CHAPTER 5

RECOGNITION OF TRACE FOSSILS IN CORES

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INTRODUCTION

The Value of Trace Fossils in Core Studies

The study of trace fossils is a useful and necessary part of any core study and should be joined with other paleontologic, petrologic and sedimentologic data to give the most plausible geological interpretation. For the petroleum industry, cores, in many instances, are the best or only source of data for determining the paleogeography and paleoenvironment of subsurface deposits. Consequently, the study of trace fossils in cores becomes especially important in order to acquire the maximum information from costly samples. Such studies can be applied either to single facies or to a more general basin analysis.

In the course of an ichnological study, sedimentologic, stratigraphic, structural, paleontologic, paleoecologic, paleogeographic and paleoenvironmental data may be included. Sedimentologic events that are influenced by biologic activity include: 1) alteration of grains by ingestion; 2) disruption of fabric and creation of new fabric, which may reduce or increase permeability and porosity within beds or transmissibility between beds; 3) production of sediments by organisms, and 4) trapping of sediment by organisms (e.g., stromatolites, sabellarid worms; see Chapter 2). Some sedimentologic interpretations that can be made by investigation of certain traces include: 1) initial history of lithification; 2) rates of deposition; 3) current energy levels (Howard, 1964; Spencer, 1976); 4) relative amounts of erosion and deposition; 5) coherency (stability) of the medium burrowed; and 6) relative degrees of compaction (see Chapters 2 and 6).

Where the rocks are otherwise "unfossiliferous", trace fossils may provide biostratigraphic information (Seilacher, 1970). Trace fossils frequently have a biostratigraphic value as marker beds within particular basins (e.g., Oquirrh basin, Chamberlain and Clark, 1975).

Trace fossils, even in cores, also may be used for structural interpretation to recognize deformation of beds, or especially to recognize structural attitudes (top or bottom of beds).

Paleontologic and paleoecologic applications of core data may include evidence of soft-bodied animals, which is especially useful where the environment might otherwise be interpreted as a stagnant basin. Evidence for stages in the evolution of metazoans, and the evolution of behavioral and morphologic characteristics also may have biostratigraphic applications. Furthermore, trace fossils may yield pertinent information about the diversity of organisms or trophic levels in fossil assemblages, which may relate to paleogeography or local biostratigraphy.

Although borings (Chapter 4) and biolaminae (= stromatolites) are not discussed in this capter, they may be encountered in cores and provided data similar to that of other traces.

In the past, ichnological studies on paleoenvironments and paleogeography have been based largely on bathymetry (Seilacher, 1964; see Chapter 6). As a result, the use of trace fossils as bathymetric indicators became somewhat of a panacea among ichnologists. Currently, paleoenvironmental and paleogeographic interpretations that contain trace fossil information are based on more than bathymetry. Such studies are becoming increasingly more common and important because of the need for detailed environmental interpretation (e.g., for predicting reservoir geometry).

BIOTURBATION AND SEDIMENTARY FACIES

Bioturbation is extensive in most sedimentary facies, and bioturbated rock fabrics typically are well represented in core and outcrop samples. As a general rule, nonmarine deposits contain fewer trace fossils than marine deposits and thick, rapidly deposited beds contain fewer traces than slowly deposited ones. In some higher energy deposits, however, where the degree of bioturbation is less intense, individual trace fossils may be more distinct. Thin-bedded deposits tend to be more bioturbated than thick-bedded ones. Generally, the top few centimeters thick-bedded deposits are extensively reworked, whereas at the base they are only slightly reworked. (Chapters 2 and 6 go into more detail on these topics).

High energy facies, such as those found in riverine sandstones, Gilbert-type deltas (Mackenzie, 1971), storm deposits (Howard, 1972), and turbidite as well as other sediment gravity flow deposits (Chamberlain, 1975, 1978), typically have little bioturbation. Slowly deposited beds on continental shelves commonly are completely reworked by organisms. Similarly, fine-grained sediments on continental slopes, and in the deeper parts of basins usually are thoroughly bioturbated. (See Chapter 2)

CORES VERSUS OUTCROPS

The study of trace fossils in sawed rock slabs is a natural and necessary supplement to the direct study of trace fossils in outcrops. Each provides a different understanding of trace fossil morphology, the form of the trace maker, and the history of preservation. The study of trace fossils in cores, although similar to outcrop studies, is somewhat different however, as I explain below.

Outcrops provide numerous, broad surfaces for the study of trace fossils, including many depositional surfaces but, perhaps, fewer cross sectional surfaces than do cores. In addition, differential weathering of the outcrop surface reveals varying profiles into the structures of trace fossils. On the other hand, weathering normally is not pronounced in cored rocks; hence, surfaces are more uniform and do not provide varying profiles of the traces.

Outcrops provide relatively easy access to widespread lateral and vertical sequences and facies; however, cored wells normally are widely spaced. Consequently, cores provide less opportunity than outcrops for comparing lateral and vertical sequences. More cores generally are available in producing fields, particularly where they have been cut for reservoir engineering studies.

Outcrops were being studied long before technology made cores readily available; indeed, most geologists have had extensive experience studying outcrops. However, fewer geologists have such experience in core studies; fewer still where trace fossils are concerned. Yet most cores are cut in and around the most economically important facies -- the reservoir rock. Millions of dollars are spent each year to obtain cores, but seldom are reasonable proportional monies spent for developing the expertise to understand the geologic significance of the features and structures in the samples.

Outcrop study of trace fossils deals mainly with resistant beds of siltstone, sandstone, or limestone; the poorly preserved, softer siltstone, mudstone and shale are more difficult to study in outcrop. Cores, in contrast, may include well preserved, thick sequences of fine-grained sediment, particularly when they are cut in the center of depositional basins. DSDP cores are notably fine-grained, for example. Historically, geologists have less experience, and thus less awareness of the techniques for the investigation of fine-grained sediments, especially of the trace fossils in them.

The scale of features seen in cores commonly cannot be fully appreciated. Broad crossbedding as well as meter-wide looping burrows may be represented in cores by such a small part of the total structure that only limited interpretation may be possible. Again, larger features in outcrops have been given close attention, whereas smaller features have been less studied. Consequently, we have little basis for interpreting smaller features in cores.

ICHNOFACIES IN CORES

The study of trace fossils in cores is essentially a study of full relief preservation (e.g., Chondrites, Zoophycos, Teichichnus) (see Chapter 1 for defination of terms). Correspondingly, epireliefs and hyporeliefs have essentially not been studied. As a result, trace fossils in particular facies are not well known.

In the relatively massive beds of the Skolithos ichnofacies, full relief trace fossils (e.g., Skolithos, Diplocration, Ophiomorpha, Arenicolites) are more common than epireliefs and hyporeliefs. Horizons of epirelief and hyporelief traces interbedded with full relief traces are more readily visible in cores than in outcrops, however, because cores provide a more complete, vertical, unweathered sample.

Bioturbation generally is very intense in most lithologies of the Cruziana ichnofacies, and includes epirelief and hyporelief traces (e.g,. Scolicia, Fucuopsis) as well as equal numbers of full relief traces (e.g., Asterosoma, Teichichnus, Thalassinoides). However, because of their inherent characteristics, full reliefs are most easily studied.

The Zoophycos ichnofacies consists mainly of the full relief Zoophycos, but the facies is not always well developed. I am not aware of any core studies on this facies.

Fewer full relief trace fossils are known from the Nereites ichnofacies, where they probably occur mostly in shales. Few indurated sandstone, siltstone or limestone core surfaces are available in the Nereites facies for study of the more common epirelief and hyporeliefs (e.g., Lophoctenium, Scolicia, Helminthopsis, Paleodictyon, Spirophycus).

The ultimate consequence of bias from core samples is that full relief preservation is most easy to recognize and thus, fossils of this type are mostly commonly studied. More than this, the bias is toward recognizing only a few distinctive, or generalized, full relief cosmopolitan forms such as Chondrites, Zoophycos, Teichichnus, and Planolites (Warme et al., 1973; Chamberlain, 1975; Ekdale, 1974, 1977a, b; Ekdale and Berger, 1977).

CORE PROCEDURES

Trace fossils can be studied in whole cores, but the core surface generally is rough, having transverse grooves and scratches caused by rotation of the core bit and the core within the barrel. The surface is curved such that the traces mostly are cut at an oblique angle. Even so, the spatial relationships and form of the trace fossil can be studied in washed, whole, cores. As a result, many common forms can be recognized in whole cores (e.g., Chondrites, Zoophycos, Teichichnus, Ophiomorpha).

However, cores are traditionally quarter slabbed 4 cm (1 1/2") thick or cut in half to: 1) reduce the bulk, 2) provide a sample that does not roll, and 3) to provide a planar surface for study.

In the petroleum industry, most cores are cut within the cleaner, generally higher energy reservoir rock; commonly these cores represent the Skolithos ichnofacies, in which vertical burrows are the most common. Cores also are taken in the Cruziana ichnofacies, where stratigraphic tests often are made. Such cores generally penetrate more than the reservoir rock.

Stratigraphic tests in turbidite basins, such as in offshore California or subsurface Arkoma Basin, Oklahoma have been in the Nereites ichnofacies. Slabs of cores from these facies generally show longitudinal or transverse sections of more or less horizontal traces. The plan pattern of many trace fossils in the Cruziana or Nereites facies usually is critical for the identification of the trace fossils. Longitudinally slabbed cores have limited use for determining plan patterns; some forms can be determined by checking both sides of the slab to see the trend of burrows on both faces of the core. Even in the limited diameter of a whole core, enough plan pattern may be present for identification of certain trace fossils. Transverse cuts of cores provide planar surfaces that are approximately parallel to bedding. Such cuts usually provide a plan section of the trace fossil. Sawed traces of cores commonly are rough and grainy. Moistening heightens visibility of some traces; gylcerine in water prolongs wetness. Some surfaces may require polishing to get sharp enough detail to recognize morphologic characteristics and the relationship between the trace fossils and sediment.

Small trace fossils and highly bioturbated sequences are difficult to study. Thin, successive slabs through structures provide serial sections through structures that can be examined on all sides, furnishing a basis for three dimensional reconstruction of the trace. "Thin" sections, which are cut thicker than usual (30 to 75 um), make it possible to study fabric within and around the trace fossils. Sections such as these also show the relationship between the trace and surrounding sediments. This technique also may show the manner in which the trace was made. Staining techniques especially applicable to trace fossils are in early stages of development, but may be useful for enhancing visibility and, perhaps, as an aid for determining biologic affinities (Risk and Szczuczko, 1977).

X-ray radiography can record traces through the diameter of the core without damaging the core. Such an application is particularly valuable for obtaining trace fossil and other sedimentologic data from rubber-sleeve cores, which tend to disaggregate rapidly once they are exposed to air. Radiographs made from whole, or even half-cores, however, are difficult to make because the middle is denser than the edges. In addition, all structures are recorded on the single plane of the film. Stereo pairs and staining also can be beneficial for the identification of trace fossils, but many fine-grained sediments are too dense, or traces are too delicate, or traces have insufficient contrast in grain size or minerology, as compared to the host sediment, to be clearly visible in the radiograph.

CONCEPTUALIZED RECONSTRUCTION OF TRACE FOSSILS

Samples of trace fossils in cores are limited in several ways already described (e.g., planar surface transverse to trace). The nature of the data available (dictated by size, type of sample, method of preparation, and available time for preparation and study) requires development of increased acuity in observation and conceptualization. Fortunately, visualization and conceptualization, from one or two dimensions to three dimensions, are inherent skills of most geologists. One way to develop such perception is to be aware of some of the most common traces in particular ichnofacies, and their orientation in the rocks of the facies. A more detailed discussion can be found in Chapter 6, but I briefly summarize some of the pertinent characteristics are summarized here.

Generally, more horizontal or oblique trace fossils are displayed in cores than are vertical ones. The _Skolithos_ ichnofacies, which contains mostly vertical traces, for example, is relatively narrow, and commonly reworked during transgression or progradation. The _Cruziana_ ichnofacies, on the other hand, is relatively broad at any moment in time, commonly is preserved and contains more horizontal traces than vertical ones.

Interpretations of Traces from Cross Sectional Views

Core samples are cut and usually retrieved unoriented and random relative to trace fossil communities. Consequently, trace fossils in cores generally will not be cut truly transversely or longitudinally, but rather obliquely. If a slab face contains circular cross-sections of a trace fossil, the cut must have been: a) exactly transverse to the trace, or (b) through a spherical trace (see Fig. 1A).

If a slab face contains elliptical cross sections of a trace fossil, the cut must have been: (c) oblique through a circular burrow, (d) through ellipsoid or discoid traces, (e) transverse to an elliptical trace or (f) oblique to an elliptical trace (see Fig. 1A).

Confirmation of a trace fossil reconstruction can be made by comparing the opposite face of the slab with the original slab face. Generally, such a technique requires matches between both faces for (a) or (e), no matches for (b) or (d), and offset matches for (c) or (f) (See Fig. 1B). A face cut perpendicular to the slab requires continuation of traces through the slab for verification of (a), (b), (d), or (e), and offset matching of (c) or (f) (See Figs. 1C, D).

