

which is enriched in volatile elements (27), accreted later than the other meteorites, even though the white inclusions in the carbonaceous chondrites are older.

We are presently investigating further the initial Pb problem by means of an internal isochron. However, the small initial Pb change discussed above hardly affected the ages of achondrites because these leads are very radiogenic and the time difference is significant.

In conclusion, we observed clear evidence for a time difference either in the formation of meteorites or in metamorphic events. Averaging the ages of the same type of meteorites or of a class of meteorites may not have significance beyond enabling us to obtain a mean age of formation. The older ages reported here, 4.56×10^9 years for Angra dos Reis and 4.57×10^9 years for Beardsley, coincide well with the moon's age. The moon's model age, originally reported from the Apollo 11 study and further documented from subsequent missions as 4.63 to 4.65×10^9 years (26), is recalculated to be 4.56 to 4.58×10^9 years on the basis of new U decay constants. This mutual consistency in the age allows us to state the age of these members of the solar system as about 4.57×10^9 years. In the present investigation emphasis has been placed on obtaining the precise age measurement, which is of great significance in resolving small time differences, as well as on obtaining the primordial Pb isotopic composition which is the most fundamentally important parameter for Pb isotope research.

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Fossil Parasitic Copepods from a Lower Cretaceous Fish

Abstract. *Well-preserved Lower Cretaceous fossil copepods related to the superfamily Dichelesthioidea have been collected from the gill chamber of the ichthyodectid fish Cladocycclus gardneri. The fossils provide conclusive evidence supporting recent theories that link caligid copepods, which are parasitic on fish, to the invertebrate-associated siphonostomes. This is the first discovery of fossil parasitic copepods, and they are by far the oldest copepods of any sort known.*

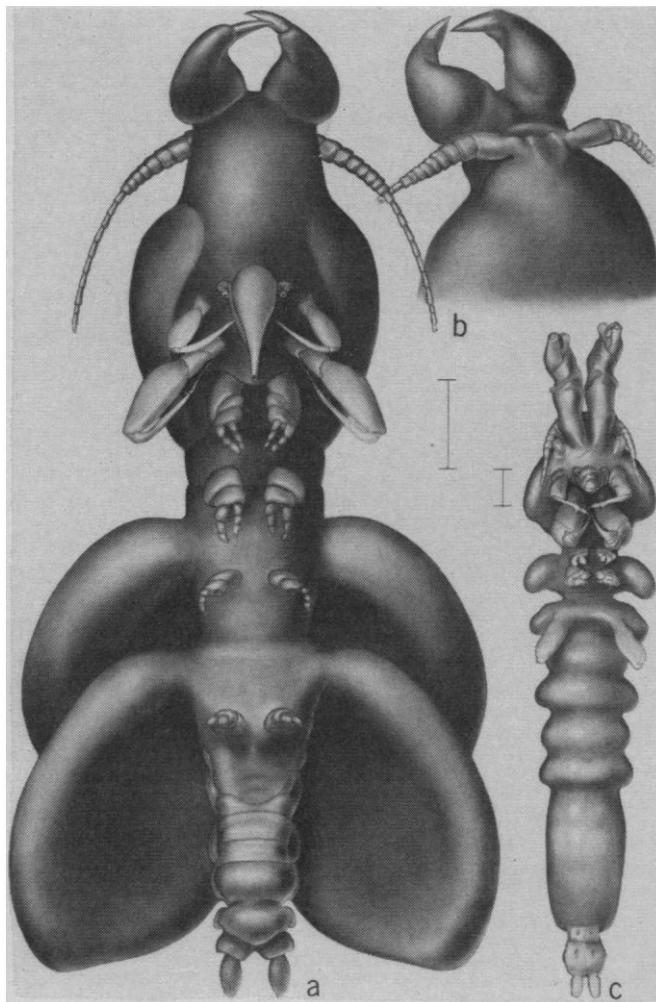
Copepod crustaceans, both free-living and parasitic, are abundant in marine and freshwater communities today. In spite of this ubiquity, and a taxonomic rank that implies an origin in Paleozoic times, copepods are extremely rare as fossils. A few fossils of free-living forms are recorded, the earliest from the middle or upper Miocene (10 to 20 million years ago) (1). This is a report of the first discovery of fossil parasitic copepods, dating back approximately 100 million years.

The specimens reported here were found by one of us (C.P.) in the gill chambers of two skulls of the teleost fish *Cladocycclus gardneri* Agassiz (family Ichthyodectidae) during an acetic

acid preparation of the fish by the transfer technique (2). These fish are from the Santana Formation, Serra do Araripe, Ceara, Brazil, which is well known for abundant, uncrushed fish preserved in limestone nodules. The Santana Formation is of Lower Cretaceous age, probably Aptian (3, 4). One skull yielded parts of three copepods, one of them almost complete; the other skull yielded fragments of two or three individuals. The specimens were coated with platinum and examined with a Cambridge Stereoscan microscope.

