Pre-Cambrian Animals

Until recently the fossils of organisms that lived earlier than the Cambrian period of 500 to 600 million years ago were rare. Now a wealth of such fossils has been found in South Australia

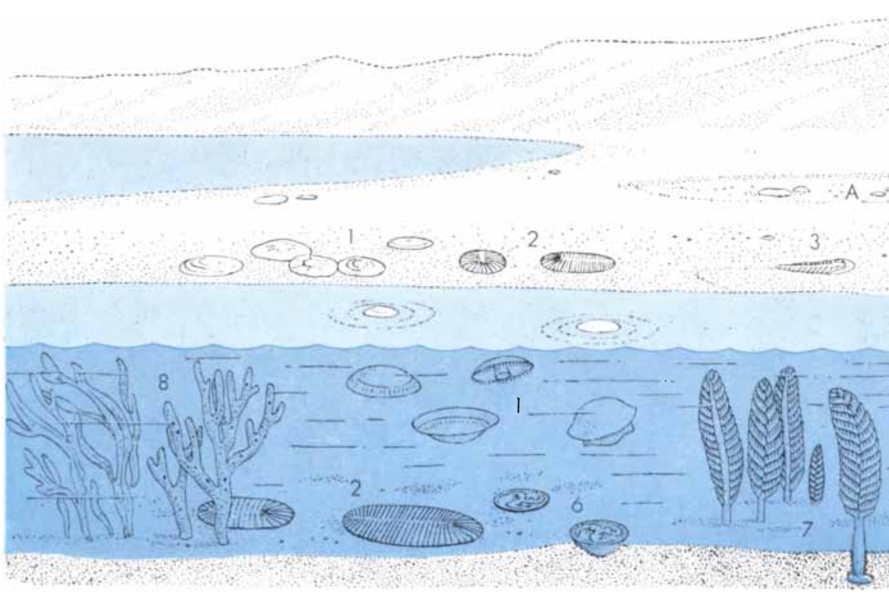
by Martin F. Glaessner

The successive strata of sedimentary rock laid down on the earth's crust in the course of geologic time preserve a rich record of the succession of living organisms. Fossils embedded in these rocks set apart the last 60 million years as the Cenozoic era—the age of mammals. The next lower strata contain the 150-million-year history of the Mesozoic—the age of reptiles. Before that comes the still longer record of the Paleozoic, which leads backward through the age of amphibians and the age of fishes to the age of the invertebrates. Then, suddenly and inexplicably, in the lowest layers of the Paleozoic the record of life is very nearly blotted out. The strata laid down 500 to 600 million years ago in the Cambrian period of the Paleozoic era show a diversity of primitive marine life: snails, worms, sponges and the first animals with segmented legs, the trilobites and their relatives. But the record fades at the bottom of the Cambrian. The greater part of the journey to the beginning of sedimentation, at least another 2,000 million years, still lies ahead. Yet apart from algae and a few faint traces of other forms, the Pre-Cambrian strata have yielded almost no fossils and have offered no clues to the origin of the Cambrian invertebrates.

The geological record necessarily becomes more obscure the further back it goes. The older rocks have been more deeply buried and more strongly deformed than the younger rocks. They have undergone longer exposure to the heat and pressure and the mineralizing solutions by which fossils are commonly destroyed. One can find fossils, however, in greatly deformed younger sediments, including metamorphic rocks, which have been even more thoroughly reworked by geologic processes than some older rocks. What is more, no rock-forming process affects the entire surface of the globe. Some Pre-Cambrian formations have escaped extreme alteration, just as the lower Cambrian rocks are altered in some places and not in others.

The abrupt termination of the fossil record at the boundary between the Cambrian and the Pre-Cambrian has appeared to many observers as a fact or paradox of decisive importance. They have advanced many different explanations for the mystery, from cosmic catastrophes to the postulate of an interval of time without sedimentation; from the assumption of a lifeless ocean to the thought that all Pre-Cambrian organisms may have lived at the surface of the sea and none on its bottom, or all in the deep sea and none on its shores.

The need for such speculation has at last been obviated by the discovery in the Ediacara Hills in South Australia of a rich deposit of Pre-Cambrian fossils. The first finds at this site were made in 1947 by the Australian geologist R. C. Sprigg. In sandstones that were thought to belong to the lowest strata of the Cambrian he came upon varieties of fossil jellyfish. Sprigg's find was followed up by other geologists and by students under the leadership of Sir Douglas Mawson, who found some



PRE-CAMBRIAN SEASHORE AREA, **reconstructed from fossils found in South Australia, supported several types of animal. Some are shown stranded in dried-up mudholes (*A*) and on sand of beach, where they were fossilized. Others appear (*lower left*) in sand and**

plantlike impressions that appeared to be algae. Some time later two private collectors, Ben Flounders and Hans Mincham, brought to light not only large numbers of presumed fossil jellyfish but also segmented worms, worm tracks and the impressions of two different animals that bear no resemblance to any known organism, living or fossil. These discoveries prompted the South Australian Museum and the University of Adelaide to undertake a joint investigation of the region. Re-examination of the geology now showed that the fossil-bearing rocks lie well below the oldest Cambrian strata. This finding, taken together with the nature of the fauna represented in the fossils and their evident relationship to certain fossils discovered in South Africa before World War I and more recently in England, established that all these fossils date from the Pre-Cambrian era.