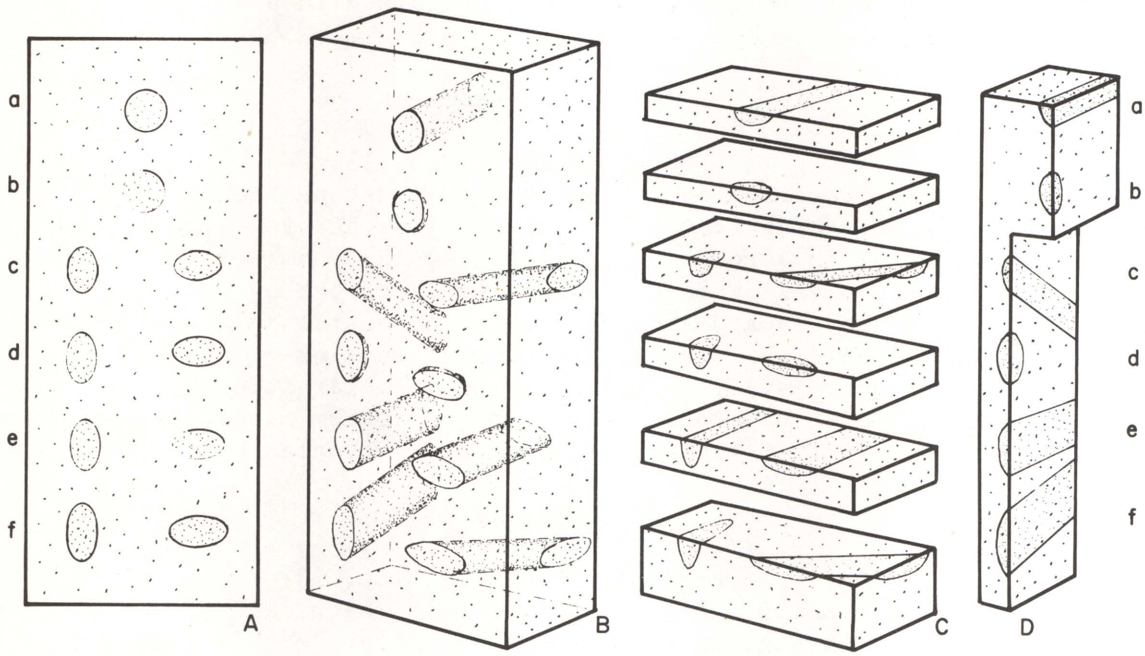


Fig. 1. Conceptual models of the shape and form of trace fossils depending on orientation and shape of burrow relative to surface of intersection of slab. A. forms on slab surface. Aa, Ab, circular outline. Ac-Ae, oval outline. Af, elongate oval outline. B. Actual three-dimensional forms and intersection on other surfaces of slab. Ba, circular tube, more-or-less perpendicular to surfaces of intersection. Bb, spherical structure. bc, circular tube, inclined or oblique to surface of intersection. Bd, ovoid structure. Be, oval-form tube, more-or-less perpendicular to surface of intersection. Bf, oval-form tubes inclined or oblique to surface of intersection. C. Transverse sections. D. Longitudinal sections. Diameter in C and D of _a_ and _e_ remain the same on face as through slab, but diameter of _c_ and _f_ is less within slab than on surface.

DESCRIPTION OF SELECTED TRACE FOSSILS COMMON (?) IN CORES

Arenicolites

Figs. 2B, 4-7, 70-75, 131

Simple, vertical "U"-shaped tube. Wall usually smooth. Tubes range 1-10 mm or more in diameter and "U" range 10 to 100 mm across. Preserved as full relief but may be recognized in plan view by paired tubes. Cambrian to Holocene.

Asterosoma

Figs. 8-10, 79-83, 131

Usually preserved on the bottom of sandstone beds as elongate, oval structures branching from a central point either fan-like or radially. Patterns 14-30 cm across. Individual ray 15-30 mm across and 30-80 mm long. Asterosoma is recognized in cross sections by concentric laminae of sand and clay packed about and below a central tube. Oblique and longitudinal sections display concentric ovals or elliptical laminae and transverse ones display circular or semicircular structures with the thickest and most numerous laminae on the bottom, indicating repeated and upward migration by downward packing. Devonian-Cretaceous.

Chondrites

Figs. 11-13, 84-89, 116, 131

Three-dimensional branching system in which each branch diverges at approximately 45 degrees from the previous tube either laterally or less inclinded horizontally. Tubes generally straight and equal width throughout. System ranges to several centimeters across, but typically 10-20 mm across. Tubes up to 15 mm across, but more commonly 1 mm diameter. Sections usually display short branching tubes. Ordovician-Holocene.

Composite Burrows

Figs. 13-16, 131

Consisting of one larger tubular burrow ranging from 2-5 mm across and one or more different smaller burrows and/or pellets within the larter one. Cambrian-Tertiary.

Serial sections enable matching from slab to slab and, although requiring numerous cuts, may provide more information than whole core, slab, and cuts perpendicular to slab (Fig. 2).

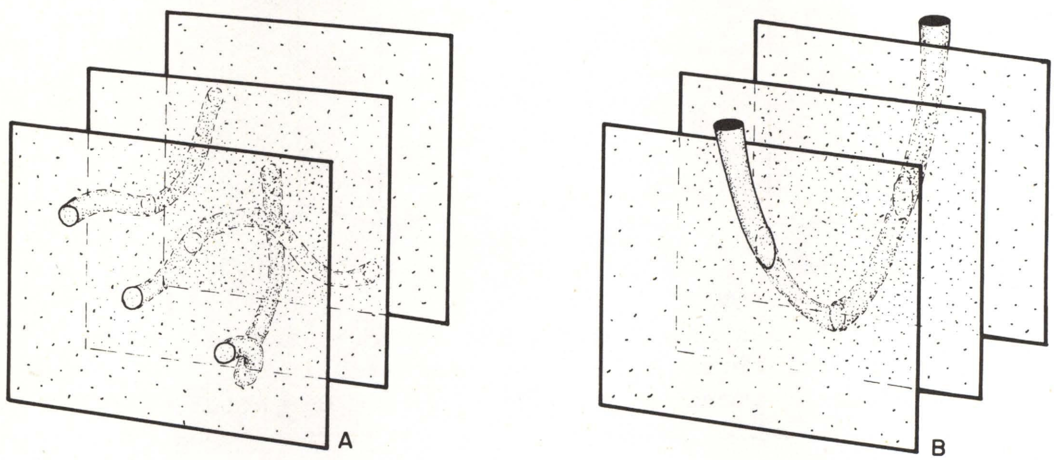


Fig. 2. Serial sections through burrows provide more detail than single surfaces. A. Meandering-forms may continue through the rock, as the one at the upper left, or deviate and loop as shown by the right two. B. Large Arenicolites, or similar simple structure, may be recognized only as oval or circular tubes in single section, but found to be something more important in additional cuts.

Traces having meniscate backfilling (e.g, Muensteria) or spreiten (e.g, Rhizocorallium, Zoophycos) can be differentiated by checking for tabular forms or circular cross section either in serial section, perpendicular cuts, or checking other sides of core or slab (see Fig. 3).

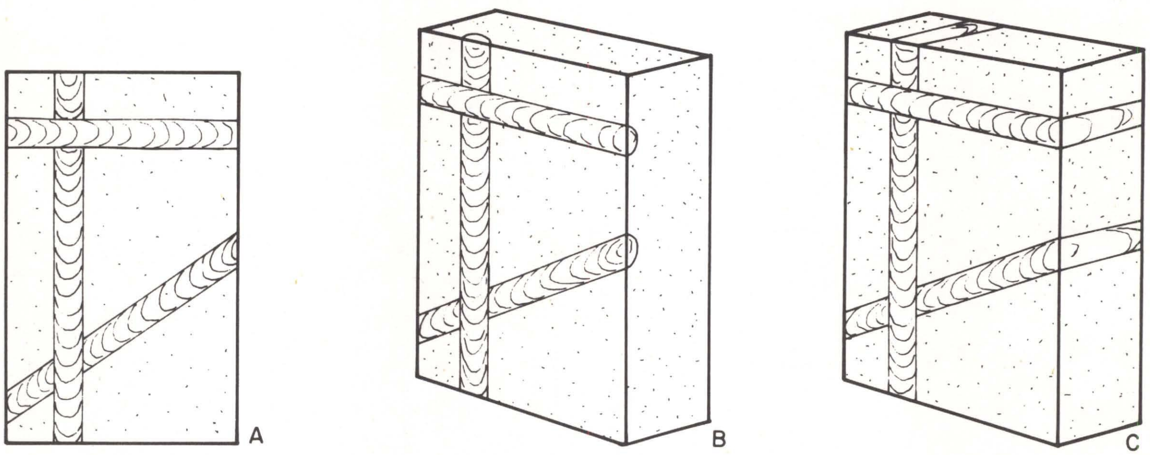


Fig. 3. A. Cross laminated structures in cores may be meniscate, backfilled burrows or spreite filled tabular structures. B. Actual form if meniscated tubes (e.g, Meunsteria). C. Actual form if spreite filled, tabular bodies (e.g, Teichichnus, Zoophycos, Diplocraterion).

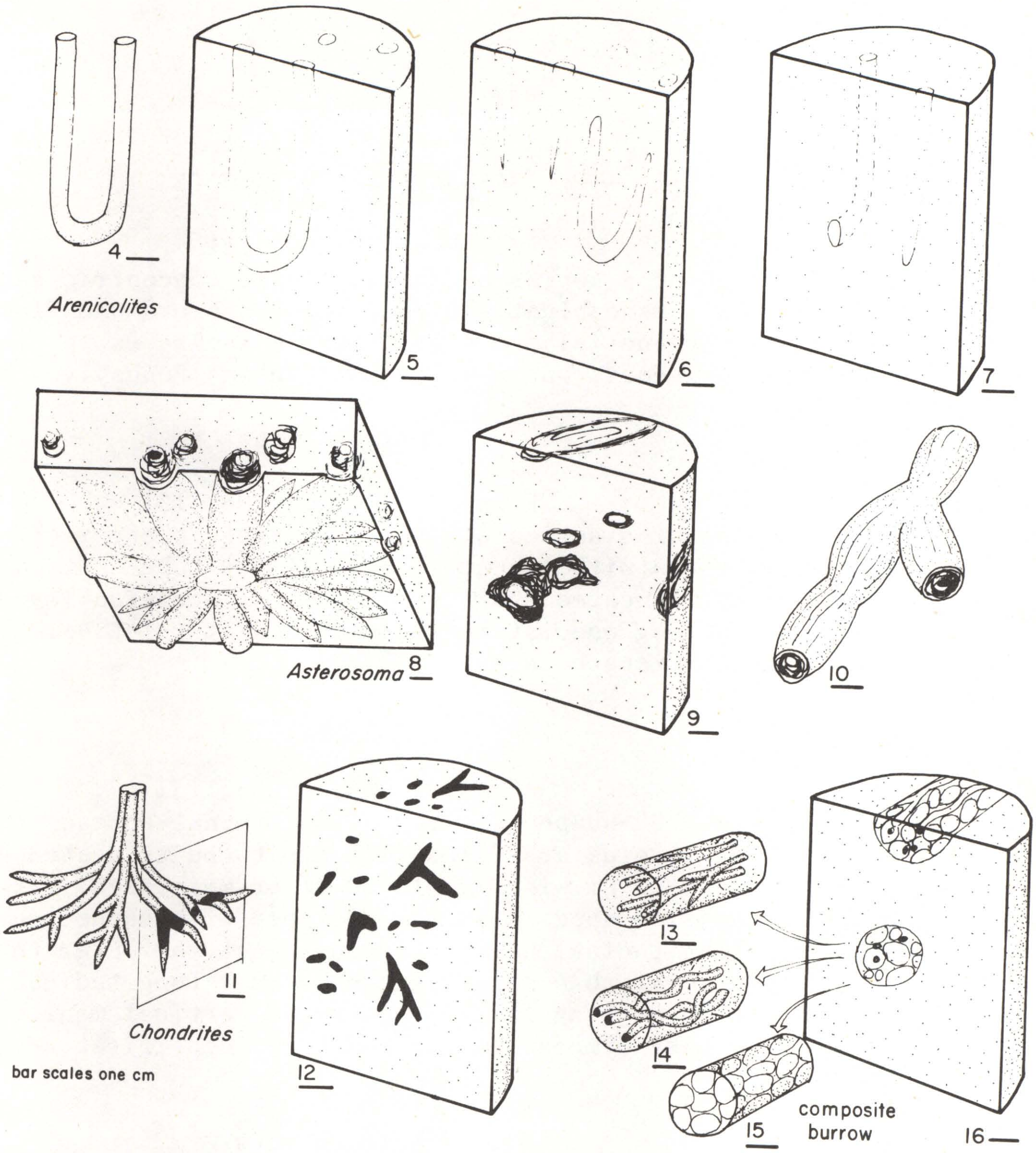


Fig. 4-7. Arenicolites. 4. A. sparsus. 5. Both sides of "U" within longitudinal slab. 6. Both sides oblique to longitudinal slab. 7. One side within slab and one from another "U" in cut surface thus appearing like Skolithos.

8-10. Asterosoma. 8. Radial form, (A. radiciforme) on base of bed. 9. Zoned (Spencer, 1977, personal communication): compare Echirus burrows (Reinceck, et al., 1968). 10. Branched (Dresser, 1970, written communication), typical Cretaceous form.

11-12. Chondrites. 11. Three-dimensional model. 12. Expressed in cores as circular and oval structures, sometimes branching, and usually light colored.

13-16. Composite burrow. 13. Chondrites within. 14. Helminthoida within. 15. Pellets within. 16. Composite burrow, with all three within larger burrow.

Conostichus/Bergauria

Figs. 17-20, 131

Built up of a series of short, broad, concentric sand and clay conical sheaths. Base blunt and rounded; top broad and flaring. Range 5-10 cm across and 7-15 cm high. Like Rosselia except for blunt base. Cambrian-Cretaceous, but mainly Cambrian and Pennsylvanian.

Cylindrichnus

Figs. 21-23, 105-106, 131

Built up of a series of tall, tapering, subconical, concentric sand and clay sheaths with a central sand-filled tube. Straight to curving. Top commonly truncated sharply by erosion, occasionally ends in a strongly tapering one. Like Rosselia except relatively taller. Mississippian-Cretaceous.

