Alpert, 1976b

Depositional Environments of Lower Paleozoic Rocks in the White-Inyo Mountains, Inyo County, California

PACIFIC COAST PALEOGEOGRAPHY FIELD GUIDE

Editors

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October 16, 1976

Published by

The Pacific Section
Society of Economic Paleontologists and Mineralogists
Los Angeles, California
U.S.A.

Pacific Coast Paleogeography Field Guide 1

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INTRODUCTION

Trace fossils (or ichnofossils) are biosedimentary structures formed by the activity of living organisms on or in the substrate. The most common types of trace fossils are burrows, tracks, trails, and borings. In the Precambrian-Cambrian section of the White-Inyo Mountains, trace fossils are abundant and diverse and are evidence of the presence of many classes or phyla of organisms not represented by the also abundant and diverse skeletal fauna in the section. Most of the trace fossils present are sufficently distinctive to indicate the type of organism that made the structure. Trilobites made distinctive structures, as did molluscs and coelenterates (sea anemones). Cylindrical burrows probably were made by worms or worm-like organisms.

In the White-Inyo Mountains, trace fossils occur primarily in shale, siltstone and quartzite; very few are found in limestone. The great majority of trace fossils indicate intertidal to shallow water areas of deposition.

In sections such as this one, spanning the Precambrian-Cambrian boundary, trace fossils are important for the information they provide about early metazoans, and for their possible use in delineating or defining the basal Cambrian boundary.

TRACE FOSSILS AND THE ORGANISMS THAT MADE THEM

TRILOBITES

The trilobite trace fossils in the White-Inyo Mountains (Alpert, 1976) consist of four ichnogenera:

Rusophycus - bilobed resting burrows (Fig. 1A).
Cruziana - elongate bilobed furrows (Fig. 1B).
Diplichnites - walking trackways (two separated rows of individual inprints) (Fig. 1C).
Monomorphichnus - parallel scratchmarks made by lateral movement (Fig. 1D).

In addition, individual claw scratchmarks are present.

Rusophycus is the most common trilobite trace fossil, and is locally abundant in the Deep Spring, Campito, and Harkless Formations. Several species or forms each of *Rusophycus*, *Cruziana*, and *Diplichnites* are present (Alpert, 1976).

The trilobite trace fossils may be used to delineate the basal Cambrian boundary (see last section of paper).

MOLLUSCS

The only molluscan body fossils present in the Cambrian of the White-Inyo Mountains are small conical shells of probable molluscan affinities, but these are far too small to have produced the molluscan trace fossils that occur in this section. The molluscan trace fossils probably were made by primitive gastropod-like molluscs, possibly shell-less, that crawled or grazed horizontally on or within the substrate.

Typical molluscan trails consist of horizontal longitudinal grooves and ridges in varied arrangement (Fig. 1H-M), formed as the animal plowed through or crawled over the substrate. Some fossil forms are similar to modern mollusc trails.

If the animal burrowed horizontally within the sediment, a similar three-dimensional ribbon-like burrow may be produced. Transverse markings may be present, representing peristaltic movement or a backfilling of the burrow.

Various molluscan trails and burrows have been assigned many ichnogeneric names (such as *Aulichnites*, *Bolonia*, *Archaeonassa*, *Psammichnites*, *Subphyllochorda*, *Paleobullia*, *Didymaulichnus*, *Olivellites*, and *Curvolithus*) but possibly they all could be put into synonymy with the oldest genus, *Scolicia*.

Scolicia sp., consisting of a groove bordered by two lateral ridges, up to 50 mm in diameter (Fig. 1L), is common in the upper Poleta and basal Harkless Formations. The trails cover large bedding surfaces, commonly cross themselves, and may form distinctive loops. Transverse markings are not present. This ridge-groove-ridge formula also occurs at a much smaller scale in the trail *Archaeonassa fossulata* (Fig. 1H).