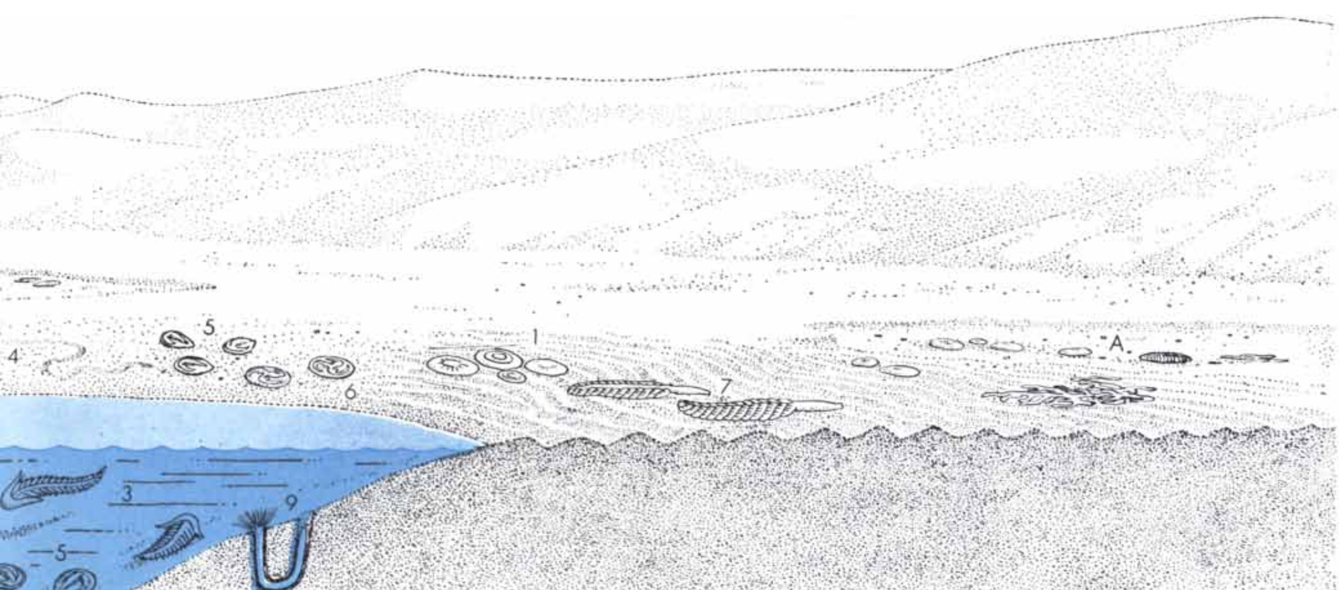
To date some 600 specimens have been collected in the Ediacara Hills. The fauna include not only jellyfish representing at least six and probably more extinct genera but also soft corals related to the living sea pens; segmented worms with strong head shields; odd bilaterally symmetrical animals resembling certain other types of living worm; and the two animals that look like no other living thing.

All the Ediacara animals were soft-bodied; none had hard shells, and their soft tissues were strengthened by nothing more than spicules: needles of calcium carbonate that served as a primitive support. All, of course, lived in the sea, some fixed to the bottom, some crawling and others free-floating or swimming. Their preservation is due to rather unusual, though not unique, conditions. The animals lived or were stranded in mud flats in shallow waters. Their impressions or their bodies were molded in the shifting sands that washed over the flats and were preserved as molds or casts in sandstone, mostly on the lower surfaces of sandstone beds. The resulting rich and varied assemblage of fossil animals gives the first glimpse of the marine life of the Pre-Cambrian era. It is a glimpse not merely of several types of animal but also of an association of creatures living together in the sea.

The soft-bodied nature of these fossils justifies the characterization of the Pre-Cambrian as the "age of the jellyfish." The term jellyfish, however, applies to a number of highly diverse and only remotely related forms, of which the most common belong to the coelenterate phylum. These are animals that alternately take the free-swimming medusoid, or jellyfish, form and the sedentary polyp form. Sprigg concentrated on the medusoid jellyfish among his finds. He arranged some of them in two classes and four orders that have living representatives and placed the more commonly occurring specimens, which he called *Dickinsonia,* in a more problematic position with respect to living forms. But further study has indicated that none of the Pre-Cambrian medusae can be tied with any confidence to living orders, suborders or families.

