple prorsiradiate primaries are present, numbering 8 per half whorl at 9 mm diameter. At 35 mm, primaries are slightly concave on the rounded umbilical shoulder with a prominent pyramidal tubercle at the upper third of flank height. Each primary branches into 3 prorsiradiate secondaries. Single primaries are also present near the constriction, which number two per half whorl. With increasing shell diameter (50-60 mm), the primaries are pronouncedly prorsiradiate at the broadly rounded umbilical shoulder, with strong, sharp and pyramidal tubercles, numbering 6 per half whorl. Primaries branch into 6 prorsiradiate secondaries with 2 intercalatories in outer whorls.

At 35 mm, the whorl section is oval and the venter is broadly rounded. The mid-ventral groove remains distinct and well marked.

**Remarks:** In Europe, as at Kuldhar, the less evolute forms are more common. Cariou and Krishna (1988) noted that this index species has a large distribution in the Tethys – from France, Spain, Germany, North Africa, to Madagascar and Kachchh. It is considered as an index of the base of Tethyan Middle Callovian (Table 2).

**Occurrence and Age:** early Middle Callovian (Bed 11; Locality III).

**Microconch [m]**
(Pl. IX, figs. c-e)

**Locality:** North East of the village of Jumara in the southern flank of the Dome, Jumara, Kachchh.

**Material:** One nearly complete specimen (Ju/C2/1).

**Horizon:** The holotype comes from Bed C2, Ramosa subzone, Anceps Zone.

**Diagnosis:** Shell small (phragmocone =100 mm) with a maximum estimated diameter of 120-125 mm. Primaries sharp, slightly rursiradiate at the umbilical region, divide at the lower third into 3 prorsiradiate secondaries with a single intercalatory. After 100 mm, there are 4-5 secondaries to a primary with one or 2 intervening intercalatories. At the point of branching, the primaries bear a prominent pyramidal tubercle, which, with increasing diameter becomes blunt and strong. Primaries number 10 at 98 mm and 8 at 110 mm. Constrictions number 2 per half whorl; they are deep, distinct and prorsiradiate. Whorl section is oval.

**Description:** Phragmocone measures 100 mm with a maximum estimated diameter of 120-125 mm. Shell small, complete, evolute and moderately inflated with a T/H ratio of 1. The primaries, until 60 mm, are sharp, slightly rursiradiate at the umbilical area and divide at the lower third of the whorl height into 3 prorsiradiate secondaries with a single intercalatory. At the point of branching, the primaries bear a prominent pyramidal tubercle, which, with increasing shell diameter becomes blunt and strong. Primaries at 110 mm are prorsiradiate, secondaries more blunt and inclined, crossing the rounded venter with faint but distinct mid-ventral groove. Primaries become distant, 10 at 98 mm to 8 at 110 mm and the tubercles, placed at lower third of the whorl height, become stronger and higher, though retaining their pyramidal nature. Shell at 110 mm is nearly complete, judging by the absence of the umbilical seam of the succeeding whorl. Whorl section is
a-b. *Reineckeia (Reineckeia) anceps* (Reinecke) [M], Septate specimens, bed 11, Locality II, Anceps subzone, Anceps Zone,
   a. sample no. SJK/11/4. Lateral view,
   b. sample no. SJK/11/5. Lateral view.

c-e. Microconch [m]. Bed C2, sample no. Ju/C2/1, Ramosa subzone, Anceps Zone, Jumara (Kachchh). Bar represents 1 cm. All specimens unless mentioned belong to the Kuldhar section.
oval. Constrictions are deep, distinct and prosirradiate, numbering 2 per half whorl. Absence of trace of umbilical seam, sudden prosirradiate nature of ribboning and the presence of 4-5 secondaries to a primary with one or 2 intervening intercalatories, attests to its adult nature. The body chamber occupies \( \frac{3}{4} \) of the outer whorl.

**Remarks:** Its small size, pattern of ornamentation, dimensional proportions and the absence of umbilical seam indicates its maturity and hence a microconch designation. So far, the description of *Reinekeia (R.) anceps* (Reinecke) is based solely on Macroconch forms, as done by Cariou (in Enay et al., 1994) based on examples of d’Orbigny [(1847, p. 462, pars), pl. 166, figs. 1-2 (non figs. 3-5), pl. 167, figs. 1-2 (non fig. 3)] and Bayle (1878, pl. 56, fig. 1). The present specimens match closely in terms of both morphological and dimensional proportions with the macroconch specimens of illustrated by d’Orbigny (1847), Bayle (1878), Cariou (1980), Cariou and Krishna (1988) and Cariou (in Enay et al., 1994). However, in the present specimen, the phragmocone only measures 100 mm with a maximum estimated shell diameter of 120-130 mm as opposed to ~300 mm in the macroconchs (Cariou and Krishna, 1988). Hence, based on its small size and maturation of the costations it is considered a microconch.

**Occurrence and Age:** Both at Jumara (Kachchh) as well as in Kuldhar (Jaisalmer) this species marks the beginning of the Anceps Zone. *R. (R.) anceps* is an index of the Anceps Zone, the base of Middle Callovian in the Submediterranean province (Cariou, 1984; Cariou and Krishna, 1988).