Diplocraterion

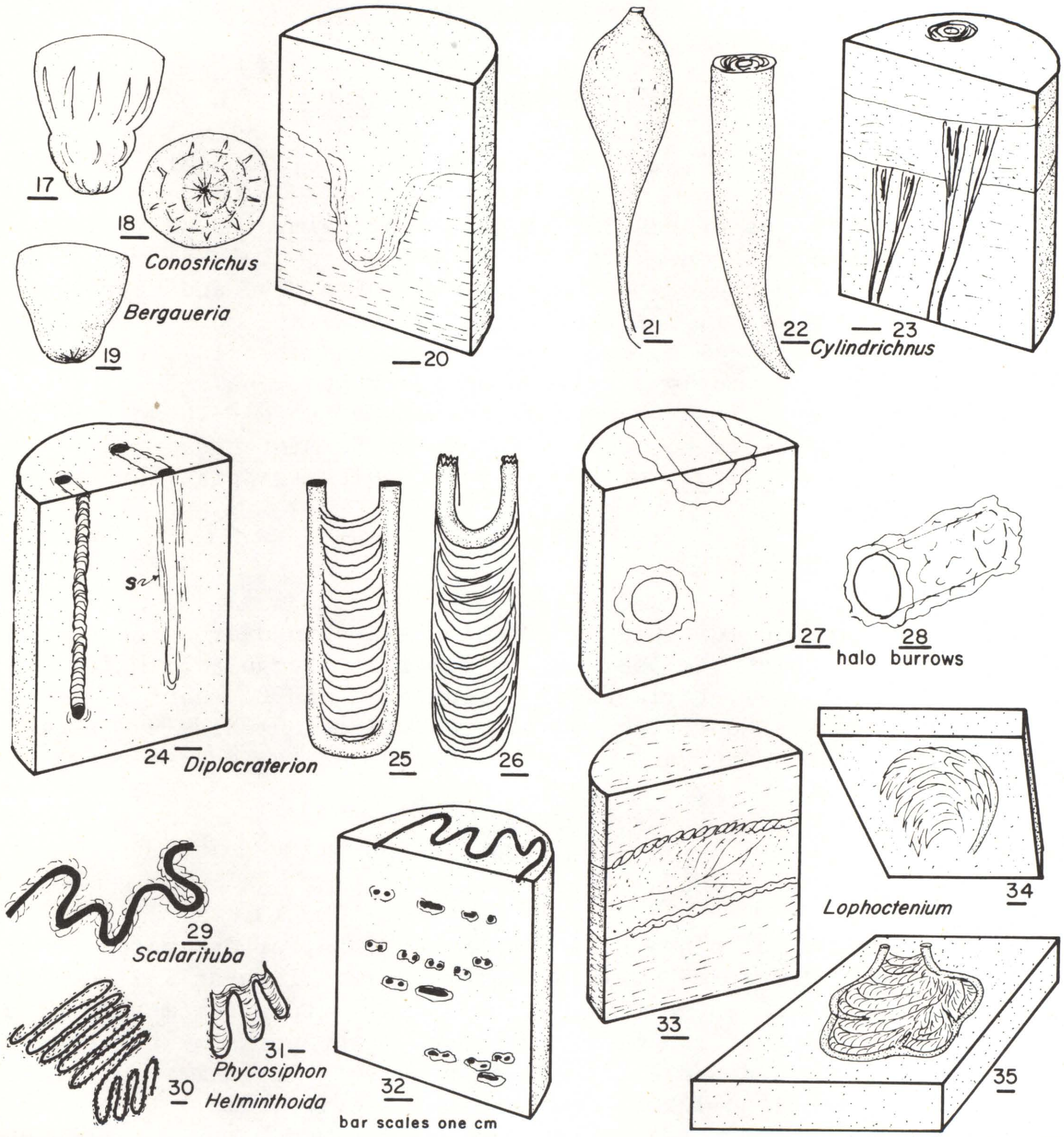
Figs. 20-26, 95-96, 131

Vertical "U"-shaped burrow having laminae spread across. Laminae may merge on margins as nested "U"s are to be truncated by an outer "U" tube. Range 3-15 cm wide and 15-60 cm or more high. Transverse section of Diplocraterion appears as paired tubes with connecting structure between. Longitudinal section through just the outer tube is distinguished by several thin concentric sheaths. Longitudinal sections through the connecting laminae appear as vertical meniscae and require checking further dimensions for positive identification. Cambrian-Cretaceous.

Halo Burrows

Figs. 27-28, 131

Some simple and composite burrows are defined by a diagenetic halo of light-colored material around or through the tube. The color change is gradual through 3 to 20 mm. The burrows range from 10 to 40 mm across. Cretaceous-Pliocene.



Figs. 17-20. 17-18, 20. Conostichus. 18. Bottom view. 20. Longitudinal section. 19. Side view Bergaueria.

21-23. Cylindrichnus. 21. With tapering top. 22. Truncated or open top. 23. Longitudinal section.

24-26. Diplocraterion. 24. Slabbed expression through spreite of retrusive form and through outer tube showing sheaths (s). 25. Retrusive. 26. Protrusive.

27-28. Halo burrows in core and model.

29-32. Helminthoida relationships. 29. Scalarituba, fecal ribbon form. 30. Helminthoida, basic looping pattern of a fecal ribbon. 31. Phycosiphon. 32. Helminthoida.

33-35. Lophoctenium. 33. Cross section in core. 34. Hyporelief. 35. Epirelief.

Helminthoida

Figures. 14, 16, 30, 32, 84, 87, 116, 118-121, 123, 131

The outcrop expression of classical Helminthoida is that of tightly looping fecal ribbons. In some forms, narrow lateral rigdes like Nereites are also preserved. Scalarituba (Fig. 24) and Phycosiphon (Fig. 31) can be similar, but the looping ribbons are much less regular than in Helminthioda. A common trace fossil in cores is that of continuous fecal ribons commonly displayed as horizontal, paired tubes with a halo between, around, and especially below the tubes. These are irregular meanders and it is not clear if this is Helminthoida, Scalarituba/Nereites, or Phycosiphon. Mississippian-Tertiary.

Lophoctenium

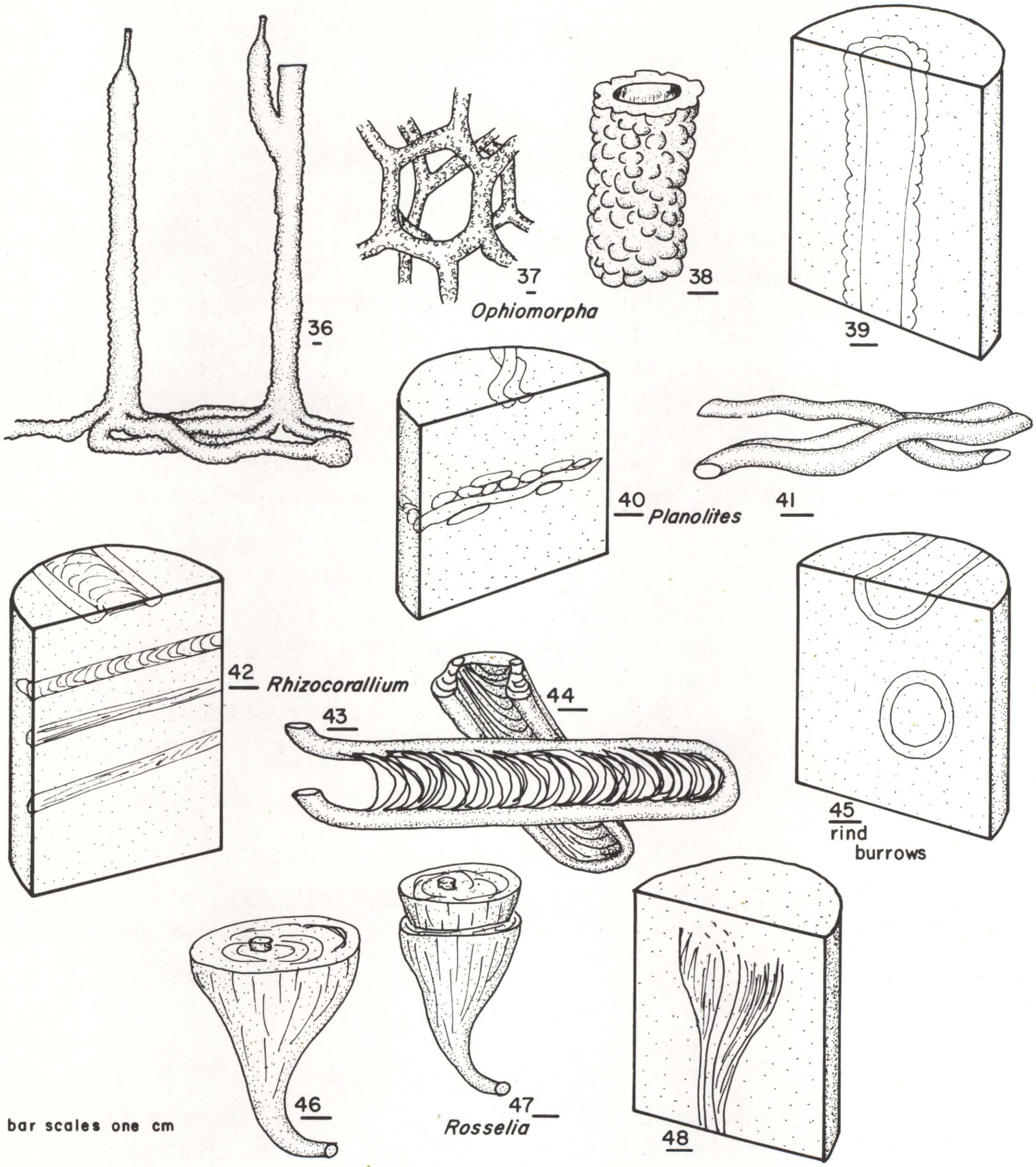
Figs. 33-35, 90, 131

Single and multiple subcircular fan-shaped areas covered with spreite in which the laminae are somewhat irregular. Major laminae are built up of smaller ridges of oblique laminae to major laminae. Similar to Zoophycos. Poorly known in cores. Sections display tabular structures in which top and bottom boundaries of the meniscae are corrigated. Ordovician-Tertiary.

Ophiomorpha

Figs. 36-39, 91-103, 131

Cylindrical pipes having a smooth interior and nodose, pelleted exterior. Range 3-5 cm in diameter, wall thickness 1-7 mm. Ophiomorpha commonly occurs as vertical stack a few cm to a few meters high, as complex, horizontal branching mazes, and as boxworks. The central gallery may be left void and later filled passively or it may be filled actively with meniscate laminae. Longitudinal sections display parallel bands having smooth surfaces toward one another and bumpy surfaces outside. Some horizontal ones show only pelleted lining on the top of the burrow. Permian, Jur.? - Holocene.



Figs. 36-39. Ophiomorpha nodosa. 36. Shafts and maze. 37. Boxwork 38. Enlarge view nodose exterior. 39. Shaft in core

40-41. Planolites, in core and free model.

42-44. Rhizocorallium. 42. Core expressions. 43. Horizontal form. 44. Oblique form.

45. Rind burrow in core.

46-48. Rosselia. 46. Single structure with central, sand-filled shaft. 47. Double endoconic structure. 48. Core expression.

Scalarituba/Nereites

Figs. 49-52, 117, 122, 131

Scalarituba is usually preserved as an interlaminar, meandering, meniscate ribbon of fecal material. The preservation on the top of beds has been called Phyllodocites and consists of a central furrow (sometimes containing alternate dark and light meniscae or a continuous ribbon) and parallel, lateral ridges made of smaller oblique ridge-furrows. The Neonereites view is on the bottom of beds and appears as a series of merging, alternating bumps. Transverse section displays the crescent-shape of the fecal ribbon or pellets with a disturbed area about it that bulges out on both sides. Cambrian-Tertiary.

Scoyenia

Figs. 53-54, 91-92, 131

Curvilinear rods with wrinkled or striated exteriors. Ranging from horizontal to vertical and 1-3 cm in diameter. Some may form branching boxworks. In cores Scoyenia appears as linear, circular, or oval structures in sane-in-sand having a very thin lining. Permian? to Holocene?

Skolithos

Figs. 55-56, 124-127, 131

Skolithos is any simple, even width, vertical rube. Diameter varies 2-10 mm. The walls are usually smooth, but may be segmented or striated.

Teichichnus

Figs. 57-60, 76-78, 131

Vertical, tabular structures built of successively stacked, side-plated, or under-plated biogenic laminae. Ranges 3-20 mm wide, up to 10 cm high, and 40 cm or more long. Transverse cuts of Teichichnus display meniscate laminae bowing either up or down, depending on direction of construction. Longitudinal cuts display wavy, long laminae that usually merge upward at the ends. The more common oblique cuts display shorter, truncated laminae. Cambrian-Holocene.