Greater interest perhaps attaches to the leaf- or frondlike stalked fossils that Sprigg apparently took to be algae. The stalk is some 12 inches long and three-quarters of an inch wide. The body measures up to nine inches long and four and a half inches wide; it is characterized by transverse ridges branching off from either a tapering median field or a median zigzag groove and divided in turn by longitudinal grooves [*see bottom illustrations on page 75*]. No living algae display such structures. The true nature of these fossils appears in specimens that show the impressions of spicules in the stalk and along the lower edges of the side branches. These suggest the spicules of otherwise soft alcyonarian corals living today and identify the fossil fronds as animals of the coelenterate phylum rather than as plants.

One group of modern corals—the sea pens (*Pennatulacea*)—has a similar arrangement of spicules, along with the stalk and side branches. Thus the fossils

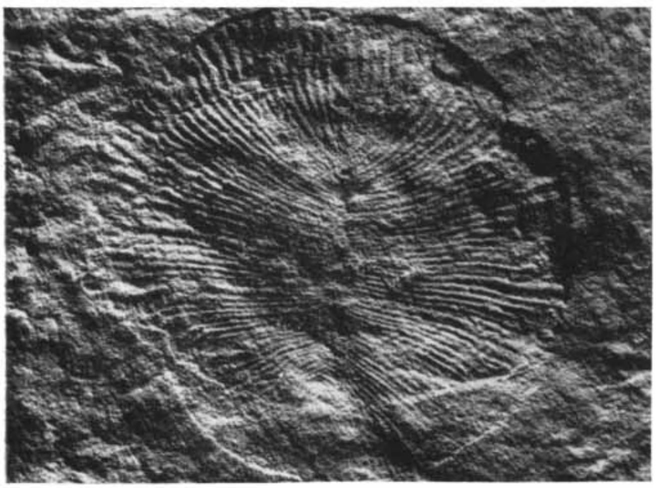


water as though seen in an aquarium. They are jellyfish-like creatures (*1*); the wormlike *Dickinsonia* (*2*); the segmented worm *Spriggina floundersi* (*3*) and worm trails (*4*); *Parvancorina* (*5*), which resembles no other known animal; *Tribrachidium* (*6*), another unknown type; the sea pens *Rangea* and *Charnia* (*7*); hypothetical algae and sponges (*8*), and a worm in a sand burrow (*9*).

appear to be sea pens, which are normally rare in the geological record. The differences between the Pre-Cambrian sea pens and the modern animals are remarkably small, considering the 600 million years of evolution that separate them. In the living sea pens the frond is either deeply dissected into movable side branches or it forms an entire plate-like body. In the fossil the lateral ridges are separated by furrows and not by open slits. Coral polyps that occupy the surfaces of the fronds and stalks in modern sea pens are so small that they would not be apparent in the rather coarse sandstone casts of the fossils.

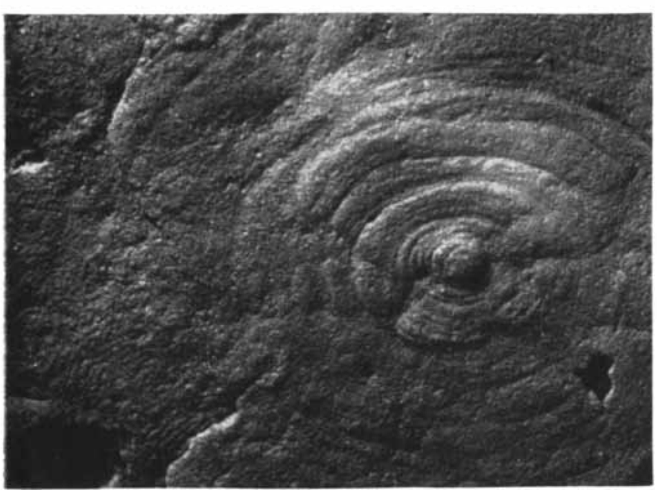
The Australian frond fossils are similar to those discovered before World War I by German geologists in Southwest Africa. Those fossils were named *Rangea* and *Pteridinium*. The Pre-Cambrian fossil discovered recently in England and named *Charnia masoni* also resembles certain of the fossil Australian sea pens. The English fossil seems to possess a circular disk with concentric ribs at the end of the stalk opposite the frond. Although the connection between these two structures is uncertain, it may be that this fossil represents the two alternating coelenterate forms, that is, the free-swimming medusa and the branching colony of small polyps that remains fixed to the ocean bottom. In this case one might speculate that the Pre-Cambrian sea pens grew from free-swimming, solitary medusae. But this is as yet pure guesswork about the reproductive processes of long-dead organisms. Further discoveries may prove or disprove the connection between fronds, stalks and disks.