**Subfamily Eucycloceratinae Spath, 1928**

**Remarks:** Waagen (1875, p. 107-109) in his Macrocephalinae considered 2 divisions - the Recticoistati and the Curvicostati. In the Recticoistati he included *M. semilaevis* and in his Curvicostati both *Subkossmatia opis* and *Eucyclorcas eucyclum*. Later Spath (1928) studied the taxonomic and classification issues of the genus *Eucyclorcas* and related genera. Later Spath (1928) was of the view that the “runcinate stage” (tabulate stage) first appeared in the inner whorls of the Macrocephalitids or Eucycloceratids and considered the Eucycloceratids to have evolved from *Dolikephalites subcompressus* (Waagen).

Spath (1928) was also of the view that *Eucyclorcas* and *Subkossmatia* are transitional forms between Macrocephalitids and Kosmocephalitids. However, Arkell (1956), Arkell et al. (1957) and Westermann (1968) placed Eucycloceratids under Macrocephalitidea. Later Westermann and Wang Yi-Gang (1988) included Eucycloceratins under Mayitanae. But Westermann and Callomon (1988) gave the Eucycloceratids a subfamily status. He was of the view that Macrocephalitinae were “replaced by their endemc offshoot Eucycloceratinae” which in turn were the ancestors of Mayitanae. Thierry (1977) considered Eucycloceratins as a subfamily under Macrocephalitidea. But Callomon in Donovan et al. (1981) had placed Eucycloceratids as an independent subfamily under Family Sphaeroceratidae. Jana et al. (2005) in their analysis from the adjoining Kachchh basin noted that of the 14 species under 4 genera described for subfamily Eucycloceratinae Spath, can be grouped into 2 highly variable monospecific genera of *Eucyclorcas* Spath, 1924 and *Idiocyloceras* Spath, 1928. But, morphological changes in the present specimens could not confirm this integration. Hence, the classical version of Spath (1928) and as followed by Callomon in Donovan et al. (1981) is used here. However, for sake of comparative morphology, the present species described in this contribution have also been categorized following the classification of Jana et al. (2005) and is given in Table 5.

Additionally, Jana et al. (2005) divided the microconch [m] of their *Eucyclorcas opis* (Sowerby) into 5 variants (infrauspecies). Their general characters and corresponding species described in the present study are given in Table 6: However, a comparative plotting of all the Jaisalmer (this study) and Kachchh data (Jana et al., 2005) reveals that the Jaisalmer *Subkossmatia/Eucyclorcas* population, though numerically very low, is significantly different (p<0.001) and more evolve (Fig. 8). Thus, pending collection of further specimens, this contribution follows the taxonomic classification of Spath (1924-1928) and Callomon in Donovan et al. (1981).

**Eucyclorcas eucyclum** (Waagen) 1875 [M]

(Pl. X, figs. a-c)

*Stephanoceras eucyclum* Waagen, 1875, p. 142, pl. 35, fig. 1. - Spath, 1924, p. 8 and 12. -Spath, 1928, p. 299, pl. 23, fig. 4; pl. 25, fig. 4; pl. 27, fig. 7. - *Eucyclorcas opis var opis* (Waagen) - Jana et al., 2006, p. 902, pl. 3, figs. 6-10. - Prasad, 2006, p. 25, pl. 5, fig. 2.- non Prasad, 2006, p. 25, pl. 19, fig. 3. - *Eucyclorcas dungrakotti* Prasad, 2006, p. 26, pl. 5, fig. 4.

**Material:** 4 specimens (SJK/9/5, SJK/11/8, SJK/12/8, SJK/13/4-5).

**Horizon:** Bed 9, Anceps Zone, Locality II; beds 11-12, Anceps subzone, Anceps Zone, Locality III; bed 13, Eucyclum subzone, Anceps Zone, Locality III.

**Emended Diagnosis:** Shell large, tabulate to discoidal and strongly to moderately compressed. Phragmocone large, compressed initiating very late between 90-130 mm (could be as large as 165 mm). Primaries until 70-80 mm are long, sharp to moderately crested, strongly prosirradiate and branch into 2 or rarely 3 secondaries with a single intercalatory, arising from just below the rounded umbilical margin. At or near the end of the phragmocone primaries are blunt, coarse and strong, branching into 3-4 secondaries. On the body chamber the primaries become very strong and the secondaries fade leaving the outer laterals and the venter smooth. Umbilical wall vertical, becomes steep to slanting with increasing shell diameter. Umbilical edge always remains distinct and rounded. Laterals tabulate in the initial whors which change to slightly arched in the middle whors to moderately convex at the outer whors. Venter changes from being slightly tabulate (initial whors) to broadly rounded (middle whors) to narrowly rounded (outer whors). Maximum estimated shell diameter 260-270 mm.