Less commonly, in the Campito and Harkless Formations, molluscan trails occur with groove-ridge-groove (Fig. 1K), and ridge-groove-ridge-groove-ridge (Fig. 1M) formulas.

A new genus of molluscan trail occurs in the Campito and Poleta Formations. These trails are flat, smooth, and ribbon-like, and 4 to 40 mm wide. The surface of the trail is smoother than the surrounding rock and commonly a different color. These are probably mucus trails of molluscs. Three species of these "smooth trails" are present (Figs. 1E-G): no longitudinal ridges or grooves; lateral ridges or grooves; median ridge or groove.

Also present are assorted wide trails, 3 to 9 cm wide, in the Campito and Harkless Formations, and annulated trails in the middle member of the Deep Spring Formation (Cloud & Nelson, 1966; Durham, 1974), which may be molluscan in origin.

WORMS

The following trace fossils were made by unknown organisms, most probably worms or worm-like animals.

Vertical unbranched burrows:

Skolithos - vertical, cylindrical burrows, about 5 to 15 mm wide (Alpert, 1975), (Figs. 2A, 4E).
Monocraterion - similar to *Skolithos*, but with a funnel-like expansion at the top of the burrow (Fig. 2B).
Laevicyclus - similar to *Skolithos*, but with circular markings on the bedding surface around the