The most spectacular finds in the Pre-Cambrian strata of South Australia were small annelid worms named *Spriggina floundersi* after their discoverers, Sprigg and Flounders. They had a narrow, perfectly flexible body up to one and three-quarter inches long, a stout horseshoe-shaped head shield and as many as 40 pairs of lateral projections (parapodia) ending in needle-like spines. A pair of fine threads projected backward along the sides of the body from the lateral horns of the head shield, and another thread probably grew from the segment behind it [*see illustration at top right below*]. Although such worms no longer exist, they resemble the living marine *Tomopteridae,* which have similar but wider heads, transparent narrow bodies and parapodia ending in flat paddles [*see illustration on page 76*]. These modern worms, because of their special paddle adaptation to the free-swimming life,



PRE-CAMBRIAN FOSSILS preserved in sandstone are seen in these eight photographs. This is *Dickinsonia costata,* shown actual size.

SEGMENTED WORM *Spriggina floundersi,* shown about twice actual size, resembles certain segmented worms living today.



JELLYFISH *Spriggia annulata* is one of the many types of this organism that have been found. The fossil is very slightly enlarged here.

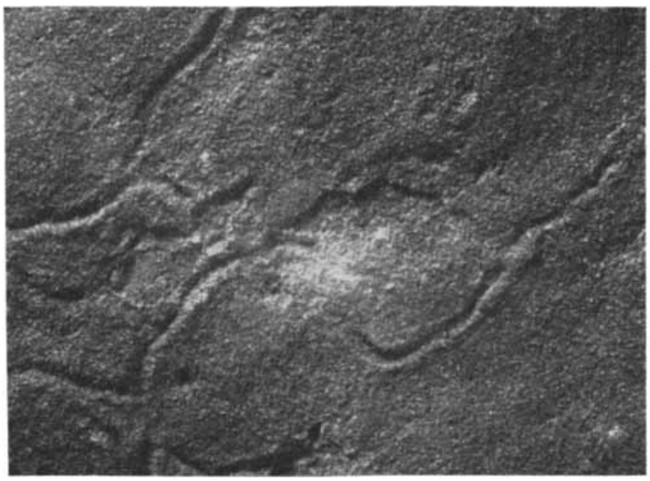
ANOTHER JELLYFISH, *Medusina mawsoni,* is shown nearly three times actual size. Jellyfish were the first fossils found.

had not been considered primitive or of ancient origin. It now appears, however, that they are directly descended from extremely ancient forms. The shape of the head of the Pre-Cambrian worms suggests the possibility of a relationship between them and the arthropods, such as the now extinct trilobites, which first appear in large numbers in the Cambrian. All of these later animals represent a considerable advance over the primitive anatomical organization of the coelenterates.

The most common fossil at the Ediacara site, the *Dickinsonia,* represented by more than 100 specimens, may also be related to living worms. The fossilized bodies are quite remarkable. They are more or less elliptical in outline, bilaterally symmetrical and are covered with transverse ridges and grooves in a distinctive pattern. The size of the bodies and the number of ridges vary so much that Sprigg attempted to distinguish species by counting the ridges. One recently discovered specimen has some 20 ridges; a larger one may have had as many as 550. The animals range in length from a quarter of an inch up to two feet. The numerous impressions of wrinkled and folded-over specimens indicate that all were soft-bodied, for there are none of the fractures that would be apparent if the creatures had possessed shells. These animals vaguely resemble certain flatworms living today. There is also one genus of annelid worm with a strikingly similar pattern of ridges formed by extensions of its parapodia. This similarity proves little or nothing, especially since no traces of eyes, legs or intestines are preserved in the fossils, but it provides some hope of finding out what these strange creatures were.

There is possibly less hope of placing in the family tree of the animal kingdom the two completely novel forms discovered in the Ediacara Hills. One had a shield- or kite-shaped body with a ridge that looked like an anchor. It was named *Parvancorina minchami* [*see illustration at top right below*]. The first specimen was tiny, but others found later measure up to one inch in length. Some show faint oblique markings within the shield on both sides of the mid-ridge, as if the animal had had legs or gills underneath. Here again folded and distorted specimens occur, proving that their bodies were soft.

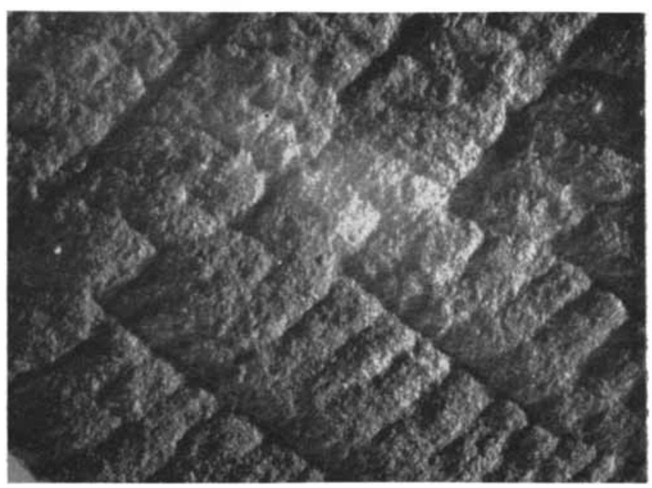
The other entirely new creature is even stranger. Named *Tribrachidium,* it has three equal, radiating, hooked and tentacle-fringed arms [*see illustration on the cover of this issue*]. Nothing like it has ever been seen among the known