**Description (Early stage):** Shell is strongly compressed and discoidal with maximum inflation near the umbilical shoulder. The primaries form a distinct concave sinus near the umbilical area and are then strongly projected forward at the slightly arched to flat laterals. The primaries arise from just below the distinct but rounded umbilical edge. They branch into 2 or rarely 3 secondaries with a single intercalatory. The rib furcation varies from middle to the outer third of flank height. The primaries, at this stage are moderately crested and sharp, becoming slightly thick near the end of the phragmocone. The secondaries are sharp forming a faint sinus at the broadly rounded to slightly tabulate venter. Umbilical wall until 60 mm is vertical and changes to gently slanting at around 70-80 mm. Whorl section is compressed oval.
Table 6: A correlation and listing of general characters of the *Subkossmatia* species presently identified from Kuldhar with the variants (infrasubspecies) recorded by Jana et al. (2005).

<table>
<thead>
<tr>
<th>Species</th>
<th>Description</th>
<th>This study</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Eucycloceras nigrescens</em> (in M)</td>
<td>Shell large (200-230 mm), relatively strongly evolute (U/D = 20:0.42), compressed (T/H = 0.67-0.68), Whorl section elliptical to subquadrate. D at end-planoconic ~102-133 mm, P = 16-21 and S = 51-62. Umbilical margin sharp with steep wall. Rib faces: primarly rises immediately from umbilical shoulder, straight with forward projection and furcate below mid-flank. Secondaries have the same forward bend, goes over rounded ventrolateral margin with a further bend and cross center with prominent forward projection.</td>
<td>Large (D = 90-140 mm, D at end-planoconic = ~165-175 mm), strongly to moderately compressed (T/H = 0.72-0.86), moderately evolute (U/D = 0.18-0.28); primarly bread; rounded at middle whirls and blunt at outer whorls. Center is continuous at the umbilical region and then moderately pronicate, bifurcating with very rare single intercalary. Scenconds cross the center with a pronounced sinus. Extraventriculation begins close to the end of the planoconic stage.</td>
<td><em>Eucycloceras nigrescens</em> (Wageni) [M]</td>
</tr>
</tbody>
</table>

| *E. opis* var. A | Smallest variant (D = 57-83 mm, D at end-planoconic = 45-54 mm), most compressed (T/H = 0.71-0.84); relatively less evolute (U/D = 0.30-0.34); very densely, finely ornament until the end (P = 21-29, S = 46-68); rib-crest sharp, symmetrical across-section, ribs always isocostate and show approximation towards adult aperture. Umbilical wall remains more or less steep in adult stage, umbilical margin always prominent and sharp. | Smallest variant (D = 70-110 mm, D at end-planoconic = ~85 mm), most compressed (T/H = 0.70-0.82); relatively less evolute (U/D = 0.21-0.24); very densely, finely ornament until the end (P = 32-34, S = 45-50); costation sharp, ribbing isocostate. Umbilical wall steep throughout, umbilical margin always sharp | *Subkossmatia opis* (Sowertky) [M] |

| *E. opis* var. obscura | Small (D = 86-113 mm, D at end-planoconic = 63-56 mm), moderately compressed (T/H = 0.76-0.89), evolute (U/D = 0.31-0.35), densely, finely ornament (P = 21-29, S = 40-66); ribs isocostate, sharp symmetrical crest; most abundant. | D = 112-132 mm, D at end-planoconic = 70-90 mm, weakly compressed (T/H = 0.70-0.76), evolute (U/D = 0.21), strongly, distinctly ornament (P = 18-21, S = 42-47); ribs isocostate, primarly slightly concave at the umbilical region and then moderately pronicate, bifurcating with very rare single intercalary. Scenconds cross the center with a sinus. Extraventriculation begins close to the end of the planoconic stage. | *Subkossmatia obscura* Spath [M] |

| *E. opis* var. decedea | Small (D = 77-97 mm, D at end-planoconic = 52-70 mm), moderately compressed (T/H = 0.75-0.89), evolute (U/D = 0.31-0.35), distinctly ornament (P = 17-20, S = 36-45); ribs isocostate with angular crest; rare | Small (D = 73-97 mm, D at end-planoconic = 52-70 mm), moderately compressed (T/H = 0.77-0.81), evolute (U/D = 0.31-0.35), distinctly ornament (P = 21-25, S = 42); ribs isocostate. Primarly very slightly concave at the umbilical region and then moderately pronicate, bifurcating with very rare single intercalary. Scenconds cross the center with a pronounced sinus. | *Subkossmatia decedea* Spath [M] |

| *E. opis* var. cocchinea | Small to medium sized (D = 85-115 mm, D at end-planoconic = 73 mm), strongly to moderately compressed (T/H = 0.72-0.86), least evolute variant (U/D = 0.27-0.33); primarly bread, blunt, concave forward and lower in number (P = 14-20); ribs varicosecostate, primarly much the same as secondaries (S = 40-54) which become faint to obscure in center, common. | Not recorded in Jaisalmer; present in Junagarh | *Eucycloceras cocchinea* (Wageni) [M] |

| *E. opis* var. obscura | Largest variant (D = 121-128 mm, D at end-planoconic = 71-82 mm), weakly compressed (T/H = 0.80-0.89), most evolute variant (U/D = 0.32-0.38), strongly, distinctly ornament (P = 17-27, S = 40-53); ribs isocostate, high created, rounded and symmetrical with gentle slope towards aperture; abundant. | *Subkossmatia obscura* Spath [M] |