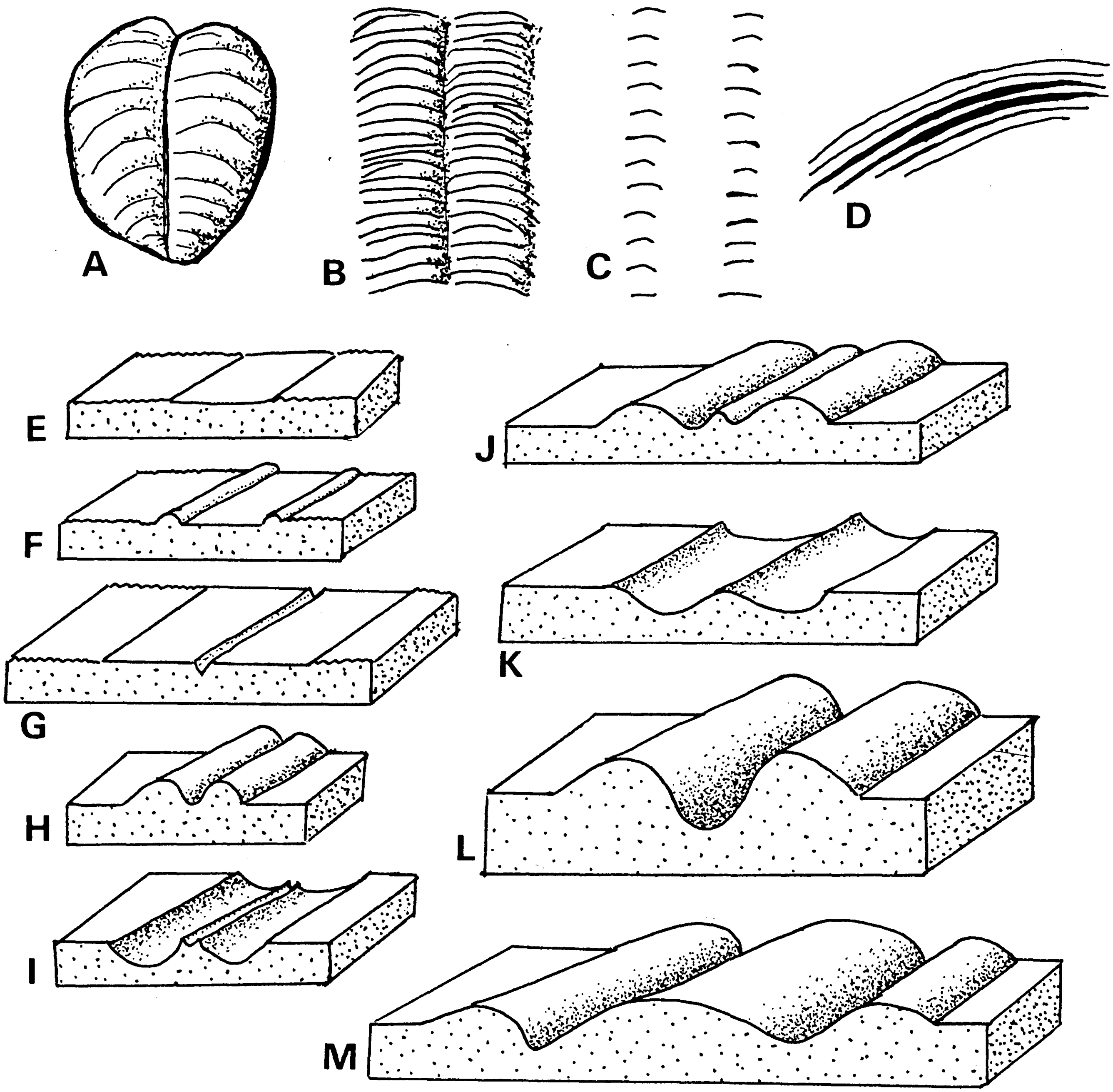

Figure 1. Lower Cambrian trace fossils.

A-D. Trilobite trace fossils, bedding plane views.

A. Rusophycus, x 1. B. Cruziana, x 1. C. Diplichnites, x 1.
D. Monomorphichnus, x 2.

E-M. Molluscan trails, oblique views.

E. smooth ribbon trail, x 1.5. F. smooth ribbon trail with lateral ridges, x 1.5. G. smooth ribbon trail with median groove, x 1. H. Archaeonassa fossulata, x 2.5. I. Archaeonassa, x 5. J. Scolicia, x 1. K. Scolicia, x 1.5. L. Scolicia, x 1. M. Scolicia, x 1.

top of the burrow (Fig. 2C).

Simple horizontal feeding burrows:

Planolites - unbranched cylindrical burrows, primarily horizontal, from 1 to 20 mm wide (Figs. 2F-I). Generally nondescript with an irregular course. This is the most abundant and widespread trace fossil in the White-Inyo Mountains (Alpert, 1975).

Cochlichnus - similar to Planolites, but burrow has a sinusoidal course (Fig. 2J).

Belorhaphe - similar to Planolites, but burrow has a zig-zag course (Fig. 2K).

Helminthopsis - similar to Planolites, but burrow has a loose meandering course (Fig. 2M).

More complex horizontal feeding burrows:

Palaeophycus - similar to Planolites, but with branching of burrows (Fig. 2L).

Phycodes - bundled, branching burrows (Fig. 2O).

Arthrophycus - similar to Phycodes, but with transverse constrictions (resembles branching crinoid stems), (Fig. 3A).

Zoophycos - circular feeding structure with spiral markings (Fig. 3B)

Star-like traces (Alpert, 1976) were possibly also made by worms (Figs. 2N,P).

Vertical feeding burrows:

Teichichnus - horizontal, cylindrical burrow that was systematically displaced upward or downward, forming a wall-like structure (Fig. 2E).

SEA ANEMONES

Sea anemones form trace fossils by burrowing vertically into the substrate until their oral end is more or less flush with the sediment surface. After the animal dies, the burrow is filled with sediment from above, and a cast of the burrow is formed, which closely reflects the aboral end of the anemone. Sea anemone burrows (or casts) have radial symmetry, are shallow to deep, and in general are larger in diameter than vertical burrows made by worms. Some burrows are hemispherical, others are cylindrical to conical with a rounded lower end. The casts commonly weather out of the rock (Figs. 4C,D).