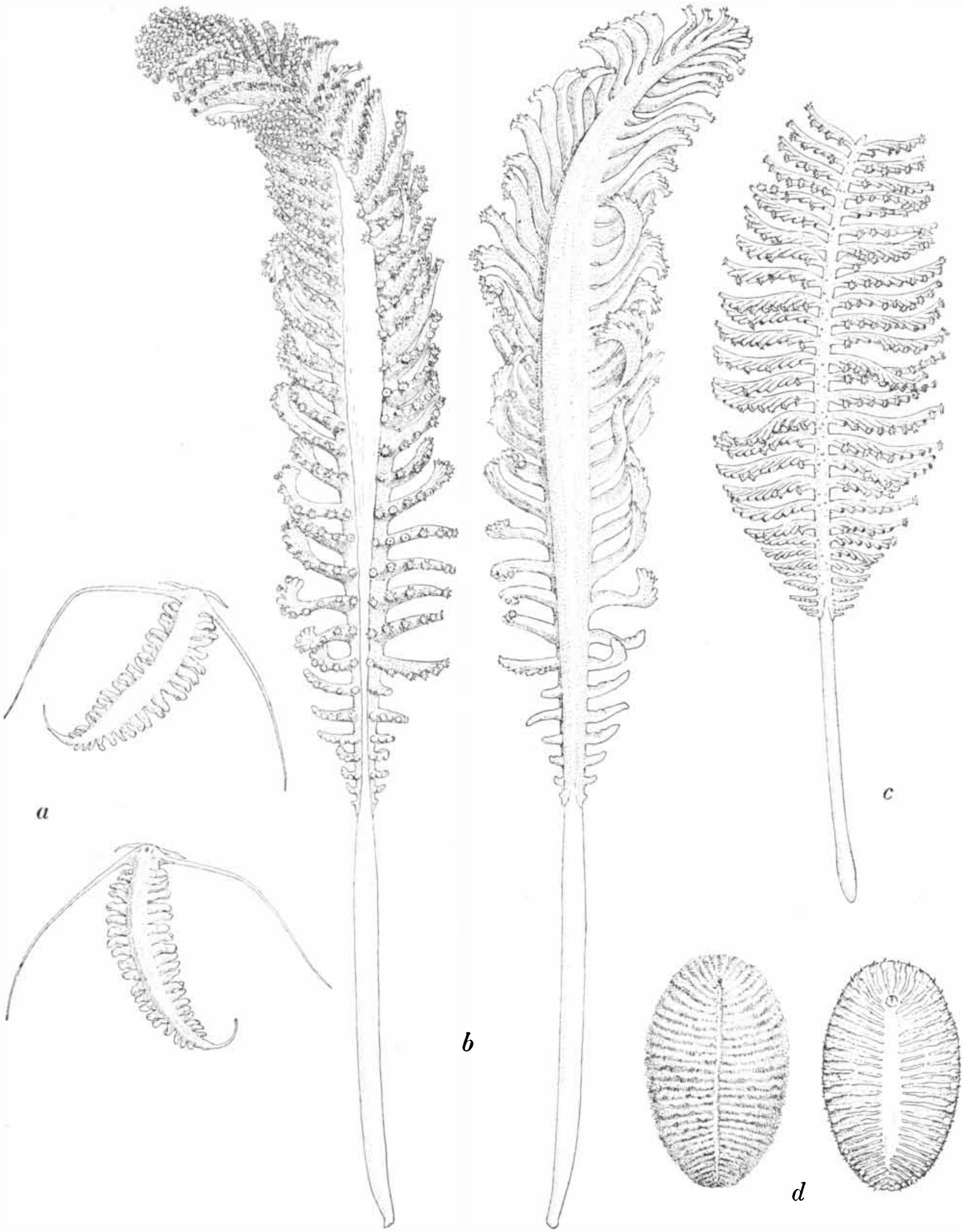
WORM TRAILS, approximately actual size, provide proof that fossilized worms lived in the area where they were preserved.

UNKNOWN TYPE OF ANIMAL, *Parvancorina minchami,* here enlarged nearly three diameters, resembles no other known organism.

SEA PEN *Rangea arborea* left this imprint, shown here twice actual size. The fossil resembles some of the living sea pens.



ANOTHER SEA PEN, *Charnia,* is shown actual size. Viewing photographs upside down may give fuller idea of animals' appearance.