| *E. opis* var. obscura | Small (D = 77-97 mm, D at end-planoconic = 52-70 mm), moderately compressed (T/H = 0.75-0.89), evolute (U/D = 0.31-0.35), distinctly ornament (P = 17-20, S = 36-45); ribs isocostate with angular crest; rare | Small (D = 73-97 mm, D at end-planoconic = 52-70 mm), moderately compressed (T/H = 0.77-0.81), evolute (U/D = 0.31-0.35), distinctly ornament (P = 21-25, S = 42); ribs isocostate. Primarly very slightly concave at the umbilical region and then moderately pronicate, bifurcating with very rare single intercalary. Scenconds cross the center with a pronounced sinus. | *Subkossmatia decedea* Spath [M] |

| *E. opis* var. cocchinea | Small to medium sized (D = 85-115 mm, D at end-planoconic = 73 mm), strongly to moderately compressed (T/H = 0.72-0.86), least evolute variant (U/D = 0.27-0.33); primarly bread, blunt, concave forward and lower in number (P = 14-20); ribs varicosecostate, primarly much the same as secondaries (S = 40-54) which become faint to obscure in center, common. | Not recorded in Jaisalmer; present in Junagarh | *Eucycloceras cocchinea* (Wageni) [M] |
Fig. 8. A comparative plotting of all Kukubari (Hisayu) and Kachaka population data from Jain et al. (2005) in the Streptococcus pneumoniae group reveals that the lalolmer population, though numerically very low, are significantly different (p<0.01) (C) in its ceiling ratio (B) and is more extreme (A). Although, the whorl thickness (T2) (B) does seem to indicate a separate population too but statistically, it cannot be separated. Additionally, the ceiling ratio also shows more variability as demonstrated by the boxplot diagram (A). Note that the line in each box indicates the median value of the dataset for that variety and that the "box" outlines 75% of the data. The "whiskers" show the high and low values and the black dots are outliers.
Middle stage: At this stage, the primaries are long, prorsiradiate, strong, blunt, and divide at the middle of the whorl height into somewhat indistinct 3-4 secondaries with an intervening single intercalatory. The secondaries persist until this stage, crossing the venter with a negligible forward sinus. Maximum inflation remains at the umbilical edge. Umbilical edge continues to be rounded and distinct. Umbilical wall is steep. At the end of the phragmocone uncoiling is noticed. The shell at this diameter is compressed and discoidal with a broadly rounded to slightly flat venter. Whorl section is subelliptical. There are 22 primaries at 95 mm.

Adult stage: Primaries are very strong, prorsiradiate and branching into 3 secondaries with a single intercalatory. Branching is at the middle of the whorl height. The secondaries persist until 170-180 mm and fade after 190-220 mm leaving the outer one third of the lateral and the broadly rounded venter smooth. Maximum estimated diameter is 250-270 mm. Occurrence and Age: latest Early Callovian to early Middle Callovian (Beds 9-13; Locality II). This species is restricted to the early Middle Callovian sediments in Kachchh and at Kuldhar (Jaisalmer) ranges from latest Early Callovian to early Middle Callovian, being recorded from bed 9 and associated with latest Early Callovian Collotia oxyptycha and first Indosphinctes errans (Fig. 3).

Genus Subkossmatia Spath, 1924
Subkossmatia opis (Sowerby) [m]
(Pl. XI, figs. a-d and f-h)
Ammonites opis Sowerby, 1840, pl. 23, fig. 9. Subkossmatia opis (Sowerby) - Spath, 1928, p. 210, pl. 36, fig. 2; pl. 39, figs. 2a-b and 7. S. cf. opis (Sowerby) - non Prasad, 2006, p. 27, pl. 17, fig. 10.
Material: 5 specimens (SJK/9/3-4, SJK/11/5, SJK/12/1, SJK/13/3).
Horizon: Bed 9, Anceps Zone, Locality II; beds 11-12, Anceps subzone, Anceps Zone, Locality III; bed 13, Eucyclum subzone, Anceps Zone, Locality III.
Description (Early stage until 45 mm): Primaries are fine, dense and sharp, arising prorsiradiately from below the rounded umbilical margin. By 25 mm, the primaries become prorsiradiate, branching occasionally into 2 and rarely into 3 prorsiradiate, equally fine and sharp secondaries that cross the acutely rounded venter straight. By 40 mm, the forward ventral sinus becomes noticeable. Flanks at this stage are tabulate to flat, umbilicus shallow and umbilical wall vertical. At 50 mm there are 60-64 primaries per whorl.
Middle stage (Phragmocone): The ribbing is fine and dense but with increasing shell diameter becomes coarse and sparse. Primaries become less prorsiradiate and secondaries cross the somewhat tabulate venter with a more pronounced forward ventral sinus. The phragmocone measures 81 mm with 42 primaries per whorl.
Adult stage (Body chamber): Shell tabulate with sparse and coarse ribbing. Primaries at this stage are comparatively straight, prorsiradiate and long, dividing into 2 or rarely 3 secondaries that cross the acutely rounded venter with a pronounced forward sinus and without fading. Maximum estimated shell diameter is between 165-170 mm (Plate 9, figs. a-b). Body chamber occupies nearly a complete whorl.
Remarks: The specimens described here match with the holotype of Subkossmatia opis (Sowerby). Interestingly, even with such a small population, S. opis displays variability in its ribbing pattern. Table 6 gives a brief comparative description of the various Subkossmatia species / morphs recorded in this study (based on the traditional taxonomic approach of Spath, 1927-33) and the one by Jana et al. (2005) from a much larger Kachchh population. Where these two populations (Jaisalmer and Kachchh) are plotted together on coiling ratio (umbilicus/diameter) and whorl thickness (thickness/height), the Jaisalmer population is separate with a significantly (p<0.002) different coiling ratio (Fig. 8). For the various morphs identified by Jana et al. (2005), the coiling ratio (U/D) also shows large variability as opposed to whorl thickness (T/H). More samples from Jaisalmer are needed to confirm the stand-alone nature of the Kuldhar population.