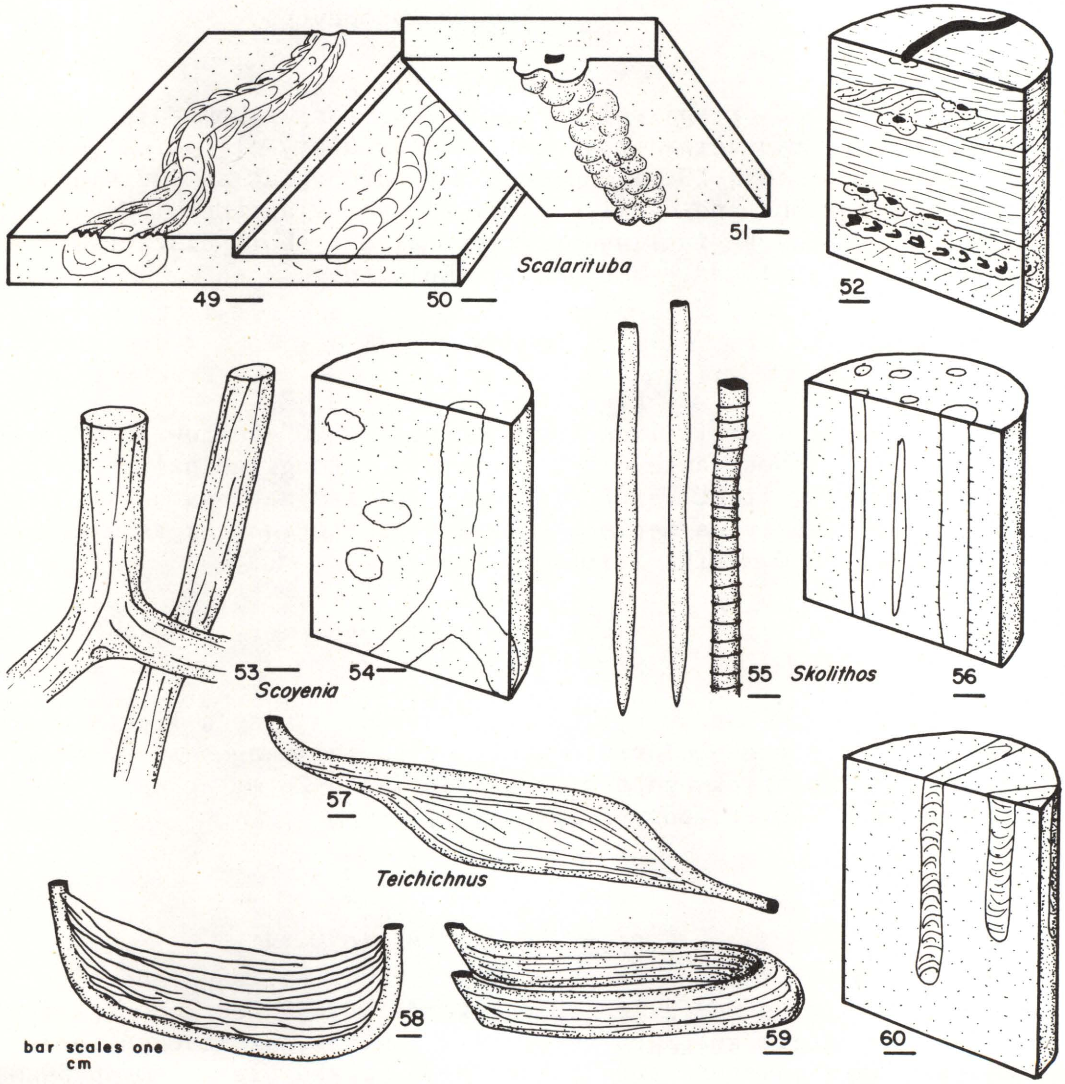


Fig. 49-52. Scalarituba missouriensis. 49. Phyllodocites, top view. 50. Scalarituba, internal view. 51. Neonereites, bottom view. 52. Core expression.

53-54. Scoyenia, model and core expressions.

55-56. Skolithos, model and core expressions.

57-60. Teichichnus. 57. Sigmoidal form. 58. T. rectus. 59. T. repandus. 60. Vertical tabular spreite-filled structures in cores.

Planolites/Palaeophycus

Figs. 40-41, 131

Unbranched or sparsely branched burrows without distinct internal structure. Transverse cross section circular, elliptical, and lenticular; diameter 0.5-23 mm and constant throughout an individual. Commonly gregarious and overlap parallel to one another. Usually horizontal, but may be inclined or vertical for short distances. Wall distinct but unlined. Precambrian-Holocene.

Rhizocorallium

Figs. 42-44, 111-112, 114

Horizontal or inclined spreite-filled "U"-burrow. "U" ranges 2-15 cm across. Tubes range 0.5-3 cm across. Longitudinal sections diaplay long, dark and light bands with parallel laminations or with the spreite showing unclearly as meniscate back-fill chevrons or as micro-cross laminations. Cambrian-Tertiary.

Rind Burrows

Figs. 45, 131

Cylindrical or subcylindrical burrows having a light-colored outer layer and a darker-colored center. Diameter ranges 10-40 mm across with rinds 3-10 mm thick and central galleries 3-28 mm across. Similar to *Terebellina.* Cretaceous-Pleistocene.

Rosselia

Figs. 46-48, 104-107, 131

Built up of a series of concentric conical sand and clay sheaths with a central sand-filled tube. Longitudinal section of *Rosselia* displays concentric subcircular or oval laminae, or stacked conical structures. The diameter ranges from 25-35 mm and high from 30-50 mm. The central sand-filled tube continues throughout the structure and turns horizontal below; above, it may pass into other cones or flatten into zones of *Planolites.* Like *Cylindrichnus*, except relatively shorter and broader. Cambrian? through Cretaceous.

Terebellina

Figs. 61-26, 108-110, 131

Unsculptured, grain-lined tubes 2-10 mm in diameter and 5-20 cm long. Wall thickness 0.5-3 mm consisting of coarser grains relative to matrix. Tubes inclined downward and curve horizontal. Several usually clustered together. Cretaceous.

Thalassinoides

Figs. 63-64, 131

Large branching burrow and tunnel system, usually horizontal maze system. Surface usually smooth, some slightly nodose or pelleted. Branching commonly at 120 degrees. Range 1-7 cm in diameter. Infilling commonly as successive laminae larger at bottom and sides, and thinnest or absent at the top. Pennsylvanian?, Triassic-Holocene.

Trichichnus

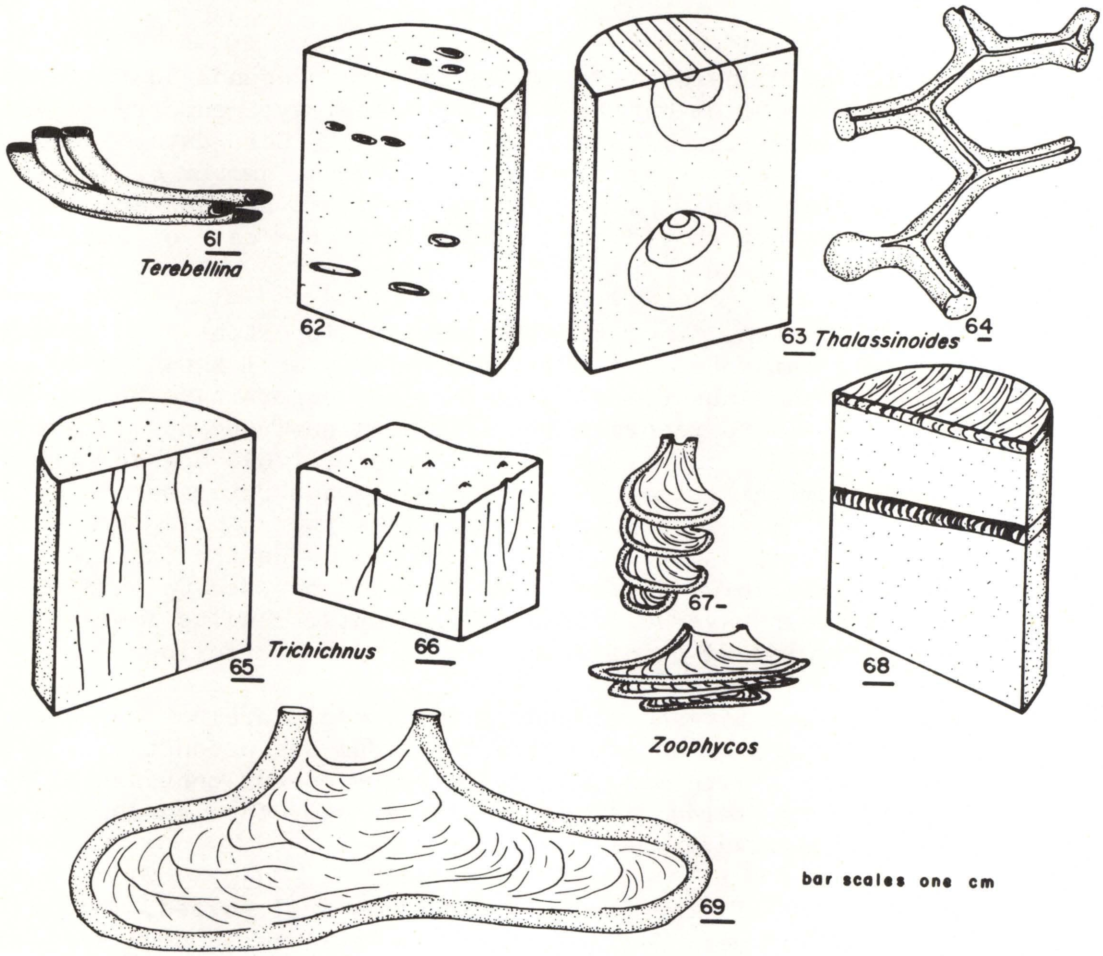
Figs. 65-66, 89, 131

Small vertical tubes 0.5-1.5 mm in diameter and 30-50 mm high. Usually straight, some curved to slightly sinuous. Commonly clay-filled in sandstone matrix. Cretaceous.

Zoophycos

Figs. 67-69, 113-116, 131

Zoophycos ranges from 10-100 cm across and consists of one or more broad, spreite filled loops. These feeding fields are horizontal or inclined and may spiral. In cross section Zoophycos appears as thin meniscate bands crossing the core horizontally or inclined. The meniscae alternate fine and coarse with the coarser widest at the top and fine meniscae thickest at the bottom and thinning to the top. Zoophycos usually occurs as a tabular structure through the entire diameter of the core. Cambrian-Holocene.



Figs. 61-62. Terebellina (communal tubes, pleural curving tubes, Siphonites or Hallimondia of some); three-dimensional cluster and core exposure respectively.

63-64. Thalassinoides showing succession of filling with final channel at top; core and dimensional model.

65-66. Trichichnus.

67-69. Zoophycos. 67. High and low spirals. 68. Tabular, horizontal spreite in core. 69. Single loop, essentially horizontal form.

TRACE FOSSIL ASSEMBLAGES AND PALEOENVIRONMENTS IN CORES

Recognition of paleoenvironments in cores depends on the same sort of data obtained from outcrops (e.g., lithology, geometry of sedimentary bodies, sedimentary structures, fossils). Core data, however, are limited by the size of the core, and by the number of cores available in a particular area. Paleoenvironmental distinctions are not nearly as refined as they should be, especially in the case of deltaic complexes or submarine fans.

Many of the same trace fossils that are important for defining paleoenvironments in outcrops, are also sufficiently well known in cores to be useful in the subsurface. However, few papers have been published using trace fossils to recognize depositional environments in core samples. Tillman (1975), and Tillman and Dresser (1976), Spender (1976, and written communication, 1977), and Basan and Peterson (1978) probably have made the most significant progress toward using trace fossils in cores. Spencer's studies have been mainly on the Cretaceous of the Western Interior. He uses a model that is based on relatively slow deposition in wave-dominated environments, ranging from higher to lower energy levels. A brief synthesis of his work follows.

Backshore and foreshore sandstones commonly are not cored in oil and gas wells, because backshore deposits seldom are productive due to their juxtaposition with massive, nontrapping porous continental sandstones. The foreshore seldom is preserved when shoreface sandbodies are overlain by transgressive marine shales.

The foreshore is represented by porous, well sorted, medium to thin bedded sandstone. Horizontal to low level cross beds are common, whereas current and symmetrical ripples are present only some of the time. Medium-sized vertical burrows are distinctive, especially *Arenicolites* and *Diplocraterion* (= *Corophioides*). Large *Ophiomorpha* occur sparsely.

The shoreface consists of good to fairly porous, well sorted sandstone in thick to thin beds. Clay chips and shell fragments occur sparsely and some ripple marks are present. Large (1 to 3 cm) *Ophiomorpha* are abundant as vertical shafts or horizontal mazes. A few *Diplocraterion* and zoned *Asterosoma* also may be present. Intense bioturbation may have destroyed much of the bedding.

Shoreface-toe consists of interbedded sandstone and shale generally grading upward from shale and siltstone. The sandstone is clayey, fine- to very-fine grained, and contains current ripples, rip up clasts and shell fragments, in medium to thin beds. The shale is rich in organic matter.

Zoned Asterosoma and small (1 cm diameter) shafts and mazes of Ophiomorpha and Thalassinoides are common. Chondrites, Rhizocorallium, Teichichnus, Arthophycus, and Scalarituba (= Nereites) are rare. Thick, storm-deposited sands are burrowed intensely only in the upper part. Shales are commonly highly burrowed by small Helminthoida and other nondescript horizontal burrows.

Tidal flat deposits, which are similar to the shoreface-offshore transition, contain siltstone and shale, and some thin sandstones that have laminar, flaser, and graded bedding; small vertical traces in tidal flat deposits distinguish this environment from the shoreface-offshore transition zone. Siltstone of the offshore transition contains small plant fragments, fish scales, and whole shells. Horizontal feeding traces are most common. Thalassinoides, zoned Asterosoma, and flattened Terebellina (= Siphonites) are present. Bioturbated beds are common. Rhizocorallium and Ophiomorpha are rare.

Siltstone, shale and thin sandstones also characterize the offshore. Bedding is discontinuous, very thin to laminar, wavy, and micro-cross laminated. Nondescript, horizontal burrows are common. Small Terebellina and Planolites are present.

Figure 131 summarizes the environmental distribution of select trace fossils commonly seen in cores. Details of the character and distribution of trace fossils in cores are just beginning to be reported.

ACKNOWLEGEMENTS

P. B. Basan (Amoco Research, Tulsa, Oklahoma) and especially C. W. Spencer (USGS, Denver, Colorado) provided numerous photographs of trace fossils in cores, personal observations and interpretations on the significance of the particular traces, and reviewed the manuscript, for which I am very grateful. Thanks also to Ruth F. Roark (University of Nevada, Las Vegas), who edited, typed, and retyped the manuscript. The Center for Trace Fossil Research has been supported by NSF Award No. EAR-77-144300.