The sea anemone ichnogenus Bergaueria (Figs. 4A-D) is common in siltstone and quartzite in the White-Inyo Mountains (Alpert, 1973). Specimens commonly occur in pairs (Figs. 4A,B). Bergaueria occurs in the Campito, Poleta, and Harkless Formations.

The ichnogenus Dolopichnus Alpert & Moore (1975) is also present (Fig. 2D). These anemone burrows are larger and deeper than Bergaueria and apparently contain a cast of the coelenteron or stomach, discernible as a cylindrical column in the center of the burrow. The coelenteron cast may contain stomach contents of the anemone, primarily trilobite hash. Dolopichnus occurs in the Poleta Formation.

STRATIGRAPHIC DISTRIBUTION OF TRACE FOSSILS BY FORMATION

WYMAN FORMATION

The Wyman Formation (9,000 ft, 2800 m) is the oldest formation exposed in the White-Inyo Mountains. Rare horizontal burrows (Planolites?) a few millimeters wide (Langille, 1973), from near the top of the formation, are the only trace fossils known.

REED DOLOMITE

The Reed Dolomite (2,000 ft, 610 m) consists of upper and lower members of dolomite (without trace fossils) and the middle Hines Tongue Member (up to 800 ft, 240 m thick). The quartzite and sandstone beds of the Hines Tongue contain questionable specimens of Planolites. Wyattia, the oldest shelled fossil in the section, occurs in the top of the Reed Dolomite and base of the overlying Deep Spring Formation.

DEEP SPRING FORMATION

The Deep Spring Formation (1,500 ft, 460 m) consists of three members. The lower member contains rare Planolites. The middle member contains Planolites and annulated trails and burrows which are uncommon in the quartzite beds. Shrinkage cracks that resemble trace fossils are abundant.

The first abundant trace fossils occur in the quartzitic sandstone of the upper member. The first trilobite or arthropod traces appear here. Rusophycus is the most common trilobite trace; Diplichnites and Monomorphichnus are also present. Planolites is common, Skolithos and Monocraterion are present but rare.

CAMPITO FORMATION

The Campito Formation (3,500 ft, 1070 m) consists of two members: the Andrews Mountain Member (about 2,500 ft, 760 m thick) and the Montenegro Member (about 1,000 ft, 310 m thick).

The Andrews Mountain Member comprises the lower two-thirds to three-fourths of the formation, and consists of interbedded dark-gray quartzitic sandstone, siltstone, and shale beds. The lowest trilobite in the section, Fallotaspis, occurs in the middle and upper part of the member, and is rare. Trace fossils in this member occur mainly on bedding planes and shaly partings between sandstone and siltstone beds; they rarely penetrate the beds more than a few millimeters. In the lower half of the member, below the trilobites, the following trace fossils have been found: Planolites, Scolicia, Archaeonassa, Rusophycus, Bergaueria?, Belorhaphe, Cochlichnus, and Helminthopsis. Also present are agglutinated worm tubes composed of imbricated mica flakes (Wiggett, 1973).

Above the lowest Fallotaspis, the trace fossils are more diverse and abundant, and include Rusophycus, Cruziana, Diplichnites, Planolites, Bergaueria, Arthrophycus, Phycodes, Teichichnus, Zoophycos, and smooth ribbon trails.

The contact between the Andrews Mountain Member and the Montenegro Member is gradational. In the Montenegro Member, shale predominates over siltstone and sandstone, and limestone occurs near the top. The first abundant trilobites occur in this member. The trace fossils present include Planolites, smooth ribbon trails, Archaeonassa, Skolithos, Monocraterion, Teichichnus, Cruziana, Astropolithon?, and Dactyloidites.

POLETA FORMATION

The Poleta Formation (1,200 ft, 370 m) consists of two members. The lower member, limestone with a thin shale unit, contains rare Planolites in the shale and limestone. Pellet-lined burrows are reported in the limestone by Nations and Beus (1974).