Subkossmatia cogni-browni Spath [M]
(Pl. XI, figs. i-j)
Subkossmatia cogni-browni Spath, 1928, p. 212, pl. 31, fig. 6; pl. 35, fig. 7, pl. 38, fig. 2; pl. 41, figs. 4a-c. - Prasad, 2006, p. 28, pl. 3, fig. 2.
Material: One specimen (SJK/12/5).
Horizon: Bed 12, Anceps subzone, Anceps Zone, Locality III.
Description (Middle Stage Phragmocone): Phragmocone measures 132 mm. Ornamentation is coarse and sparse. The primaries are long, arising from below the rounded and distinct umbilical shoulder with a forward convexity at the umbilical region. Primaries strictly divide into 2 prorsiradiate secondaries at the outer one third of the whorl height with a rare single intercalatory. Lateral flanks are slightly arched with a narrowly rounded venter that becomes somewhat broad with increasing shell diameter. Umbilical wall is vertical and low. Umbilicus is wide and shallow. Ventral sinus becomes more pronounced with increasing shell diameter.

Remarks: The present specimen apart from its much larger size compares well with the holotype of Subkossmatia cogni-browni described by Spath (1928, p. 212, pl. 41, figs. 4a-c; suture line in pl. 31, fig. 6 and paratype in pl. 35, fig. 7 and also the illustration in pl. 38, fig. 2). Present species differs from S. opis (Sowerby) in the absence of the characteristic tabulate flanks. Additionally, S. opis is less compressed, more densely ribbed; possesses finer ribbing with an acutely rounded venter. S. discoidea Spath with which it compares closely is more compressed with sparser ornamentation with a highly tabulate flanks.

Occurrence and Age: early Middle Callovian (Bed 12; Locality II).

Subkossmatia discoidea Spath [M]
(Pl. XI, fig. e)
Subkossmatia discoidea Spath, 1928, p. 213, pl. 40, figs. 2a-b.
Material: One specimen (SJK/11/6).
Horizon: Bed 11, Anceps subzone, Anceps Zone, Locality III.
Description (Adult Stage body chamber): Shell small, compressed, finely ribbed and evolute. Phragmocone measures 60 mm with a maximum estimated shell diameter of 95 mm. Ribbing fine with primaries arising prorsiradiately from below the umbilical shoulder. With increasing shell diameter, they become more prorsiradiate and divide into two slightly rursiradiate secondaries. A single intercalary is also present which in very rare cases also joins as a secondary. Alternate pairing of ribs is noted. The secondaries cross the narrow rounded venter straight. There are 18 primaries and 40 secondaries per half whorl. Lateral are tabulate. Umbilicus is large, shallow with vertical umbilical walls that with increasing
shell diameter become somewhat slanting. Whorl section is compressed oval.

Remarks: This species resembles the fine-ribbed forms of *Subkossmatia opis* (see Pl. IX), but differs in possessing strongly tubulate laterals and a compressed whorl section. *S. cogni-browni* has more distant and coarser ornamentation with a more rounded whorl section. Though Spath's example (1928, pl. 35, fig. 7) of *S. cogni-browni* also has a closely comparable compressed whorl section but it has more finer costations. Thus, Spath's example appears to be transitional form between *S. discoidea* and *S. cogni-browni*. The inner whorls of *S. ramosa* are also a close match for *S. discoidea*, but the secondaries in the latter, cross the venter straight as compared to a sinus in the former.

Occurrence and Age: early Middle Callovian (Bed 11; Locality II).

*Subkossmatia ramosa* Spath

(Pl. XII, figs. f-g)

*Subkossmatia ramosa* Spath, 1928, p. 214, pl. 39, fig. 1 and pl. 41, figs. 1a-b. - Prasad, 2006, p. 27, pl. 5, figs. 1 and 3a-b.

Material: One specimen (SJK/12/3).

Horizon: Bed 12, Anceps subzone, Anceps Zone, Locality III.