REFERENCES

Ager, D. V. and P. Wallace. 1970. The distribution and significance of trace fossils in the uppermost Jurassic rocks of the Boulonnais, Northern France. In Crimes, T. P., and J. C. Harper (eds.), Trace fossils. Geol. J. Spec. Issue 3:1-18.

Basan, P. B., and W. Peterson. 1978. Trace fossil associations and depositional history, Peoria, Third Creek, and Wattenberg Fields, north central Colorado. Abst. w. progs. (in press).

Campbell, C. V. 1971. Depositional model - Upper Cretaceous Gallup Beach Shoreline, Ship Rock area, northwestern New Mexico. Jour. Sed. Petrol., 41(2):395-409.

Chamberlain, C. K., 1971a. Bathymetry and paleoecology of Ouachita Geosyncline of southeastern Oklahoma as determined from trace fossils. Am. Assoc. Petrol. Geol., Bull., 55:34-50.

________ 1971b. Morphology and ethology of trace fossils from the Ouachita Mountains, southeast Oklahoma. Jour. Paleont., 45:212-246.

________ 1975a. Biogenic sedimentary structures - trace fossils - of the Ouachitas, p. 51-68. In Briggs, G., E. D. McBride, and R. J. Moiola (eds.), A guidebook to the sedimentology of Paleozoic flysch and associated deposits, Ouachita Mountains - Arkoma Basin, Oklahoma. Dallas Geol. Soc.

________ 1975. Trace fossils in DSDP cores of the Pacific. Jour. Paleontol., 49(6):1074-1096.

________ 1976. Field guide to the trace fossils of the Cretaceous Dakota hogback along Alameda Avenue, west of Denver, Colorado. In Epis, R. C., and R. J. Weimer (eds.), Studies in Colorado Field Geology. Prof. Contr. Colorado School Mines, Number 8, 242-250.

________ 1977. Ordovician and Devonian trace fossils from Nevada. Nevada Bur. of Mines and Geol., Bull. 90, 24 p.

________ 1978. Trace fossils ichnofacies of an American flysch. Soc. Econ. Mineralog. Paleontol., Fieldguide to the Ouachita Mountains, 52nd Ann. Meeting.

________ and J. Baer. 1973. Ophiomorpha and a new thalassinid burrow from the Permian of Utah. Brigham Young Univ. Geology Studies, 20(1):79-94.

Chamberlain, C. K. and D. L. Clark. 1973. Trace fossils and conodonts as evidence for deep-water deposits in the Oquirrh Basin of central Utah. Jour. Paleontol., 47(4):663-682.

Chisholm, J. I. 1970. Teichichnus and related trace-fossils in the Lower Carbonifierous at St. Monance, Scotland. Geol. Surv. Great Brit., Bull., 32:21-51.

Crimes, T. P. 1977. Trace fossils of an Eocene deep-sea sand fan, norther Spain. In Crimes, T. P. and J. C. Harper (eds.), Trace fossils 2. Geol. Jour. Spec. Issue No. 9.

Ekdale, A. A. 1974. Geologic history of the abyssal benthos: evidence from trace fossils in Deep Sea Drilling Project Cores. Unpublished Ph.D. dissertation, Rice University, 156 p.

________ 1977a. Trace fossils in Leg 42A cores (in press). In Initial Reports of the Deep Sea Drilling Project, Washington, v. 42 (in press).

________ 1977b. Abyssal trace fossils in worldwide Deep See Drilling Project Cores. In Crimes, T. P. and J. C. Harper (eds.), Trace fossils 2. Geol. Jour. Spec. Issue 9, 163-182.

Ekdale, A. A. and W. H. Berger. 1977. Deep-sea ichnofacies: modern organism traces on and in pelagic carbonates ofs the western equatorial Pacific. Palaeogeogr., Palaeoclimatol., Palaeoecol. (in press).

Farrow, G. E. 1966. Bathymetric Zonation of Jurassic trace fossils from th coast of Yorkshire, England. Palaeogeog., Palaeoclimatol., Palaeoecol., 2:103-151.

Frey, R. W. 1970. Environmental significance of Recent matine lebensspuren near Beaufort, North Carolina. Jour. Paleontol., 44(3):507-519.

Frey, R. W., and J. D. Howard. 1969. A profile of biogenic sedimentary structures in a Holocene barrier island - salt marsh complex, Georgia. Gulf Coast Assoc. Geol. Socs., Trans., 428-444.

________ , and ________ . 1970. Comparison of Upper Cretaceous ichnofaunas from siliceous sandstones and chalk, Western Interior Region, U.S.A. In Crimes, T. P. and J. C. Harper (eds.), Trace fossils. Geol. Jour. Spec. Issue 3:141-166.

Frey, R. W., J. D. Howard and W. A. Pryor. 1977. Ophiomorpha: Its morphologic, taxonomic, and environmental significance. Palaeogeogr., Palaeoclimatol., Palaeoecol. (in press).

Frey, R. W. and T. V. Mayou. 1971. Decapod burrows in Holocene barrier island beaches and washover fans, Georgia. Senckenbergiana, Mar., 3:53-70.

Fursich, F. T. 1975. Trace fossils as environmental indicators in the Corallian of England and Normandy. Lethaia 8:151-172.

Goodwin, P. W. and E. J. Anderson. 1974. Associated physical and biogenic structures in environmental subdivision of a Cambrian tidal sand body. Jour. Geol. 82:779-795.

Howard, J. D. 1972. Trace fossils as criteria for recognizing shorelines in stratigraphic record. Soc. Econ. Paleontol. Mineral., Spec. Publ. 16:215-225.

Hubert, J. F., J. C. Butera, and R. F. Rice. 1973. Sedimentology of Upper Cretaceous Cody-Parkman Delta, southwestern Powder River Basin, Wyoming. Geol. Soc. America, Bull., 83:1649-1670.

Kern, J. P., and J. E. Warme. 1974. Trace fossils in bathymetry of the Upper Cretaceous Point Loma Formation, SAn Diego, California. Geol. Soc. Amer., Bull., 85(6):893-900.

Mackenzie, D. B. 1963. Dakota Group on west flank of Denver Basin. In Geology of the Northern Denver Basin and adjacent uplifts, 14th Field Conf. Rocky Mt. Assoc. Geol., 135-148.

________ 1965. Depositional environment of Muddy Sandstone, western Denver Basin, Colorado. Am. Assoc. Petrol. Geol., Bull., 49(2):186-206.

________ 1971. Post-Lytle Dakota Group on west flank of Denver Basin, Colorado. Mountain Geol. 8:91-131.

Perkins, B. F. (ed.). 1971. Trace fossils, a field guide to selected localities in Pennsylvanian, Permian, Cretaceous, and Tertiary rocks of Texas, and related papers. Louisiana State Univ., School Geoscience, Misc. Publ. 71-1:1-148.

Radwanski, A. 1977. Burrows attributable to the ghose crab Ocypode from the Korytnica Basin (Middle Miocene, Holy Cross Mountains, Poland). Acta Geologica Polonica 27(2):217-225.

Radwanski, A., H. Friis, and G. Larsen. 1975. The Miocene Hagenor-Borup sequence at Lillebaelt (Denmark): Its biogenic structures and depositional environment. Geol. Soc. Denmark, Bull., 24:229-260.

Reineck, H. E. 1958. Wuhlbau-Gefuge in Abhangigkeit von Sediment-Ulmagerungen. Senckenbergiana lethaea 39(1/2):1-14.

Risk, M. J., and R. B. Szczuczko. 1977. A method for staining trace fossils. Jour. Sed. Petrol. 47(2):855-859.

Seilacher, A. 1964. Biogenic sedimentary structures. In Imbrie, J. and N. Newell (eds.), Approaches to Paleoecology. John Wiley and Sons, Inc., New York, 296-316.

________ 1967. Bathymetry of trace fossils. Mar. Geology, 5(5/6):413-428.

________ 1970. Cruziana stratigraphy of "non-fossiliferous' Paleozoic sandstones. In Crimes, T. P. and J. C. Harper (eds.), Trace fossils. Geol. Jour., Spec. Issue No. 3:447-476.

Spencer, C. W. 1976. Hydrodynamic-energy classification for interpretation of cores of Cretaceous sandstones deposited in wave-dominated environments. In Wyoming Geol. Assoc. 28th Ann. Field Conf. Symposium, Geology and energy resources of the Powder River Basin, Symposium abstracts, 3-4.

Tillman, R. W. 1975. Trace fossils of the Muddy Sandstone, Wyoming and Montana as aids in Paleogeographic recontraction. Amer. Assoc. Petroleum Geol. and Soc. Econ. Paleontol. Mineralog. Ann. Mtg. Abstr. 2:74-75.

Tillman, R. W., and H. Dresser. 1976. Subtidal trace fossils, Muddy and Frontier Formations, Wyoming and Montana (abs.). Amer. Assoc. Petrol. Geol., Bull., 60(4):727-728.

Warme, J. E., and R. J. Stanton, Jr. 1971. Stop 2. Rockdale Railroad Cut. In Perkins, B. F. (ed.) Trace fossils, a field guide to selected localities in Pennsylvanian, Permian, Cretaceous, and Tertiary rocks of Texas ans related papers. Soc. Econ. Paleontol. Mineralog. Field Trip - April 1-3, 1971. School Geoscience Misc. Publ. 71-1, Louisiana State Univ., 11-15.

Warme, J. E., W. J. Kennedy, and N. Schneidermann. 1973. Biogenic secimentary structures (trace fossils) in Leg 15 cores, p. 813-831. In Edgar, N. T., et al., Initial Reports of the Deep Sea Drilling Project, v. 15, Washington (U.S. Gov. Print. Off.).

Weimer, R. J., and J. H. Hoyt. 1964. Burrows of Callianassa major Say, Geologic indicators of littoral and shallow neritic environments. Jour. Paleontol., 38:761-776.

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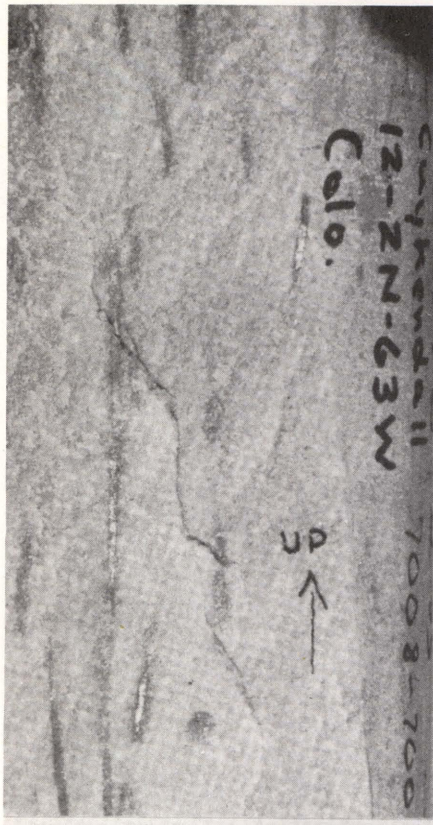
PREFACE TO PHOTOGRAPHIC FIGURES

Figs. 70-130 are intended to provide examples of most of the more important trace fossils commonly found in cores; figures are from outcrop, slabbed-outcrop, and/or core samples. The selection was made from extensive personal collections, but was greatly supplemented in corse by C. W. Spencer (U.S.G.G., Denver), as indicated by (CWS) by appropriate figure explanations.

Figs. 70-75. Arenicolites. 70. Core, Cretaceous "J" sandstone, 7008 ft., Charter 1-B Cuykendall, Colorado. X 0.7. (CWS). 71. Outcrop, Pennsylvanian Lee Sandstone, north-central Kentucky, X 0.6. 72. Top view, outcrop, Cretaceous South Platte Formation,

Alameda Drive, west of Denver, Colorado, X 0.7. 73. A. sarsus, top view, outcorp, Ordovician Eureka Quartzite, Lone Mountain, central Nevada, X 1.0. 74. Vertical cut of outcrop, A. sparsus, Cretaceous South Platte Formation, Alameda Drive, west of Denver, Colorado, X 2.2. 75. Outcrop, side view, A. sparsus, as 74, X 1.8.

Figs. 76-78. Teichichnus, retrusive forms in cores. (All CWS). 76. Cretaceous Mesaverde Group, Energetics 32-33 Fed., Sweetwater Co., Wyo., X 0.8. 77. Cretaceous Eagle sand, Concept Resource Gorr 3-10, Rapelje Field, Montana. Lower shoreface. X 1.0. 78. Cretaceous "J" sandstone, Charter 1-B Cuykendall, Colorado. X 1.0.