The upper member consists of shale, limestone, and quartzite units. Trace fossils below the quartzite unit include Planolites, Archaeonassa, smooth ribbon trails, Teichichnus, and trilobite claw scratchmarks. The quartzite unit near the top of the member contains abundant trace fossils. Skolithos is most abundant and forms a distinct marker bed. Also present are Planolites, Laevicyclus, Monocraterion, Scolicia, Bergaueria, Dolopichnus, Arthrophycus?, Rusophycus, and Psammichnites?.

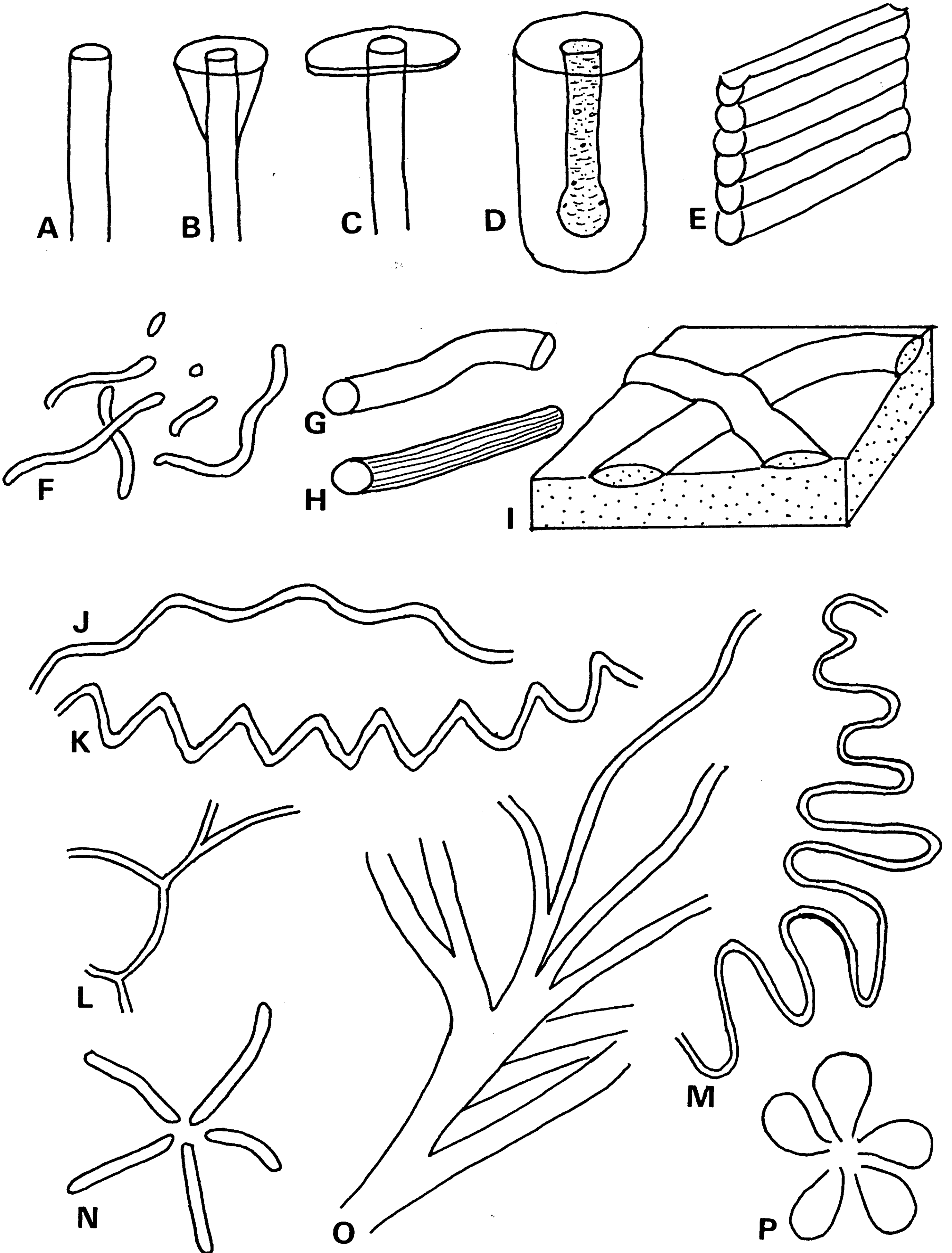

Figure 2

Figure 2. Lower Cambrian trace fossils.