Description (Adult Stage): Shell large, compressed and fragmentary. The prorsiradiate primaries are strong, coarse and sparse. There are 14 primaries and 28 secondaries per half whorl at 155 mm. The primaries arise rursiradiately from below the broadly rounded and low umbilical shoulder and thence become strongly prorsiradiate at the arched venter, dividing at the outer third of flank height into 2 prorsiradiate secondaries. These secondaries cross the venter with a pronounced forward sinus that fades with increasing shell diameter. Whorl section is compressed oval.

Remarks: Prasad's *Subkossmatia ramosa* Spath (2006, p. 27, pl. 5, figs. 1 and 3a-b) has a somewhat straighter ribbing across the venter (pl. 5, fig. 3c) as compared to the present specimen.

Occurrence and Age: Early to mid of Middle Callovian (Bed 12; Locality II).

Genus *Idiocycloceras* Spath, 1924

*Idiocycloceras dubium* Spath

Material: One specimen (SJK/12/6).

Horizon: Bed 12, Anceps subzone, Anceps Zone, Locality IV.

Description (Early Stage): Primaries at the early stage are fine, sharp, distant and radial in arrangement and arise from the sharp umbilical margin with a slight rursiradial pattern. Umbilical wall is high and vertical. Whorl section rounded, approaching a T/H ratio of 1.

Middle Stage (Phragmocone): Phragmocone measures 120 mm. Primaries remain sharp, though somewhat coarser and sparse, arising rursiradiately from below the rounded umbilical margin and strictly bifurcate into strongly prorsiradial secondaries that form a forward sinus at the broadly rounded venter. There are 20 primaries and 41 secondaries per half whorl.

Adult stage: Primaries coarse, blunt and sparse with 15 primaries per half whorl. Primaries arise rursiradiately from below the rounded umbilical shoulder. Umbilical wall is slanting. Primaries branch into two strongly prorsiradiate secondaries with a rare single intercalatory. Whorl section changes from being rounded to compressed oval, but always approaching a T/H ratio of 1. Venter also changes from being strongly rounded at 113 mm to being acutely rounded at 215 mm. At this stage, the secondaries form a pronounced ventral sinus. Umbilical wall is high and vertical.

Remarks: The present specimen in ornamentation, nature of coiling and whorl section matches with the holotype (Spath, 1928, p. 218, pl. 39, figs. 6a-b). The only difference lies in the bigger phragmocone of the holotype (still septa at 153 mm as compared to 120 mm in the present specimen). The present specimen also closely resembles *Idiocycloceras perisphinctoides* Spath [M] (Spath, 1933, p. 215, pl. 38, figs. 3a-b; holotype), but differs in having more strongly prorsiradiate secondaries and a pronounced ventral sinus at comparable diameters.

Occurrence and Age: middle part of Middle Callovian (Bed 12; Locality IV).

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**EXPLANATION OF PLATE X**

*Eucycloceras eucyclum* (Waagen) [M].

a-b. bed 13, Locality II, Eucyclum subzone, Anceps Zone.

a. sample no. SJK/13/4, Lateral view.

b. sample no. SJK/13/5, Lateral view. c. sample no. SJK/11/8, bed 11, Locality II, Anceps subzone, Anceps Zone. Lateral view. Bar represents 1 cm. All specimens belong to the Kuldhar section.

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**EXPLANATION OF PLATE XI**

a-d & f-h. *Subkossmatia opis* (Sowerby) [m].

a-b. sample no. SJK/13/3, bed no. 13, Locality II, Eucyclum subzone of the Anceps Zone.

a. Lateral view.

b. Apertural view.

c. sample no. SJK/11/6, bed 11, Locality II, Anceps subzone, Anceps Zone. Lateral view.

d. sample no. SJK/12/1, bed 12, Locality II, Anceps subzone, Anceps Zone. Lateral view.

e. *Subkossmatia discoidea* [M], sample no. SJK/11/7, bed 11, Locality II, Anceps subzone, Anceps Zone. Lateral view.

f. sample no. SJK/9/4, bed 9, Locality II, Dimerus-Transitorius-Opis Zone. Lateral view.

g-h. sample no. SJK/9/3, bed 9, Locality II, Dimerus-Transitorius-Opis Zone.

g. Apertural view. h. Lateral view.

e. *Subkossmatia discoidea* [M], sample no. SJK/11/7, bed 11, Locality II, Anceps subzone, Anceps Zone. Lateral view.

i-j. *Subkossmatia cogni-browni* Spath [M], sample no. SJK/12/5, bed 12, Locality III, Stuebeli subzone, Anceps Zone.

i. Lateral view.

j. Ventral view. Bar represents 1 cm. All specimens belong to the Kuldhar section.
Idiocycloceras perisphinctoides Spath - Jana et al., 2005, pl. 6, figs 1-9.

Material: One specimen (SJK/13/6).

Horizon: Bed 13, Eucyclum subzone, Anceps Zone, Locality III.

Description (Adult stage): Shell evolute and nearly complete. Inner whorls are not visible. Phragmocone measures 85 mm with a maximum estimated shell diameter of 130 mm. Ribbing is sharp and distant. Primaries arise from just below the umbilical edge more or less straight and branch into 2 slightly prosiradiate secondaries with 14 primaries and 28 secondaries per half whorl. Secondaries form a forwardly inclined sinus. Umbilicus is large, open and shallow. Umbilical wall is high and vertical with distinct but rounded umbilical lobe. Venter well rounded. Body chamber occupies nearly 3/4 of the last whorl.