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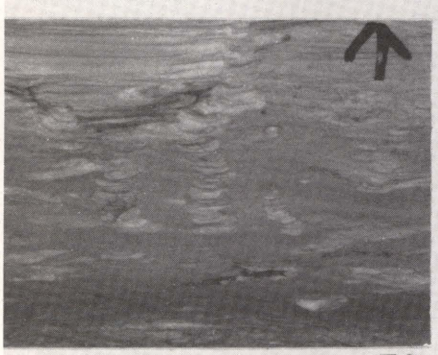

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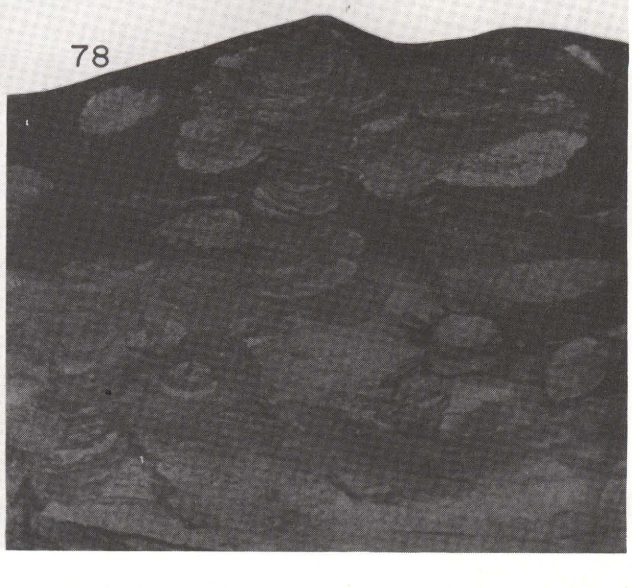

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Figs. 79-83. Asterosoma. 79, 81. *Asterosoma radiciforme*, hypogenic hyporelief, Pennsylvanian, Ohio. X 0.8. (81. vertical cut). 80. *Asterosoma* sp. and *Ophiomorpha n odosa* in core, Davis #1 Hess, Cretaceous Teapot Sandstone, 6800 ft. Shoreface. X 0.8. (CWS) 82. Zoned *Asterosoma* longitudinal section, Cretaceous Teapot Sandstone, north centarl #1 Dickau, Powder River Basin, Wyoming. X 1.0. (CWS). 83. Zoned *Asterosoma*, longitudinal section of Cretaceous Teapot Sandstone, Mitchell Energy #1-1 Conoco-Fed., 7097 ft., Converse Co., Wyoming. X 0.8. (CWS)


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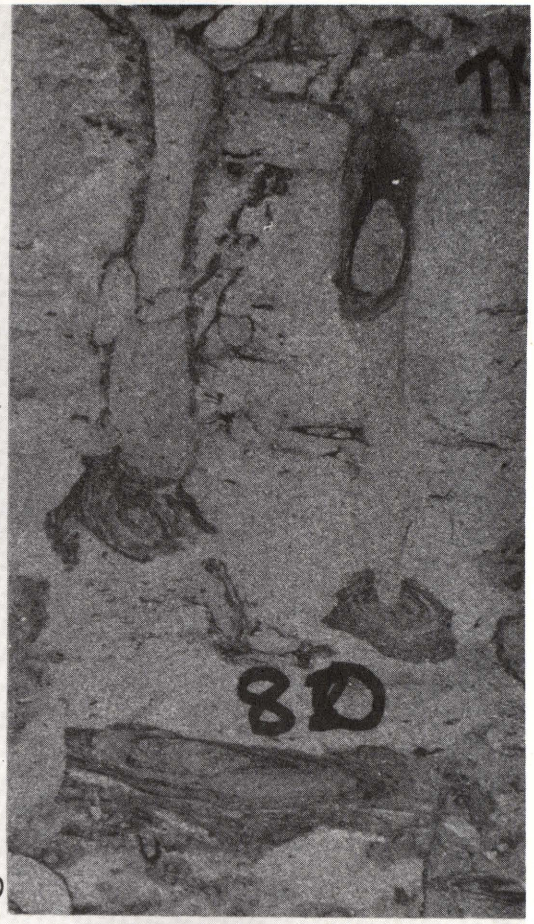
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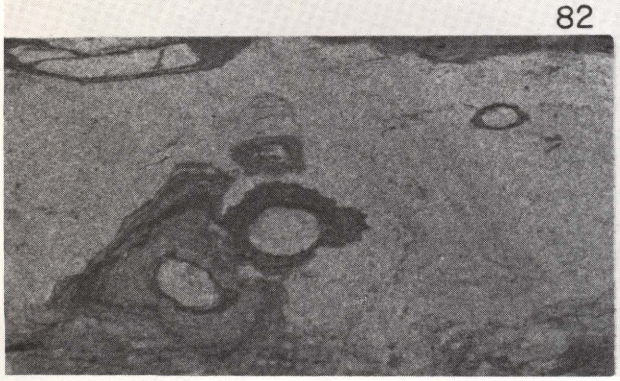
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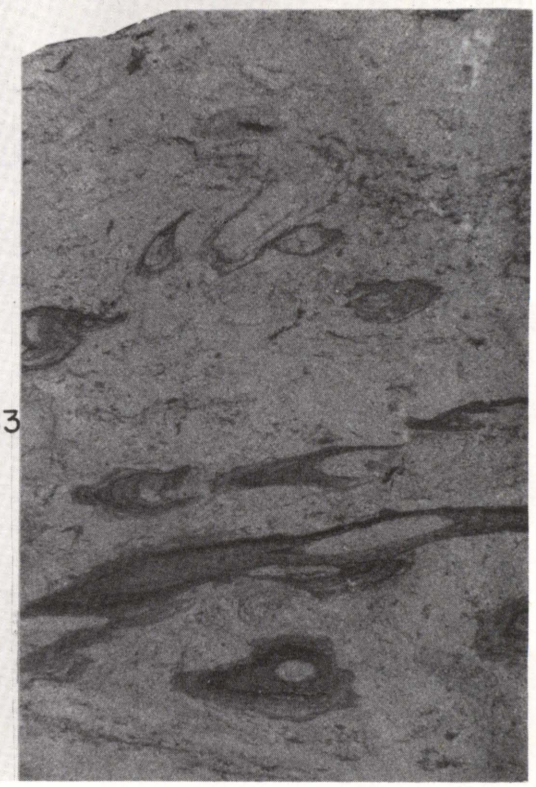
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Figs. 84-88. *Chondrites*. 84. *Chrondrites* af. *C*. *targionii*, longitudinal section DSDP Site 178, Core 28, Sec. 1, 136-141 cm, upper Miocene. X 1.3. Dark Structures *Helminthoida*. 85. Outcrop of *Chondrites* cf. *C*. recurvus Devonian Needmore Shale, Smoke Hole, W. Va., X 1.0. 86. Outcrop of *Chondrites* *targionii*, Atoka Formation, Frontal Ouachita Mountains, Oklahoma, X 0.9. 87. *Chondrites* sp., longitudinal section of Cretaceous Mesaverde Group, 2414 ft., Amerada Peteroleum Deep Creek #2 Unit, Wyhoming, X 1.0 (CWS). 88. *Chondrites* sp. longitudinal section of cretaceous Eagle Sandstone, Concept Reserouces Gor 3-10, Rapelje Field, Montana, X 1.1. (CWS).

89. *Thalassinoides* full review burrow, transverse cross section displaying successive filling on left and reburrowing by *Chondrites*. Cretaceous Paw Paw Shale, Fort Worth, Texas, X 2.0.

90. *Lophoctenium*, cross section of outcrop of Mississippian Stanley Group, central Ouachita Mountains, Oklahoma, X 1.7.


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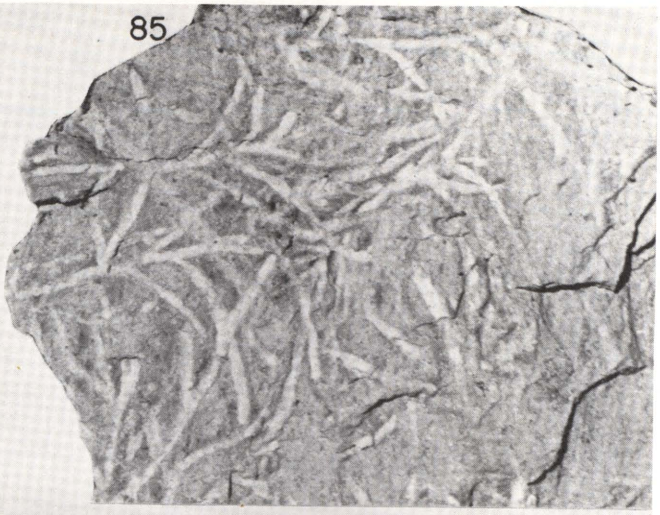
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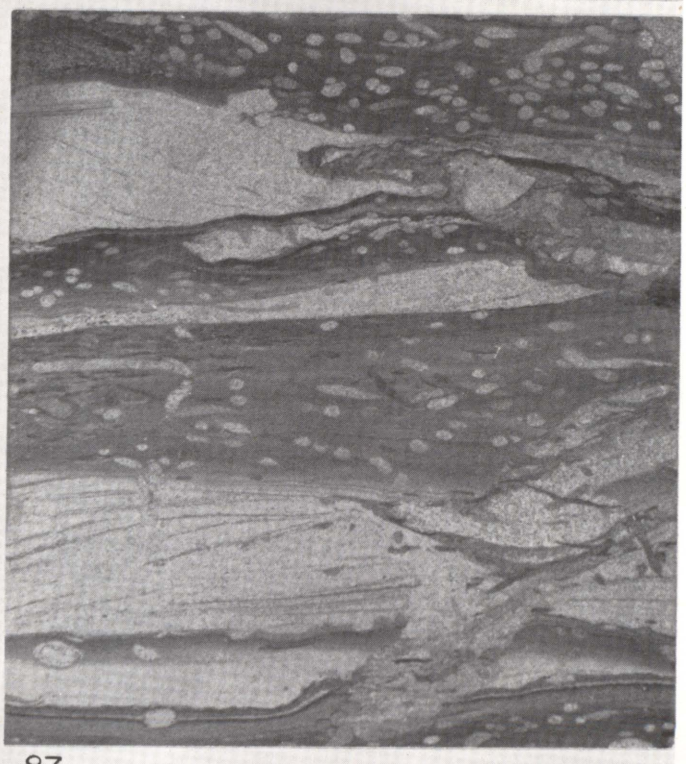
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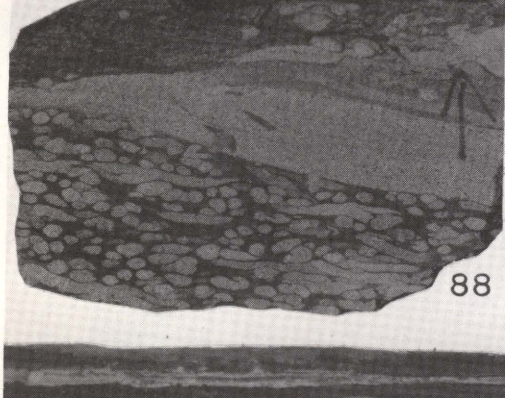
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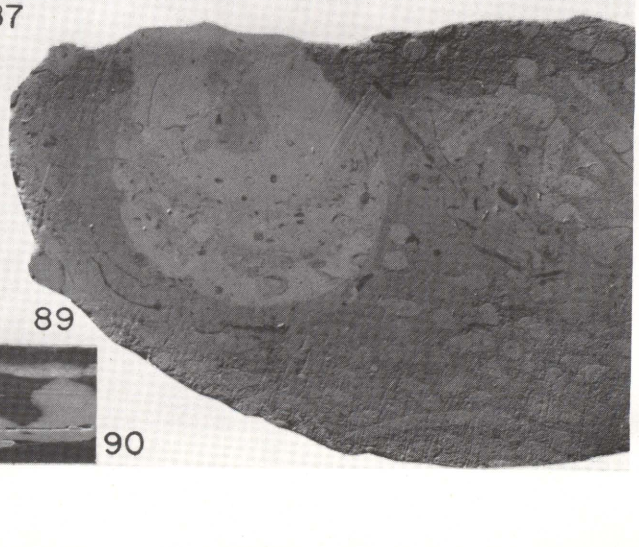
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Figs. 91-92. Scoyenia sp. 91. Side view of Muddy Sandstone, southside Spring Canyon, Colorado, X 0.5. 92. Transverse section in core from Muddy Sandstone, D-J Basin, Colorado, X 0.7.

93-96. Diplocraterion parallelum._ 93. Top view from Triassic Chinle Formation, north-central Arizona, X 0.4. 94. Side view of retrusive form lacking outside tube due to vertical upward building of spreite; from outcrop of Cretaceous South Platte Formation (Dakota Group), south side Turkey Creek, west of Denver, Colorado, X 0.8. 96, 96. From same locality as 94; from top of South Platte Formation at change from sandstone to dark shale; coarse sand and phosphatic pebble lag occur at the top of a transgressive contact in both samples. Diplocraterion is interpreted as a tidal flat indicator, but in this sample is cut by olbique Rhizocorallium that is a nearshore form (Ager and Wllace, 1970). Paraffin base petroleum has seeped into the coarse sand and into the cross-cutting Rhizocorallium but not into the earlier Diplocraterion or host sandstone. Apparently a later deeper trace fossil fauna is superimposed on the earlier shallower one. 95. Protrusive form, X 1.2. 96. Retrusive form, X 0.7.

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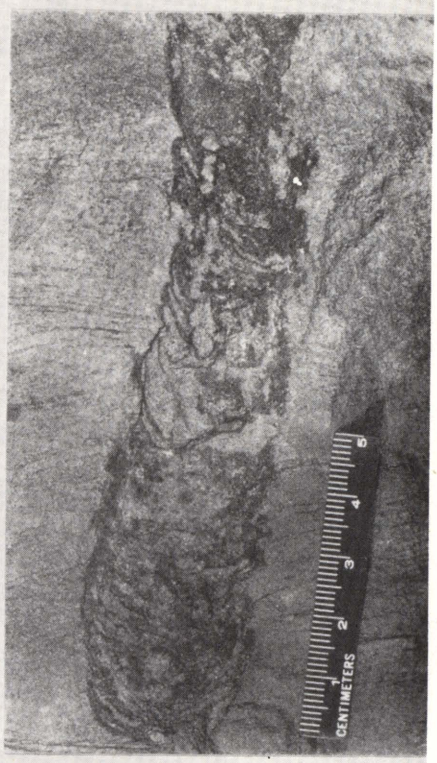

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Figs. 97-103. Ophiomorpha nodesa. 97-98. Boxwork pieces from Eoccne Rockdale Formation, Milam Co., Texas, X 1.0. 99. Maze on bottom of bed from Cretaceous Dakota Sandstone, near Cuba, San Juan Basin, New Mexico, X 0.3. 100. Shafts from lower foreshore sediments, Pamlico Formation (Pleistocene), St. Mary's River, Florida. 101. Stacks and double truncation in core from Inexco #1 Brad-Fed, Teapot Sandstone, 6961 ft., X 1.0 (CWS). 102. Shafts with brood or turnaround pouch and second pelleted shaft inside(?) original shaft. Note calcite cement around burrow. Cretacous Teapot Sandstone Davis #1, Triassic, Wyoming. (CWS). 103. Intense maze(?) bioturbation with pelleting only on top in some forms; Sinclair #A=114 Lost Soldier, Sweetwater Co., Wyoming. Cretaceous Frontier Sandstone, (CWS).