A-E. Vertical trace fossils, x 0.7.
A. Skolithos
B. Monocraterion
C. Laevicyclus
D. Dolopichnus
E. Teichichnus
F-P. Horizontal trace fossils.
F. Planolites montanus, x 1
G. Planolites beverleyensis, x 0.7
H. Planolites striatus, x 0.7
I. Planolites virgatus, x 0.5
J. Cochlichnus, x 1
K. Belorhaphe, x 1
L. Palaeophycus?, x 1
M. Helminthopsis, x 0.3
N. Asteriacites?, x 1
O. Phycodes, x 0.5
P. Dactyloidites, x 1

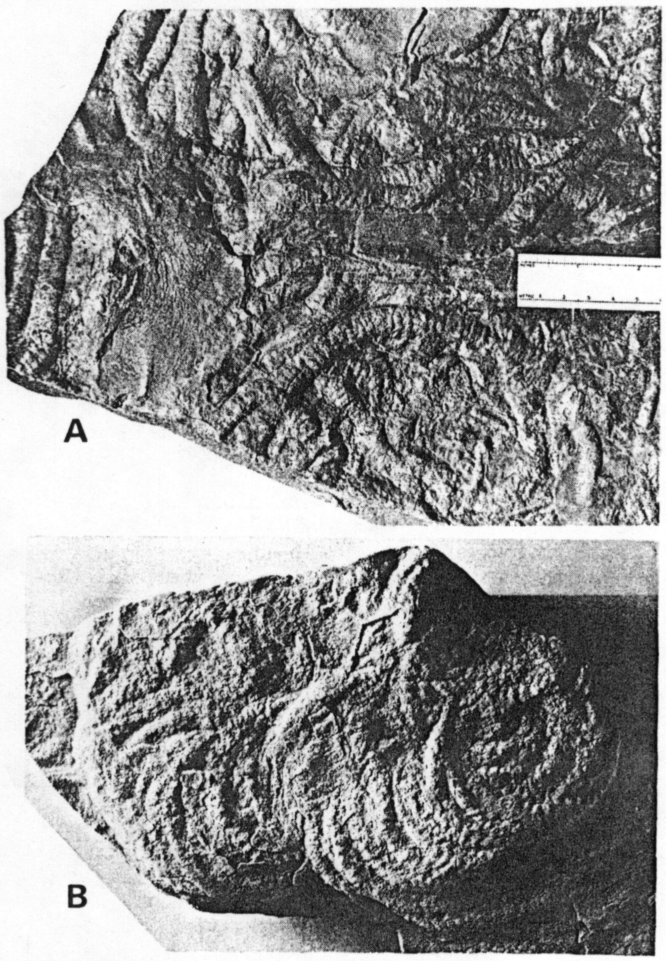

Figure 3. Trace fossils from the Andrews Mountain Member, Campito Formation. A, Arthrophycus. B, Zoophycos, x 0.6.