The fossil copepods are preserved in the round and are solid objects, not exoskeletons. They are composed of a substance identical in appearance to

Fig. 1. (a) Ventral aspect of a female parasitic copepod. (b) Dorsal aspect of the anterior portion of the head of the fossil. (c) Ventral aspect of a female *Dichelesthium oblongum*, an extant relative. The longer scale is 0.1 mm and applies to (a) and (b); the shorter scale is 0.5 mm and applies to (c). [Artwork by Carolyn Gast]



uniquely preserved ostracods from the same two nodules, which are replaced by apatite (5).

Figure 1 is a reconstruction of the female copepod, based primarily on two fragments representing one almost complete individual. No other fragments of the posterior portion of the body have been found, but details were added to

the reconstruction from other heads. Scanning electron photomicrographs of the fossil are shown in Fig. 2. Preliminary examination of the collection indicates that a male specimen may also be present.

Occasionally, in older literature, references have been made to the remarkable similarity in the mouth cones of

siphonostome cyclopoid copepods and caligid copepods. Traditionally, siphonostomes have included forms with a typical cyclopoid body shape and a conical mouth tube, and have been regarded as either free-living or known to be associated (parasitically or otherwise) with a variety of sessile or slow-moving marine invertebrates. Caligids, on the other hand, have been characterized as possessing a conical mouth tube and a modified body form, and being parasitic on fish. These two groups remained taxonomically separated until recent reports (6, 7) suggested a much closer affinity. Lang (6) pointed out similarities in other oral appendages in addition to the mouth cone. He further suggested that both groups be united systematically within the cyclopoid group Siphonostoma (the other two groups being Poecilostoma and Gnathostoma). Our fossil evidence supports this proposal. The fossil appears to be intermediate between the siphonostomes associated with invertebrates and those parasitic on fish. Of the caligid groups it is clearly related to the Dichelesthioidea because of the body form and thoracic legs, while it retains (with the exception of the second antenna) cephalic appendages more like those found on the invertebrate-associated siphonostomes. In particular, the first antenna of the fossil is strikingly like that of present-day Ascomyzontidae, generally associated with echinoderms and sponges. It appears to be composed of approximately 20 segments, as in the ascomyzontids. The first antenna of modern caligids has a maximum of 14 segments in the genus *Nemesis*, with most caligids having considerably fewer. The second antenna of the fossil, however, is strongly modified for grasping

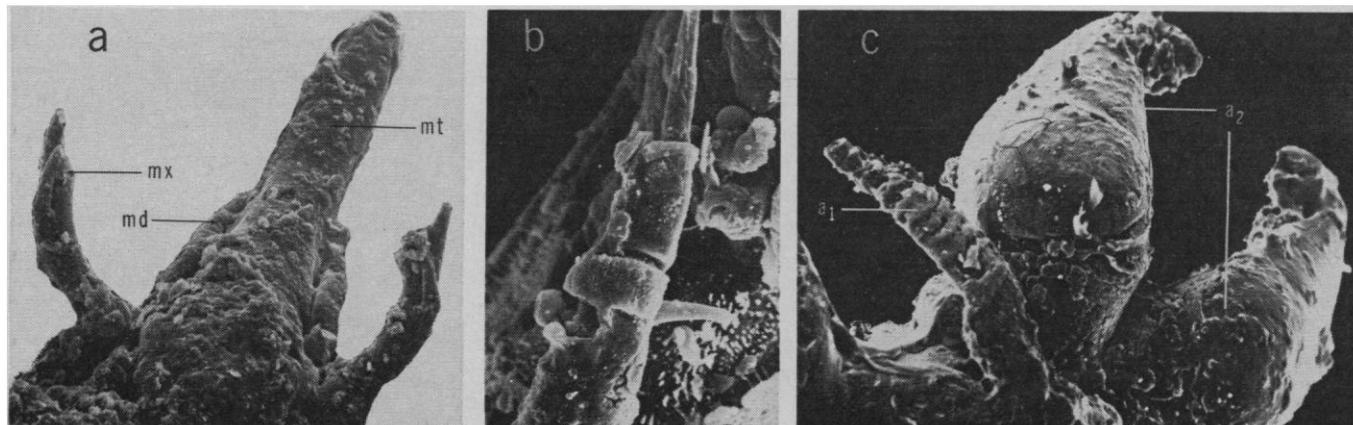


Fig. 2. Scanning electron photomicrographs of the fossil. (a) Mouth tube (*mt*), mandible (*md*), and first maxilla (*mx*) ($\times 275$). (b) Terminus of maxilliped ($\times 450$). (c) Dorsal aspect of the head showing basal portions of first antenna (*a₁*) and second antennae (*a₂*) ($\times 100$).

the host, as in most caligids; this is a modification necessary in the evolutionary transition from slow-moving invertebrate hosts to fast-moving fish (8).