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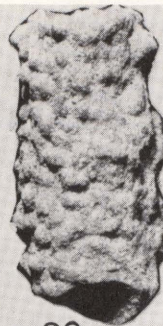

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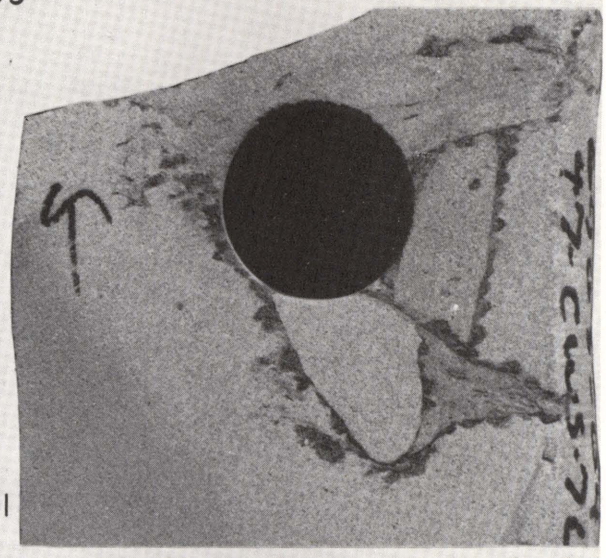

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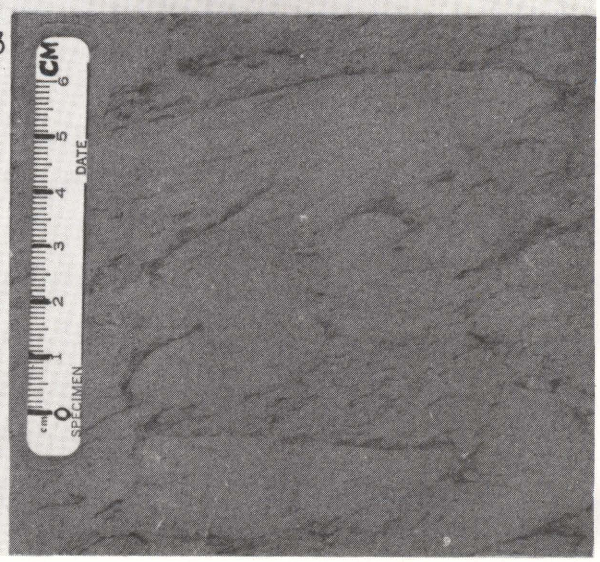

Fig. 104. Rosellia socialis, top view of outcrop, Morrowan Wapanucka Limestone, Ouachita Mountains, Oklahoma, X 0.8.

105-106. Cylindrichnus concentricus, Mississippian Logan Formation, Ohio, X 0.8. 105. Note tapering top. 106. Note typical truncated upper top and Scalarituba missouriensis as dark pellets, especially in the lower part of the photograph.

107. Rosselia sp., in core, Cretaceous Teapot Sandstone, DAvis #1 Tressie, Powder River Basin, Wyoming, X 0.8. (CWS).

108-110. Terebellina sp. (C. W. Spencer, USGS, Denver; some may be Siphonites). 108. Cretaceous Skull Creek Shale, near Spring Canyon Dam, Colorado, X 1.2. 109. Longitudinal cross section of core, Cretaceous Dakota Group, Moffat Co., Colorado, X 0.8. 110. Longitudinal cross section of core, Cretaceous Teapot Sandstone, Shenandoah #3-16. Offshore.

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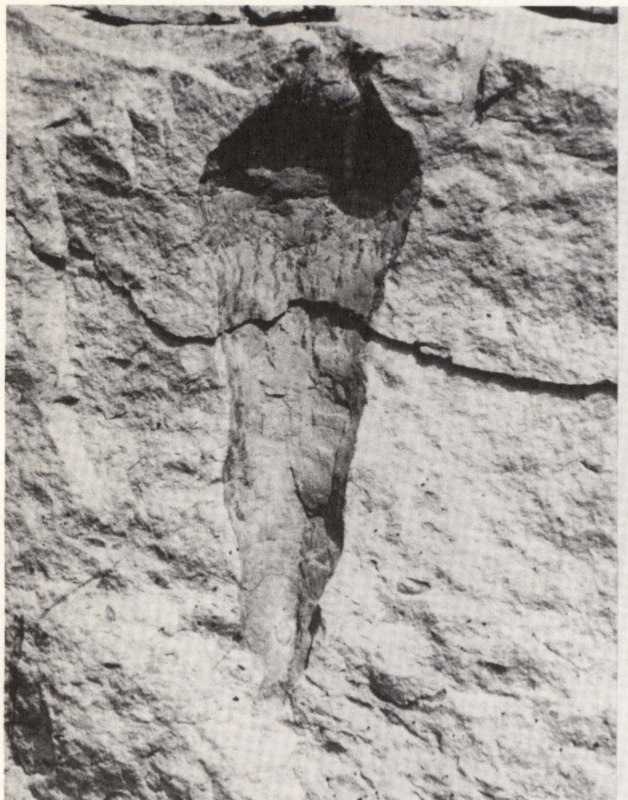

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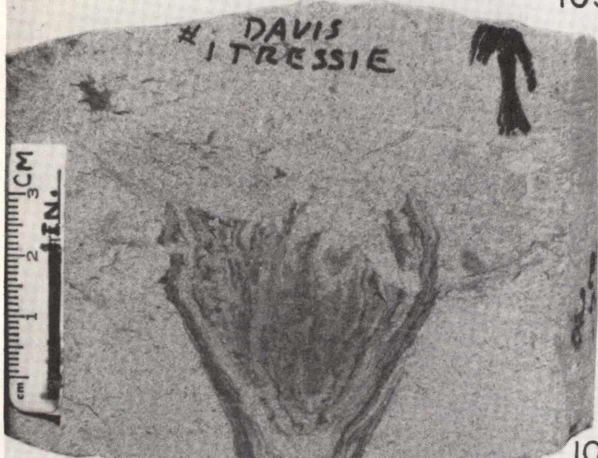

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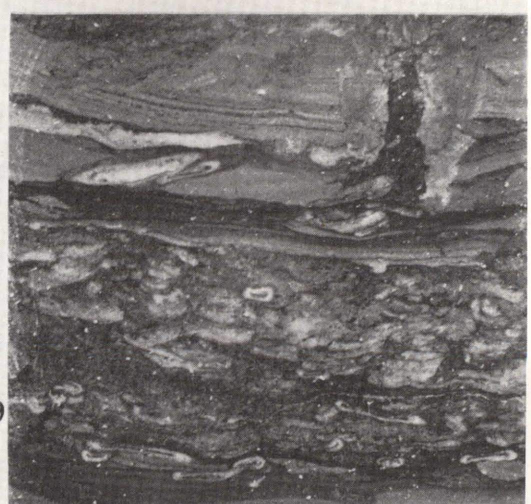

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Figs. 111-112, 114. Rhizocorallium sp. 111. Top view from Mississippian Sycamore Limestone, Arbuckle Mountains, Oklahoma, X 0.7. 111. Interlaminar fracture surface of Cretaceous Benton Shale, Alameda Parkway, west of Denver, Colorado, X 0.7. 114. Sawed face perpendicular to bedding of Cretaceous Benton Shale as in 112. Note dark laminae (l) and fine meniscae (m) distinctive of Rhizocorallium in this type of lithofacies, X 0.7.

113, 115-116. Zoophycos sp. 113. Perpendicular face to spreite fields, Devonian, New York, X 1.0. 115. Oblique view of outcrop, Oligocene Oswald West, Oregon, X 0.2. 116. Longitudinal section of core from DSDP Site 178, Core 37, Section 4, 129-136 cm, upper Miocene? Chondrites (light colored ovals and branching bars) and Helminthoida (dark colored loops and ovals) between the Zoophycos, X 1.3.

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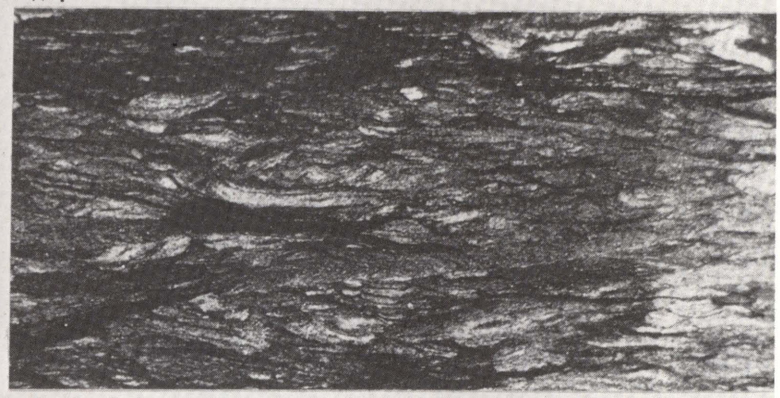

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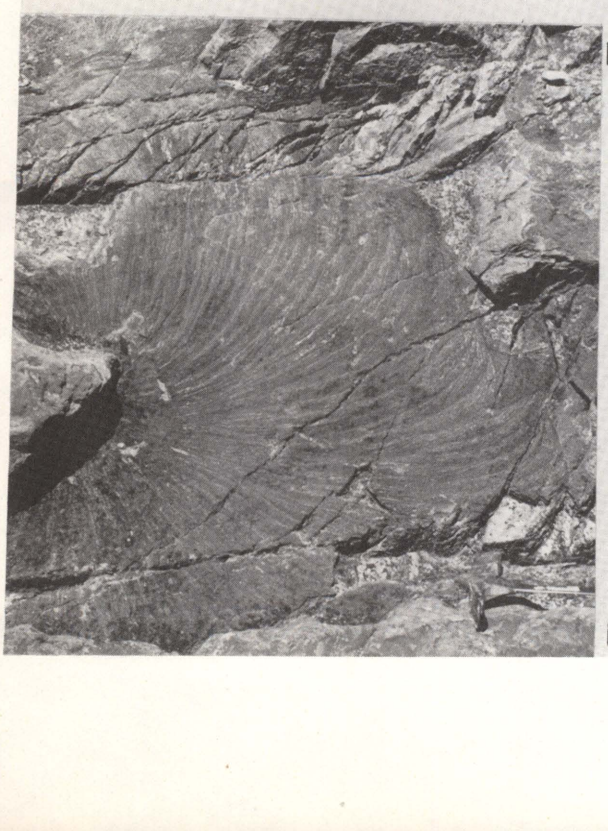

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Figs. 117, 122. Scalarituba missouriensis. 117. Longitudinal section of core from Permian, Delaware Basin, Loving Co., Texas. X 1.1. 112. Interlaminar fracture of Permian Oquirrh Formation, central Utah, X 0.8.

118-121, 123. Helminthoida sp. 118. Surface sawed perpendicular to bedding, Oligocene Oswald West, Oregon, X 2.4. 119. Bedding surface, Oligocene Oswald West, Oregon, X 1.2. 120-121. Longitudinal cross section of core from Cretaceous Mesaverde Group, 2417 ft., Armada Pet. Deep Creek 2 Unit, Carbon Co., Wyoming, X 2.4. and X 1.0, respectively (CWS). 123. Longitudinal cross section of core from late Miocene, DSDP Site 205, Core 1, Section 3, 109-123 cm, X 1.7.

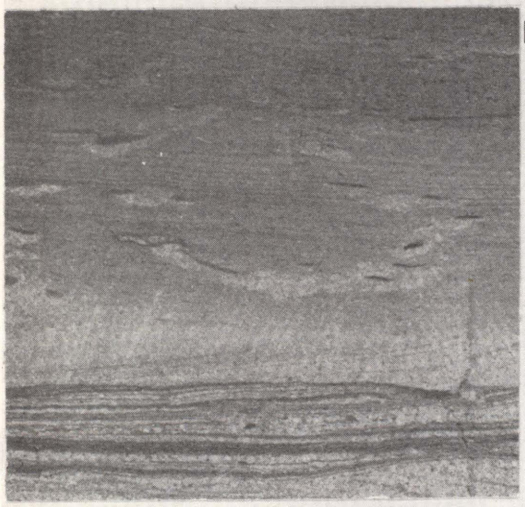
Fig. 124-127. Skolithos verticalis. 1124. Devonian Oriskany Sandstone, opposite Eagle Rock, Smoke Hole, West Virginia, X 0.5. 125. Longitudinal cross section of core from Cretaceous Muddy Sandstone, Pan Am Peoria 18-6, X 0.7. 126. Top of bed of Cretaceous South Platte Formation, Alameda Parkway, weste of Denver, Colorado; nodose rods are Ophiomorphia nodosa and linear striated pieces are plant roots, X 0.5. 127. Longitudinal cross ection of core of Cretaceous Mowry Shale, Moffat Co., Colorado, X 0.8.