Occurrence and Age: middle part of Middle Callovian (Bed 13; Locality IV).

Idiocycloceras perisphinctoides Spath [M]

Pl. XII, figs. d-e

Idiocycloceras perisphinctoides Spath, 1933, p. 215, pl. 38, figs. 3a-b; pl. 36, fig. 3.

Material: One specimen (SJK/12/4).

Horizon: Bed 12, Anceps subzone, Anceps Zone, Locality IV.

Description (Middle Stage): Phragmocone small and evolute measuring 115 mm with a maximum estimates shell diameter of 155 mm. Primaries arise slightly rursiradiately from the rounded umbilical edge and branch into two prosiradiate secondaries with a rare single intercalatory. Ribbing is sparse and sharp with 38 primaries and 80 secondaries at 115 mm. Lateral flanks are slightly arched at the phragmocone stage and change to slightly flat at the beginning of the body chamber but retaining the well-rounded venter. Primaries cross the venter with a faint forward sinus. Umbilical wall remains high throughout the shell diameter. Whorl section changes from being compressed at 66 mm to well-rounded at 90 mm. Body chamber occupies 3/4 of the entire whorl.

Remarks: This species closely resembles Idiocycloceras dubium Spath (1928, p. 218, pl. 39, figs. 6a-b), but differs in possessing prosiradiate secondaries, higher rib density, greater inflation and in being less evolute at comparable diameters. Stratigraphically I. perisphinctoides Spath occurs slightly earlier as compared to I. dubium Spath.

Occurrence and Age: middle part of Middle Callovian (Bed 12; Locality IV).

Superfamily Haploceratoidea (Zittel, 1884)
Family Oppelididae (Bonarelli, 1894)
Subfamily Hecticoceratinae (Spach, 1925)
Genus Hecticoceras (Bonarelli, 1893)

Type species: Hecticoceras hecticum (Reinecke, 1818).

Hecticoceras Bonarelli is the type genus of the subfamily Hecticoceratinae. It is used to demarcate subzones and horizons in the Subtethyan Province of Europe (Cariou 1984). In Kachchh, Hecticoceratinae are represented by eight genera ranging from the Middle Bathonian to Lower Oxfordian and are distributed throughout the Patcham and Chari formations (Spach, 1928; Kanjilal, 1980; Roy and Bardhan, 2007). Genus Hecticoceras is represented by two taxa, H. giganteum Spath and H. aff. turgidum Loczy (now synonymised with H. giganteum; see Roy and Bardhan, 2007) which ranges from the top of Early to the later part of Middle Callovian (=the upper part of the Coronatum Zone). A more detailed taxonomic study is underway and will be published elsewhere.

Hecticoceras cf. giganteum Spath, 1928 [M]

(Pl. XIII, fig. d and Pl. XIV, fig. h)

Horizon: Bed 14, Gigantea Zone, Locality IV.

Description: Shell discoidal with a subcircular whorl outline. Primaries (as noted in part of early whorls; Pl. XIII, fig. d) appear prosiradiate, arising from the rounded umbilical margin. At the mid-outter whorl, they become strong, forming elongated bullae on the lower flank and then bifurcate. At the outer whorl, the inner flank become somewhat smooth due to the disappearance of primaries from the lower flank. Now the secondaries are flat, distant, wide and rectiradiate. There are ~14 secondaries per half whorl. Other reports have noted 15-26 secondaries per half whorl (Roy and Bardhan, 2007, p. 269). Umbilicus is wide with a rounded margin. Venter is wide, and tricarinate, becoming rounded at the end. The ventrolateral margin is sharp but becomes somewhat rounded at the end of the shell diameter. Suture is complex and highly frilled (Pl. XIII, fig. d; also faintly represented in Pl. XIV, fig. h). The first lateral lobe is indistinctly trifid, broad and the first lateral saddle is narrow and long (Pl. XIII, fig. d). The present suture line (Plate 13, fig. d) matches well with the external suture line of the lectotype (Roy and Bardhan, 2007, fig. 3).

Remarks: Hecticoceras hecticum resembles the present species in possessing discoidal shell, similar degree of involution and in having smooth inner flank on the body-chamber (Jeannet, 1951, pl. C, fig. 5; Elmi, 1967, pl. 11, figs. 1-4). H. giganteum, however, can be distinguished by its large size, and in having broad and flat crested secondaries. Moreover, secondary ribs are straight and mostly rectiradiate (as in the present specimen, Pl. XIV, fig. h), while they may be concave in the type species (see Elmi, 1967, pl. 4, fig. 2; Roy and Bardhan, 2007, figs. 4-5). The closest comparison of the present specimen

