

## 11. TRACE FOSSILS IN DEEP SEA DRILLING PROJECT LEG 58 CORES

A. A. Ekdale, Department of Geology and Geophysics, University of Utah, Salt Lake City

### ABSTRACT

Bioturbation is extensive in all the facies cored during DSDP Leg 58 in the Philippine Sea, and cores not disturbed by drilling contain several distinctive trace-fossil types. Terrigenous turbidites show little, if any, bioturbation in their lower sub-units, although the upper, fine-grained sub-units commonly contain burrowed horizons. Pelagic biogenic oozes contain a typically deep-sea trace-fossil assemblage dominated by *Planolites*, *Zoophycos*, and *Chondrites*. Pelagic brown clays contain an abundance of smeared and deformed burrows, suggesting deposition of low-strength sediment at or below the carbonate-compensation depth.

### INTRODUCTION

Trace fossils are biogenic sedimentary structures, such as animal tracks, trails, burrows, and borings. They are evidences of the presence and activities of ancient organisms; thus, they often provide important information about the paleoecology of benthic creatures that may or may not be preserved as body fossils. Moreover, trace fossils are always *in situ* (it is rarely possible to transport a sedimentary structure), and so they are of considerable utility in interpreting sedimentary facies. Trace fossils have been employed in various depositional settings as (1) paleobathymetric indicators (e.g., Seilacher, 1963, 1967; Rodriguez and Gutschick, 1970; Chamberlain, 1971; Kern and Warme, 1974; Ekdale, 1978b); (2) indicators of current direction (e.g., Seilacher, 1955; Birkenmajer and Bruton, 1971; Schäfer, 1972); (3) keys to understanding erosion-redeposition events (e.g., Seilacher, 1962; Goldring, 1964; Bromley, 1967, 1968, 1975; Howard, 1978); (4) indicators of fresh-water or marine depositional environments (e.g., Howard et al., 1975; Mayou and Howard, 1975; Chamberlain, 1975); (5) indicators of the oxygenation of bottom waters (Rhoads and Morse, 1970; Kauffman, 1977); and (6) reflections of important sediment properties, such as chemical composition (e.g., Kennedy, 1975; Harrington, 1978), grain size (e.g., Sanders, 1958; Purdy, 1964; Rhoads, 1967, 1970; Warme, 1967), and shear strength (e.g., Kennedy and MacDougall, 1969; Berger and Johnson, 1976; Ekdale and Berger, 1978).

The importance of trace fossils in deep-sea sediments lies in the fact that body fossils of benthic macro-invertebrates inhabiting the abyssal realm are exceedingly rare. With few exceptions (e.g., Cheetham, 1975; Kauffman, 1976), trace fossils constitute almost the total of our paleontological information about the bottom-dwelling megafauna in ancient deep-sea deposits (Ekdale, 1978a, 1978b). The kinds of tracks and trails produced on the deep-sea floor typically are very distinctive and therefore are often cited as indicators of

abyssal depositional conditions (Bourne and Heezen, 1965; Heezen and Hollister, 1971; Hollister et al., 1975; Ekdale and Berger, 1978; Kitchell et al., 1978). These sediment-surface trails and related structures have been observed as bedding-plane trace fossils in ancient deep-water deposits, particularly turbidites, exposed on land (Seilacher, 1962, 1967, 1974; Książkiewicz, 1970; Kern, 1978). However, continuous pelagic sedimentation, accompanied by continuous biologic reworking of the sediment, generally precludes the formation of bedding planes. In fact, surface tracks and trails, as well as shallow infaunal burrows (in the upper few centimeters of sediment), have little chance of preservation, because they are continually destroyed by the intense bioturbation of deep-burrowing infauna in the deep sea.

Berger and Heath (1968) developed a quantitative theoretical model of reworking of sediment by benthic organisms, in which the surface layer of sediment (called the "mixed layer") is a zone of instantaneous, homogeneous mixing of sedimentary particles. Using abyssal box cores from the equatorial Pacific, Berger et al. (1979) demonstrate that a mixed layer does indeed exist. It is a layer some 5 to 8 cm thick in which intense bioturbation virtually homogenizes the sediment, and individually distinct burrows and any stratification features are not visible. Below the mixed layer, to depths of 20 to 35 cm below the water-sediment interface, lies the "transition zone." In this zone active burrowing also occurs, but at a rate far lower than in the mixed layer. Burrows produced in the transition zone include those which eventually are preserved in the "historical layer," which is the horizon directly underlying the transition zone. The upper boundary of the historical layer is the level below which no new burrows are produced. In calcareous oozes from low latitudes in today's oceans, that level is approximately 20 to 35 cm below the sediment surface.

Thus, the typical deep-sea ichnofacies that characterizes pelagic oozes (i.e., deposits far removed from the influence of continents) includes only infaunal traces

which happen to be produced deep in the sediment below the mixed layer. These include the ichnogenera *Chondrites*, *Planolites*, *Skolithos*, *Teichichnus*, and *Zoophycos* (Ekdale, 1978a, 1978b; Ekdale and Berger, 1978). On the other hand, the ichnofacies that characterizes abyssal clastic material, such as that deposited at regular or sporadic intervals on a submarine slope, commonly includes such surface and shallow infaunal ichnogenera as *Helminthoida*, *Nereites*, *Spiroraphe*, and *Paleodictyon* (Seilacher, 1967; Kern, 1978). Both "deep-sea" ichnofacies may be formed at the same depths; their distinction is primarily in preservation.