Cladocyclus gardneri, the host fish, is a member of the Ichthyodectidae, an extinct group of primitive teleostean fish ranging from the Upper Jurassic to the uppermost Cretaceous. It is unlikely that the ichthyodectids are phylogenetically related to any of the extant teleostean cohorts (9), so that it is not surprising that *Cladocyclus* was host to copepods morphologically close to forms (*Dichelesthium*) now restricted to sturgeons. The fish-bearing horizons of the Santana Formation have been thought to be marine (10), brackish (3), or in part hypersaline (11), but ostracods associated with the two fish under discussion indicate that they, at least, died in fresh waters (5). The superfamily Dichelesthiioidea, to which the parasites are related, is exclusively marine. This suggests that *Cladocyclus gardneri* was euryhaline, acquiring marine parasites at sea and migrating into fresh waters. A recent analog would be salmon, where fishermen recognize fresh-run fish by the presence of sea lice on the gills. As far as we know, this is the first evidence of euryhalinity in any extinct species of fish.

The apparent rarity of fossil free-living copepods is probably mainly due to the fragility of these animals. Most parasitic copepods are much more heavily sclerotized than their free-living relatives, and might fossilize more readily. The association of our specimens with ostracods showing unique preservation of the appendages and soft parts (5) suggests that the occurrence is due to unusual circumstances, but we wish to alert those making acid preparations of fossil fish to the possibility of finding parasitic copepods.

Since it is universally accepted that all parasites evolved from free-living ancestors, the discovery of parasitic copepods in the Lower Cretaceous indicates that free-living copepods were in existence before that time, and greatly lengthens the fossil record of the class Copepoda.

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Silurian Echiuroids: Possible Feeding Traces in the Thorold Sandstone

Abstract. *Problematic trace fossils collected from the Middle Silurian Thorold Sandstone bear a striking resemblance to feeding traces made by the proboscises of modern echiuroid worms. Paleoecological approximations of depth and salinity may be possible depending on population densities. Echiuroids may have been a significant element of the Paleozoic benthos.*

The Thorold Sandstone is the lowest unit of the Clinton Group (Middle Silurian) found in southwestern Ontario. It is a "massive white to light grey, fine-grained, dense compact quartzose sandstone" (1) ranging in thickness from roughly 1.5 to 4 m. Body fossils are rare in the Thorold; however, the formation does contain a fascinating variety of trace fossils: tracks, burrows, trails, mounds, fecal aggregations, and problematic markings. Several of these markings are described here as having been made by echiuroid worms (phylum Echiuroida). If correct, this interpretation represents the first description of fossil echiuroid feeding traces, and the oldest occurrence of echiuroids in the fossil record.

Trace fossils reported here were collected at the Jolley Cut, Highway 403 and Sydenham Road sections, in or near Hamilton, Ontario. The best specimens came from scree blocks, and thus assignment of stratigraphic position is impossible.

As exposed on bedding planes, the traces are fan-shaped or bugle-shaped, occurring in imbricated series radiating from a focal area, in which there is often a depression possibly representing a burrow (Fig. 1). The "fan" may be relatively narrow, or may extend almost full circle; in some cases there is symmetrical development on either side of the focus. The half-dozen specimens examined average 5 cm long by 3 cm wide, and range in length from 3 to 7 cm.

In section, there is no three-dimensional nature to the fan-shaped traces, such as would be expected in *Arthropycus* or *Daedalus* (2). X-ray radio-

graphs of several specimens show definite "burrow" structures continuing downward from the focus of the fan. In some well-preserved specimens, these burrows continue down to the bottom of the block on which the feeding traces occur, a maximum distance of 5 to 6 cm. The configuration and maximum depth of the burrows cannot be determined.

The most logical explanation of the Thorold traces is that they are feeding traces left by some protrusible element of a burrowing invertebrate. This protrusible element must have been a single unbranched organ such as a palp or proboscis, rather than a tentacle ring. Very few modern animals meet these specifications. According to Seilacher's (3) classification of trace fossils, traces left by the protrusible element would be pascichnia, or grazing traces, while the central burrows themselves would be domicichnia, or more or less permanent shelters.

Live specimens of the echiuroid *Listriolobus pelodes* Fisher collected from Santa Barbara Channel, off Southern California, by K. Fauchald, were maintained in the original mud at the Santa Catalina Marine Biological Laboratory of the University of Southern California. The bodies of the worms were 4 to 5 cm long by 1 to 2 cm wide; the proboscis length was highly variable. The worms lived about 5 to 6 cm below the surface of the sediment, in "galleries" consisting of large horizontal cavities lined with mucus and having up to four sloping openings to the surface. On the surface of the sediment, the presence of the worms during an inactive phase was indicated by burrow