EXPLANATION OF PLATE XII

a. Idiocycloceras dubium Spath [m], sample no. SJK/13/6, bed 13, Locality III, Eucyclum subzone of the Anceps Zone. Lateral view;
b-c. Idiocycloceras dubium Spath [M],

b. Lateral view, sample no. SJK/12/6, bed 12, Locality III, Anceps subzone, Anceps Zone.
c. Same specimen, ventral view;
d-e. Idiocycloceras perisphinctoides Spath [M],

d. sample no. SJK/12/4, bed 12, Locality IV, Anceps subzone, Anceps Zone. Lateral view;
f-g. Opposite lateral view. f-g: Subkossmatia ramosa Spath [M], sample no. SJK/12/3, bed 12, Locality II, Anceps subzone, Anceps Zone.
f. Lateral view, g: Ventral view;
h. Stoujiceras pararamorphum Spath [M], sample no. SJK/17/d1, bed 17, Locality IV, Eucyclum subzone of the Anceps Zone, lateral view. Bar represents 1 cm. All specimens belong to the Kuldhra section.
a. *Indosphinctes urbanus* Spath [M], bed 11, sample no. SJK/11/9, Locality II, Anceps subzone, Anceps Zone, lateral view;
b. *Choffatia transitoria* Spath [M], sample no. SJK/9/6, Locality II, Dimerus-Transitorius-Opis Zone, lateral view;
c. *Indosphinctes peregrinus* Spath [M], sample no. SJK/9/7, Locality II, Dimerus-Transitorius-Opis Zone, lateral view; d. *Hecticoscerus cf. giganteum* (Spath) [M], sample no. SJK/14/5, Locality IV, Gigantea Zone, Lateral view. Bar represents 1 cm. All specimens belong to the Kuldhar section.
a-c. *Hecticoceras proximum* Elmi [M], bed 7, Dimerus-Transitorius-Opis Zone, Locality II, sample no. SJK/7/6;

a. Lateral view,
b. opposite lateral view,
c. Ventral view,
d-f. *Hecticoceras hecticum* (Reinecke), sample no. SJK/17c/2, Locality IV, Gigantea Zone.

d. Lateral view,
e. Apertural view,
f. Ventral view;

g. *Hecticoceras ignobile* Waagen [M], sample no. SJK/17c/1, Locality IV, Gigantea Zone, lateral view;

h. *Hecticoceras cf. giganteum* (Spath) [M], sample no. SJK/14/6, Locality IV, Gigantea Zone, Lateral view;

i-k. *Sindeites madagascariensis* Spath [M], sample no. SJK/12/7, bed 12, Locality IV, Anceps subzone, Anceps Zone.

i. Lateral view,
j. Apertural view,
k. Ventral view;

l. *Hecticoceratoides cf. suborientalis* Spath [M], bed 7, Dimerus-Transitorius-Opis Zone, Locality II, sample no. SJK/7/5. Bar represents 1 cm. All specimens belong to the Kuldhar section.
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REFERENCES


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All measurements for examples used in this study.

### Appendix 1

<table>
<thead>
<tr>
<th>Species names</th>
<th>Locality</th>
<th>Spe. no.</th>
<th>Pinacometre Chamber</th>
<th>Body chamber</th>
<th>D</th>
<th>H</th>
<th>T</th>
<th>U</th>
<th>TH</th>
<th>LBD</th>
<th>P</th>
<th>T</th>
<th>S</th>
<th>Plates</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>M. para-amphiba</em> (Triangulina) <em>Spall</em> [M]</td>
<td>Jaisalmer</td>
<td>S.J.1/1</td>
<td>all body chamber</td>
<td>88.8</td>
<td>42.2</td>
<td>48.0</td>
<td>1.15</td>
<td>1.18</td>
<td>0.15</td>
<td>P1</td>
<td>2</td>
<td>8</td>
<td>4</td>
<td>c2</td>
</tr>
<tr>
<td><em>M. paradoxus</em> <em>Spall</em> [M]</td>
<td>Jaisalmer</td>
<td>S.J.1/1</td>
<td>all body chamber</td>
<td>62.0</td>
<td>31.2</td>
<td>24</td>
<td>1.12</td>
<td>0.24</td>
<td>P1</td>
<td>2</td>
<td>8</td>
<td>g</td>
<td>c2</td>
<td></td>
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<tr>
<td><em>M. stuarti</em> (Triangulina) [M]</td>
<td>Jaisalmer</td>
<td>S.J.1/1</td>
<td>all body chamber</td>
<td>51.3</td>
<td>22</td>
<td>29.8</td>
<td>1.16</td>
<td>0.13</td>
<td>P1</td>
<td>2</td>
<td>8</td>
<td>4</td>
<td>c2</td>
<td></td>
</tr>
<tr>
<td><em>H. operculum</em> (Triangulina) [M]</td>
<td>Jaisalmer</td>
<td>S.J.1/1</td>
<td>all body chamber</td>
<td>71.8</td>
<td>35.2</td>
<td>36.6</td>
<td>1.17</td>
<td>0.79</td>
<td>0.8</td>
<td>P1</td>
<td>2</td>
<td>8</td>
<td>4</td>
<td>c2</td>
</tr>
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</table>

### MIDDLE JURASSIC AMMONOIDS FROM JAISALMER, WESTERN INDIA

![Image](image-url)