FOUR LIVING ANIMALS that resemble some of the Pre-Cambrian fossils from South Australia are a segmented worm, *Tomopteris longisetis* (*a*), seen in dorsal and ventral views; sea pens *Pennatula rubra* (*b*), shown front and back, and *Pennatula aculeata* (*c*); and the worm *Spinther citrinus* (*d*), which looks like the many specimens of *Dickinsonia* in the Pre-Cambrian rocks.

millions of species of animals. It recalls nothing but the three bent legs forming the coat of arms of the Isle of Man.

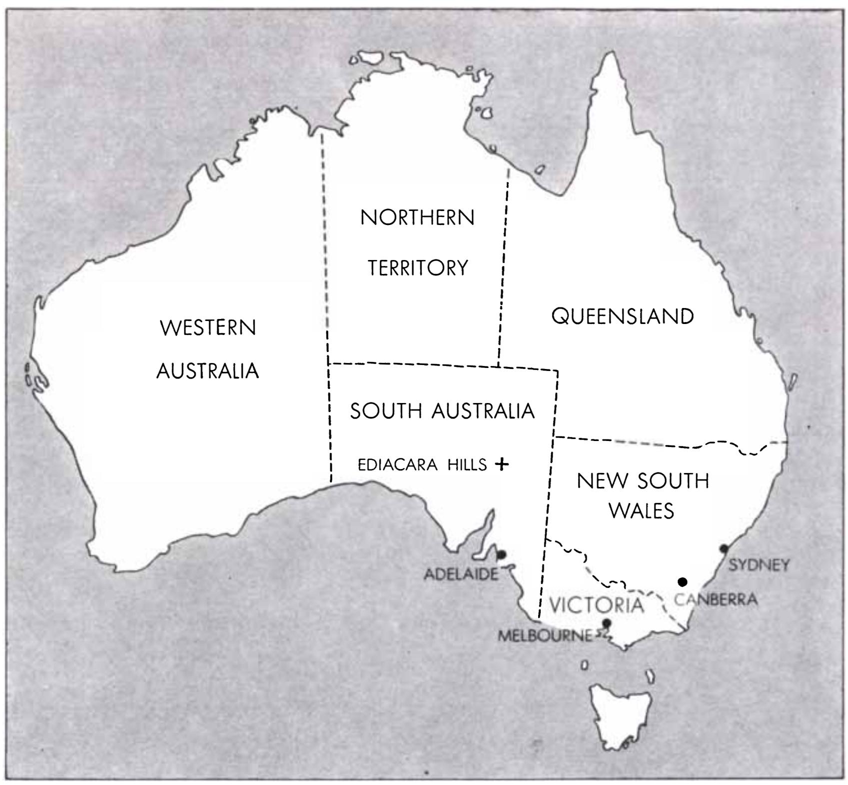
Considered together, the South Australian fossils suggest a rough and incomplete picture of conditions in the late Pre-Cambrian. Of course, such a group of fossils constitutes no more than a small, biased sample of the life of the time. Animals buried together in slabs of sandstone did not necessarily live together. Some, if they really are medusae, were floating in the sea. Others, like the annelid worm *Spriggina*, with its numerous legs and sinuously curving body, were free-swimming. *Dickinsonia* was probably also a free-swimming form, apparently along with *Parvancorina*. Scattered miniature treelike stands of sea pens, waving their flexible fronds, must have covered parts of the shallow sea floor. Elsewhere earthworm-like annelids, which have left only their tracks, crawled over and through the sediment, feeding on the decaying organic matter in it. Other worms inhabited the U-shaped burrows that have been found, consuming tiny creatures in the sediment and possibly also marine plankton, which left no traces in the rock. The fixed, three-rayed spread of tentacles of the strange *Tribrachidium* may be similar to the plankton-fishing structures around the mouth of the living brachiopods (lamp shells), bryozoa (lace corals) and some worms. If that is correct, *Tribrachidium* may have been a bottom dweller, possibly occupying low, conical, ridged cups, of which a few impressions have been found.

Bundles of impressions of needle-shaped spicules also occur in the Ediacara strata. Since spicules are characteristic of sponges, these sessile, bottom-dwelling animals may have been present. Snails and small crustaceans, as well as various protozoa (radiolarians and foraminifera), may also have existed at that time, but they would have been too small or too fragile to be preserved. Plant life likewise left no traces here.

The worm tracks are the only fossils indicating without doubt that the animals lived where their remains are found. Thus the *Spriggina* worms, the *Dickinsonia* and *Parvancorina* may have lived near or on the sedimentary beds. They are represented by individuals varying in size and growth stage, which indicates accidental death rather than transport from afar and later burial. On the other hand, the jellyfishes were probably stranded and the soft corals torn from their anchorage before they came to rest on the bottom.