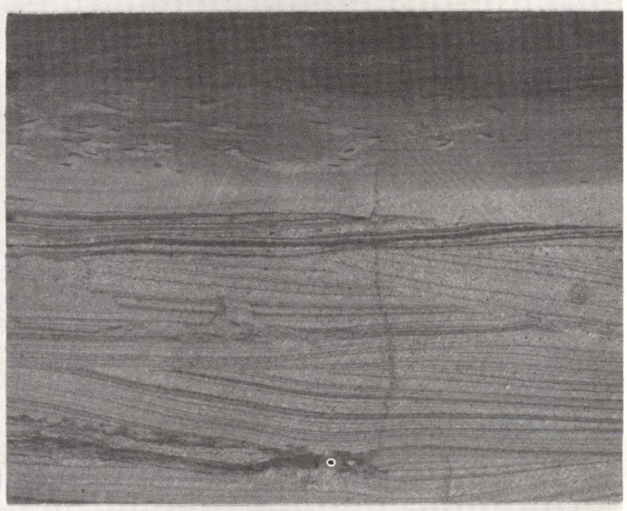
128-130. Trichichnus linearis. 128. Outcrop of Cretaceous Muddy Sandstone, south side of Spring Canyon, Colorado, X 0.8. 129. Sawed outcrop, Cretaceous South Platte Formation, Alameda Parkway, west of Denver, Colorado, X 1.8. 130. Top view of outcrop as 129, X 1.2.


117

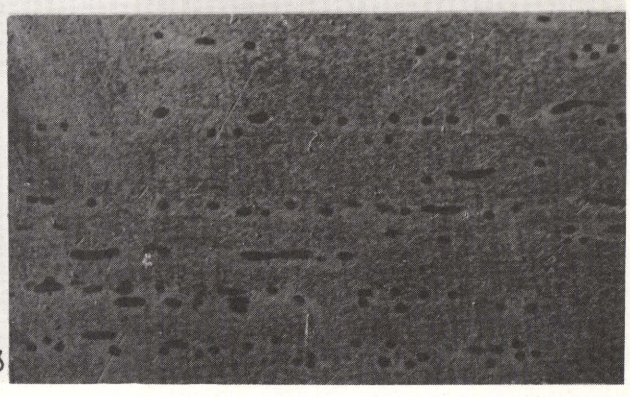

118


119


120


121


122


123

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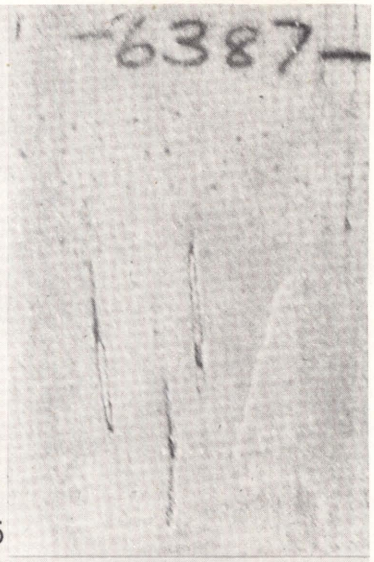
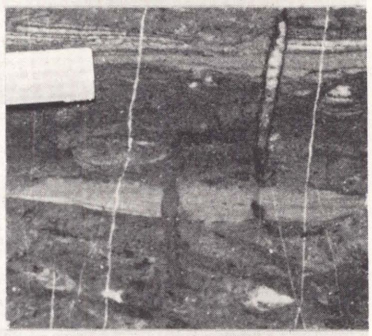
125



126

127

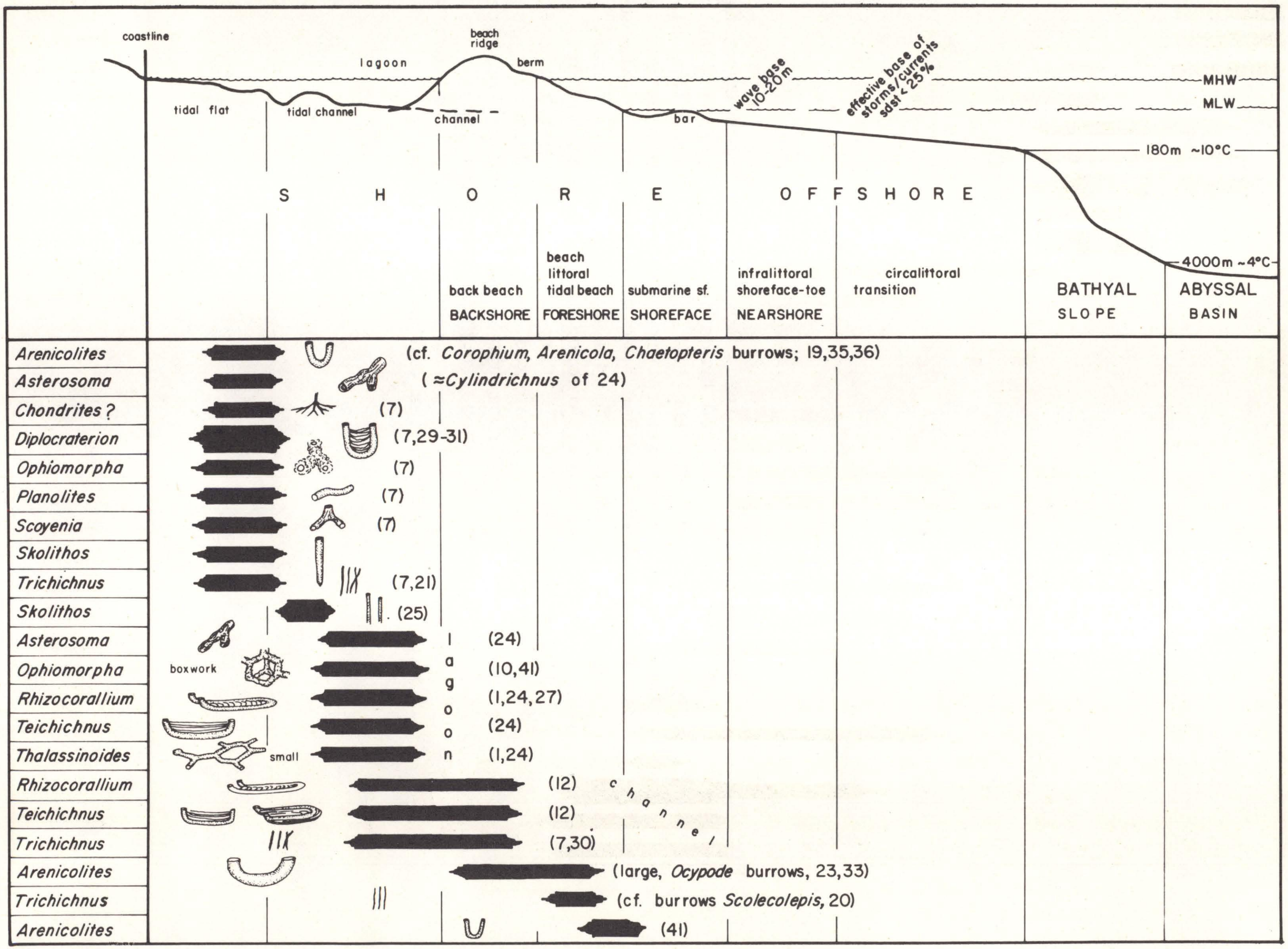


128

129

130

Fig. 131. The purpose of this figure is to show the known environmental distribution of selected trace fossils, especially those common in cores. The numbers by each distribution-bar of figure refer to the literature source of information on distribution and/or provided special information on the morphology of the trace. Many ichnogenera occur in more than one environment (e.g., Arenicolites), but it may be a different species from one environment to the next; therefore, the figure has been organized to separate different species and/or different environments of occurrence on separate lines. In some instances (e.g., Rhizocorallium), this gives the impression of quite straightforward distributions when it might be quite complex and rather unclear.



coastline
lagoon
beach ridge
berm
wave base 10-20m
effective base of storms/currents sdst < 25%
MHW
MLW
tidal flat
tidal channel
channel
bar
180m ~10°C
4000m ~4°C
S H O R E
O F F S H O R E
back beach
BACKSHORE
beach littoral tidal beach
FORESHORE
submarine sf.
SHOREFACE
infralittoral shoreface-toe
NEARSHORE
circalittoral transition
BATHYAL
SLOPE
ABYSSAL
BASIN
Arenicolites
Asterosoma
Chondrites ?
Diplocraterion
Ophiomorpha
Planolites
Scoyenia
Skolithos
Trichichnus
Skolithos
Asterosoma
Ophiomorpha
Rhizocorallium
Teichichnus
Thalassinoides
Rhizocorallium
Teichichnus
Trichichnus
Arenicolites
Trichichnus
Arenicolites
(cf. Corophium, Arenicola, Chaetopteris burrows; 19,35,36)
(≈Cylindrichnus of 24)
(7)
(7,29-31)
(7)
(7)
(7)
(7,21)
(25)
boxwork
small
lagoon
(24)
(10,41)
(1,24,27)
(24)
(1,24)
channel
(12)
(12)
(7,30)
(large, Ocypode burrows, 23,33)
(cf. burrows Scolecolepis, 20)
(41)

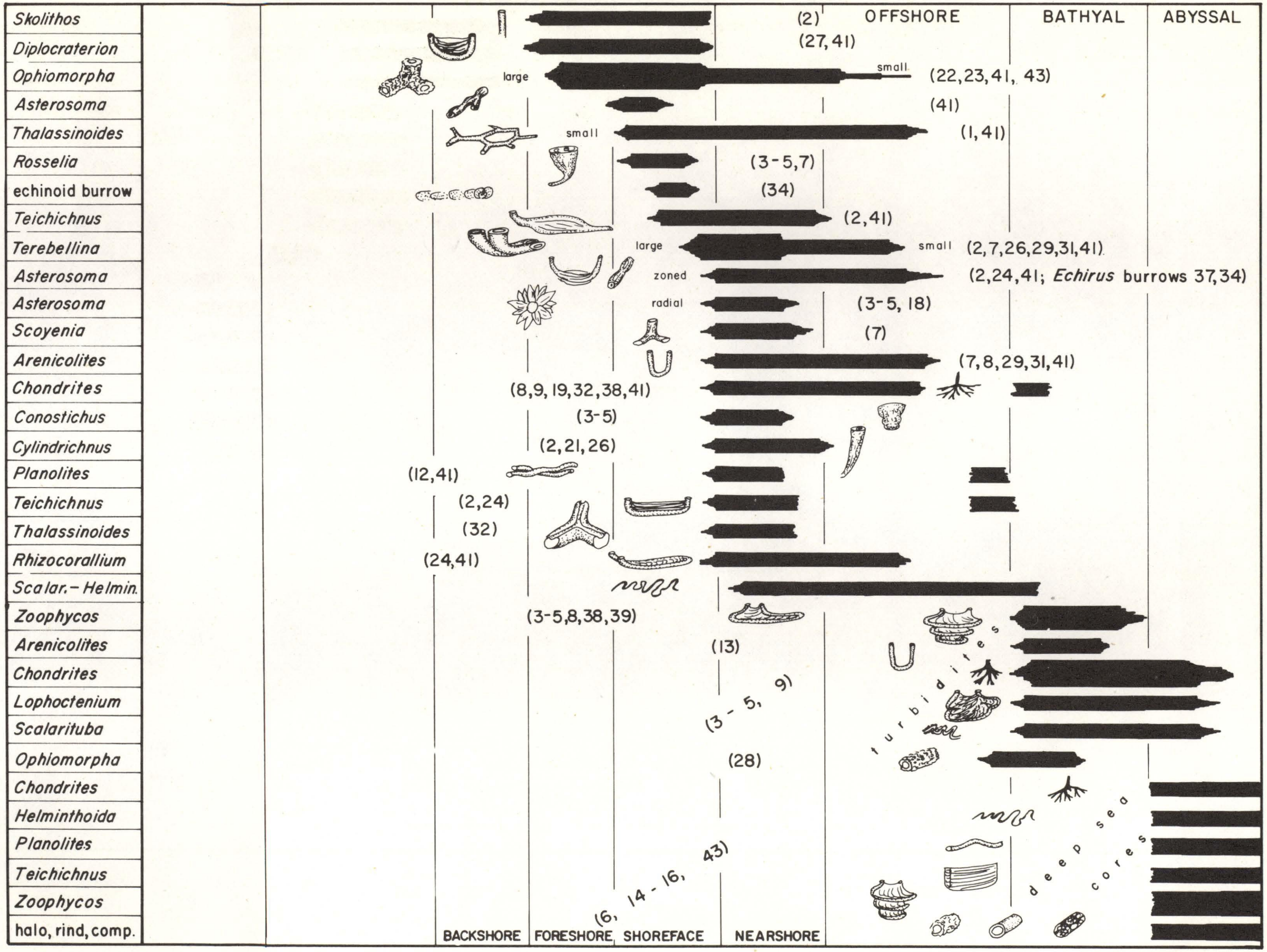

OFFSHORE
BATHYAL
ABYSSAL
BACKSHORE
FORESHORE
SHOREFACE
NEARSHORE
Skolithos
Diplocraterion
Ophiomorpha
Asterosoma
Thalassinoides
Rosselia
echinoid burrow
Teichichnus
Terebellina
Asterosoma
Asterosoma
Scoyenia
Arenicolites
Chondrites
Conostichus
Cylindrichnus
Planolites
Teichichnus
Thalassinoides
Rhizocorallium
Scalar.- Helmin.
Zoophycos
Arenicolites
Chondrites
Lophoctenium
Scalarituba
Ophiomorpha
Chondrites
Helminthoida
Planolites
Teichichnus
Zoophycos
halo, rind, comp.
(2)
(27,41)
large
small
(22,23,41, 43)
(41)
small
(1,41)
(3-5,7)
(34)
(2,41)
large
small
(2,7,26,29,31,41)
zoned
(2,24,41; Echirus burrows 37,34)
radial
(3-5, 18)
(7)
(7,8,29,31,41)
(8,9,19,32,38,41)
(3-5)
(2,21,26)
(12,41)
(2,24)
(32)
(24,41)
(3-5,8,38,39)
(13)
(3 - 5, 9)
(28)
(6, 14 - 16, 43)
turbidites
deep sea cores

Fig. 131