HARKLESS FORMATION

The Harkless Formation (2,000 ft, 610 m) consists of shale, quartzitic siltstone and sandstone, and quartzite. Trace fossils are abundant in the basal shale and siltstone beds, and include Planolites, Bergaueria, Rusophycus, Cruziana, Diplichnites, Skolithos, Monocraterion, Scolicia, Archaeonassa, and Asteriacites?. The quartzite units of the lower middle part of the formation (near Andrews

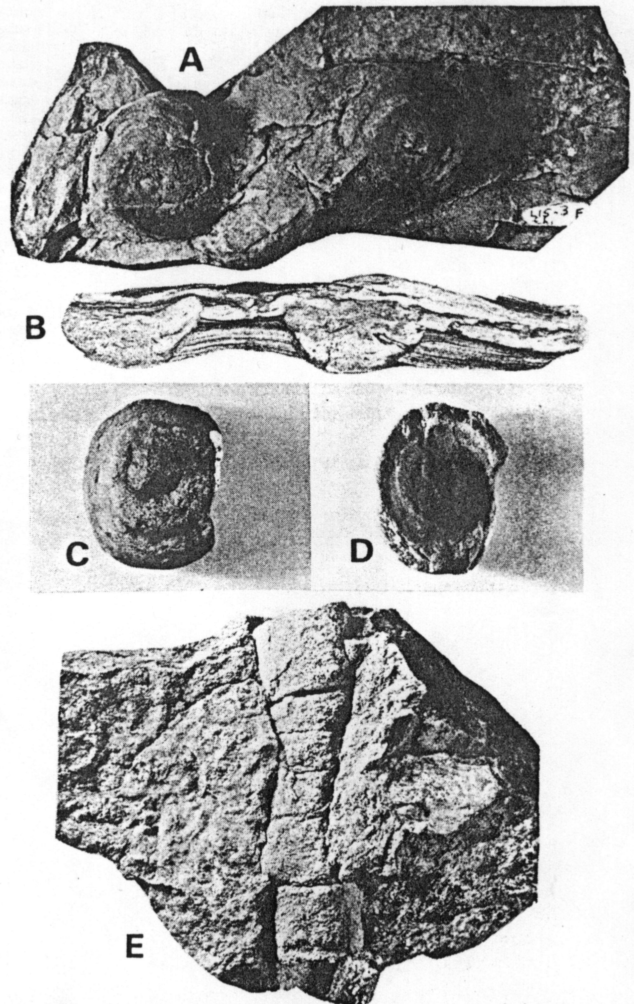

Figure 4. Trace fossils from the Poleta (E) and Harkless (A-D) Formations.
A-D. Bergaueria.
A. basal view of two specimens. x 0.6
B. vertical section through two specimens. x 0.6
C,D. weathered out specimen, basal and top views. x 0.8
E. Skolithos, side view. x 0.9

Mountain) contain Skolithos, Planolites, Bergaueria, Rusophycus, Monomorphichnus, Archaeonassa, and Teichichnus. No trace fossils were found in the upper half of the Harkless Formation.

SALINE VALLEY FORMATION

This formation (850 ft, 260 m thick) was not examined extensively for trace fossils, but Teichichnus, Planolites, and Cruziana were found in siltstone of the upper member of the formation.

TRACE FOSSILS AND THE BASE OF THE CAMBRIAN

The Precambrian-Lower Cambrian section in the White-Inyo Mountains displays the difficulties associated with the placement of the basal Cambrian boundary. The section lends itself to the study of the base of the Cambrian because it apparently spans the boundary and contains an abundant and diverse fauna of both body and trace fossils.

The Lower Cambrian extends downward at least to the presently known base of the Fallotaspis Zone, where the lowest trilobite body fossils occur, in the middle of the Andrews Mountain Member of the Campito Formation. However, if one includes all shelled metazoans in the Lower Cambrian, the base of the Cambrian would here be lowered to within the uppermost part of the Reed Dolomite, where the small, conical, shelled Wyattia occurs. Another possibility is placing the basal Cambrian boundary at the first unconformity below the lowest trilobite (here the base of the Reed Dolomite; the underlying Wyman Formation is considered Precambrian).

The interval between the lowest trilobite and the unconformity separating the Wyman Formation and Reed Dolomite has been referred to as "Cambrian or Precambrian?." Similarly labelled intervals occur in other Precambrian-Cambrian transitional sections around the world, where small shelled fossils, abundant trace fossils, or soft-bodied metazoans occur below the lowest trilobite, brachiopod, or archaeocyathid body fossils.