The sandstone in which the fossils are found shows ripple marks and other evidences of currents, which would have had to be rather strong to transport the coarse grains of sand. Thus it is difficult at first to see how imprints of delicate, soft-bodied creatures could have been preserved. Careful study of the fossils has yielded an explanation. Only a very few of the animals came to rest on the shifting sand. Most of them came down on mud flats or on patches of fine clay that settled out of the water during calmer periods. Some of the mud patches dried out, possibly between tides, and developed deep cracks. The next high tide or shifting current covered them with a layer of sand. The lower surfaces of such sandy layers preserved the clay surfaces in the form of perfect casts, showing the wrinkles in the clay and the cracks formed by drying as well as the shapes of the animals stuck in the clay. The sand grains were cemented by silica solutions and turned to quartzite in the transformation from soft sediment to hard rock. The clay changed to thin slatelike streaks of the mineral sericite and was compacted almost beyond recognition. Since the sericite inclusions are small and irregular, the rock does not split along their surfaces as slate would. Only the slow, natural weathering in the arid climate of South Australia can open up the rock along the vital sericitic partings where the fossils occur. Slabs of quartzite of all sizes remain in place, projecting from the hillsides until they break off. They often turn over when moving downhill and their lower surfaces become exposed to the infrequent rain. Then the weathering causes them to reveal their wonderful riches of Pre-Cambrian animals. But if the rocks are not collected, the fossils are ultimately worn away by the weather and by the sand drifting in on the wind from the adjoining desert plains.

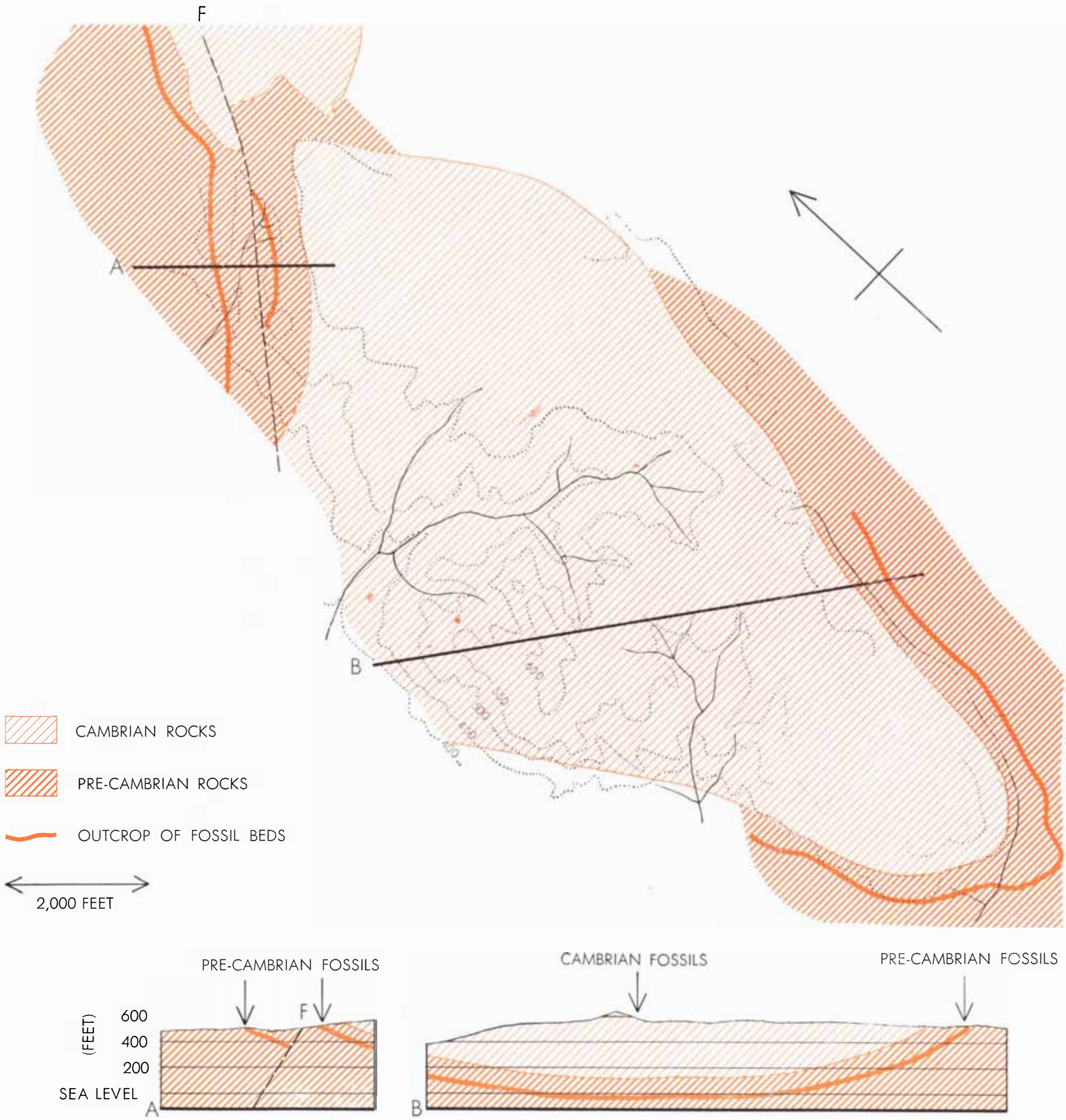
The age of the fossil-containing rocks cannot be determined directly in years because it does not contain radioactive minerals suitable for dating. Fortunately in the Ediacara Hills one can follow the stratification in unbroken sequence upward until the first undoubtedly Cambrian fossils are reached in dolomitic limestone 500 feet above the Pre-Cambrian level. These fossils in the limestone are typical of the lowest Cambrian strata elsewhere and are quite unlike the strange fossil organisms in the quartzite



LOCATION OF PRE-CAMBRIAN FOSSIL BED is in the Ediacara Hills (*cross*), some 300 miles north of Adelaide. The geologist R. C. Sprigg made the first discoveries there in 1947.

below. The quartzites higher up in the Cambrian strata do not contain any fossils of the type now known from the Pre-Cambrian, and the dolomites and limestones lower down contain no Cambrian fossils. From this distribution of fossils in the rocks it can be judged that the lack of shells and hard skeletons (other than the spicules) in the Pre-Cambrian animals was not due to any factors in the physical environment. The development of shells in the Cambrian was not a result of a sudden change in the habits or habitats of the animals. Rather, shells appeared as a step forward in biochemical evolution. Calcium metabolism underwent a change that produced hard shells and other skeletal material, providing the protection and mechanical support so important to the more advanced animals.

This is as far as the paleontologist and geologist can take the story today. The biochemist and physiologist may see in it a lead to experimentation that could well open a new chapter in the story of fundamental research in evolution.



MAP AND CROSS SECTIONS OF SITE where fossils are found show relative positions of Cambrian and Pre-Cambrian rocks. Lines *A* and *B* indicate locations of cross sections *A* and *B* (*below map*). Broken line *F* is a fault that has caused part of Pre-Cambrian fossil bed to move, creating two outcrops (*left*). Pre-Cambrian bed is under Cambrian rocks, except where its edges come to surface at periphery of Cambrian area. Dotted lines indicate contours. Part of the region shown here has been included in a fossil reserve.

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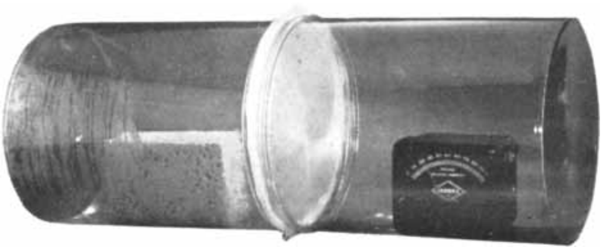

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To send for our salesman and his samples, write Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company.) Let him hint at new frontiers in fish-dipping, raisin-spraying, chicken-plucking, meat-freezing, and sealing the cut end of a hand of bananas so that the stalk can be left back at the plantation.

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So much buy, buy, buy on all sides! Many a scientific man says the clamor is too overwhelming. Perhaps it is unwise to irk him further by suggesting that his own kind bears no small part of the credit for having caused the din to be set up.

In the early 1900s Sir William Ramsay, the physical chemist who discovered the noble gases, strongly advised a student of his named Mees to get a job in industry instead of following the traditional scientist's livelihood of teaching. The young fellow therefore went to work for Wratten & Wainwright, a small firm that made photographic plates. Actually, until not so long before, Mrs. Wratten, the senior partner's wife, had been making them in her kitchen, quite successfully flowing the emulsion from a teakettle onto glass.

But young Mees brought science into the operation. The union of science and industry was blessed with new products for Wratten & Wainwright. They attracted the attention of Mr. Eastman, of Kodak, who decided it would be good for *his* business, too, to apply some science to it. Instead of emulating Wratten & Wainwright, he bought their business and brought Mees to Rochester, N. Y., U.S.A., as Kodak's research director. This happened in 1912.

After 43 years in the job, Mees retired and wrote a book about his experiences in nurturing the chemistry and physics of one industry to churn out the stuff that has to be bought, bought, bought. His long, happy, and fruitful life ended last year. This month the book will be coming out under the title "From Dry Plates to Ektachrome Film" (Ziff-Davis Publishing Co., New York, $5.95 at many camera shops). It is recommended to those who want a very grown-up viewpoint on photography and its technology. It may also prove instructive to scientists in general who have made or are contemplating a switch from the world of scholarship to the world of commerce.

Like the other great founding fathers of industrial scientific research, Mees never needed advance warning to deliver an hour's lecture on almost any subject, accurately and wittily. Readers with fairly broad scientific educations will get the most out of his book. By going into considerable technical detail about the origins of products of ours, the book may even find new customers for them. Of necessity, the details are old enough to be told.

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