With the use of trace fossils to delineate or define the base of the Cambrian, the troublesome "Cambrian or Precambrian?" interval can be eliminated in most sections.

Stratigraphic sections that span the Precambrian-Cambrian boundary have been described, with emphasis on the contained trace fossils, from the following areas: southern Cordillera of Canada, east Greenland, Finnmark, southern Sweden, South West Africa, and southern and central Australia. Almost all bear similarities to the White-Inyo Mountains section in the relationship of the trace fossils to the body fossils. The general pattern that emerges is that in rocks of definite Early Cambrian age (above the lowest trilobite body fossils), trace fossils are abundant, diverse, and structurally complex. Below the lowest trilobites, in the "Cambrian or Precambrian?" intervals, trilobite trace fossils such as Rusophycus and Cruziana occur, along with other trace fossils. Below the lowest trilobite trace fossils, trace fossils are rarer and structurally simpler, primarily horizontal unbranched trails and burrows, or simple vertical burrows. The soft-bodied metazoans (Ediacara and similar faunas), where present, occur below the lowest trilobite trace fossils. Finally, in rocks of definite Precambrian age, trace fossils are very rare or questionable.

If the beginning of the Cambrian is to be based on the first appearance of trilobites, then the base of the Cambrian could be lowered to the lowest trilobite trace fossils, because trilobite trace fossils are an indication of the existence of trilobites or the trilobite grade of organization. The fact that trilobite body fossils are not found in the units containing the lowest trilobite trace fossils probably indicates that the earliest trilobites had unmineralized exoskeletons unsuitable for preservation.

I favor placing the base of the Cambrian just below the lowest trilobite trace fossils. In the White-Inyo Mountains section, this is at the base of the upper member of the Deep Spring Formation.

The use of trilobite trace fossils to delineate the base of the Cambrian enables the use of other trace fossils to be used as indices of the Lower Cambrian. Many trace fossils occur in the Lower Cambrian and below the lowest trilobite body fossils, but do not occur below the lowest trilobite trace fossils. Thus the presence of one or more of these trace fossils in rocks of Precambrian-Cambrian transitional sequences or in rocks of doubtful Lower Paleozoic or Precambrian age, would indicate a Cambrian age. These trace fossils can be used where trilobite traces are absent, or as a check on the use of trilobite traces to delineate the base of the Cambrian.

The non-trilobite trace fossils which can be used as indices of the Early Cambrian include the following ichnogenera: Diplocraterion, Monocraterion, Laevicyclus, Bergaueria, Phycodes, Arthrophycus, Zoophycos, Teichichnus, Rhizocorallium, Chondrites, Syringomorpha, Cochlichnus, Belorhaphe, Plagiogmus, and Psammichnites.

Ichnogenera which cannot be used in this manner, because they are known or reported to occur in rocks below the lowest trilobite trace fossils, include Skolithos, Planolites, Scolicia, Curvolithus, and simple, unbranched, horizontal trails or burrows.

In summary, the use of trilobite trace fossils as indices of Cambrian age and as an aid in delineating the base of the Cambrian is advisable for the following reasons.

1. The base of the Cambrian is still founded on the presence (though indirect) of trilobites.
2. The first appearance of trilobite trace fossils roughly coincides with the first appearance of other trace fossils (U-shaped burrows, anemone burrows, branched burrows, various feeding burrows). This relatively sudden appearance and abundance of trace fossils (made by arthropods, worms, coelenterates) probably represents the first explosive radiation and evolution among the metazoans, and thus affords a convenient and meaningful position for the base of the Cambrian.
3. Trace fossils are abundant and widespread in rocks of earliest Cambrian age.

The contents of this section are more fully discussed in Alpert (in press).

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