### TRACE-FOSSIL FACIES

Lithofacies cored in the Philippine Sea during DSDP Leg 58 include (1) hemipelagic clay and mudstone; (2) resedimented mudstone, sandstone, and conglomerate; (3) resedimented carbonate; (4) pelagic non-biogenic sediment; (5) pelagic biogenic calcareous and siliceous sediment; and (6) pyroclastic material (see lithologic summaries in other chapters of this volume). These lithofacies bear characteristic suites of trace fossils and bioturbation features (i.e., ichnofacies). Detailed descriptions of the common ichnogenera are given by Chamberlain (1975), Häntzschel (1975), and Ekdale (1978a, 1978b).

Hemipelagic and resedimented terrigenous facies, such as those in the upper parts of Holes 442, 443, 444, and 446, include materials derived from shallower water or land and deposited in pulses by turbidity currents or some similar mechanism. Typically, these deposits exhibit normal "Bouma sequences" (Bouma, 1962) grading from coarse, often conglomeratic sediment with *Nummulites* at the base into fine-grained material at the top of each turbidite unit. The lower, coarser sub-units of the cycle include graded bedding, convolutions, flame structures, etc., but no burrows. In these coarse-grained deposits one might expect to see occasional "escape structures" (Schäfer, 1972) produced by organisms digging out of a newly deposited turbidite. However, such structures have been cited only rarely in the literature (Häntzschel, 1975), and none were discovered in Leg 58 cores.

The upper, fine-grained sub-units of the turbidites in Leg 58 cores typically are finely laminated and unbioturbated through most of their thickness. However, some burrowing does occur in the uppermost sub-units of many sequences, which display no laminations, but common *Chondrites*. Middle-Eocene deposits of Hole 445 typify this pattern (Plate 1, Figures 1 and 2). The well-defined burrowed horizons sometimes are only 1 or 2 centimeters thick, although the entire turbidite may be more than half a meter thick. The *Chondrites* in these fine-grained sub-units is typically small, with individual tunnels about 1 mm in diameter. Branching is primarily horizontal or subhorizontal, suggesting that organic material usable as food was concentrated along lamination planes rather than distributed uniformly throughout the hemipelagic mud.

Pelagic biogenic facies, particularly the carbonates of Hole 445, contain the richest trace-fossil assemblages. This is no doubt due to the fact that calcareous and siliceous oozes generally are deposited beneath moderately productive regions of the oceans, which provide a continuous supply of organic matter to the bottom. High benthic biomass characterizes these regions, and infaunal members of the benthic communities are common and fairly diverse. Burrowers that homogenize the sediment live in the upper few centimeters (the mixed layer); record-making burrowers live somewhat deeper in the sediment (Berger et al., 1979).

The trace fossils characterizing the biogenic-ooze facies in Leg 58 cores include *Chondrites*, *Planolites*, *Skolithos*, and *Zoophycos*. This association is particularly well preserved in upper-Miocene deposits of Hole 445 (Plate 1, Figures 4, 5, and 6). These ichnogenera are superimposed on wholly bioturbated sediment, so they are thought to have been introduced below the mixed layer, in the transition zone. *Chondrites* typically occurs in small patches and commonly cuts across all other burrows present. Unlike the *Chondrites* in hemipelagic terrigenous deposits, those in pelagic ooze commonly branch at an oblique angle to the horizontal and vary from 1 to 2 mm in the diameter of the individual tunnels. *Planolites* includes the relatively large (0.5 to 2.0 cm in diameter), unbranched, horizontal or sub-horizontal burrows in the cores. These are very common in all burrowed facies, but are especially abundant in the biogenic ooze. *Skolithos* resembles *Planolites* in virtually all respects except orientation; it is vertical or sub-vertical, and its chances of being recovered in a DSDP core are thus small. *Skolithos* occurs in very few Leg 58 core sections. *Zoophycos* is the most complex and distinctive burrow in the cores, and it is very common in the biogenic facies. Typically it is pelleted, suggesting that the burrow system was stuffed with fecal pellets (see also Ekdale, 1978a). Although the possibility exists that at least some *Chondrites*, *Planolites*, and *Skolithos* were maintained as open dwelling structures during the lives of their creators, there is little doubt that *Zoophycos* was a complex deposit-feeder burrow system that was continually filled in as the burrowing organism moved through the sediment.

The facies of pelagic brown clay, exemplified in the lower part of Hole 442B, include sediments deposited at or below the carbonate-compensation depth (CCD) beneath low-productivity regions in the oceans. One might suspect that the extremely low sedimentation rates (roughly 1 mm/1000 yr) and meager supply of organic matter to the bottom would severely limit the occurrence and abundance of benthic life in abyssal clays. Benthic biomass is indeed low — generally one or two orders of magnitude lower than that in biogenic-ooze regions (Zenkevitch, 1970) — but bottom-dwelling epifauna and burrowing infauna do occur in abyssal-clay regions. Distinctive burrows preserved in pelagic clays in DSDP cores are less diverse than those in other facies, although the intensity of the bioturbation is com-

monly just as high. The trace fossils characterizing brown abyssal clays in Leg 58 cores are dominated by *Planolites*. The low carbonate content of pelagic clay typically leaves it with little competence. Shear strength is much lower than in calcareous deposits, and burrows are much more easily deformed and (or) destroyed by sediment flow. Thus, *Planolites* and other pelagic-clay burrows are commonly smeared; the edges of the burrows are pinched out and their margins are "frazzled" (Plate 1, Figures 3, 7, and 8). This aspect of burrow preservation has been noted in box cores of modern deep-sea sediment (Berger and Johnson, 1976; Bryant, 1977; Ekdale and Berger, 1978; Berger et al., 1979) and is evident in Leg 58 cores, especially in the Miocene clay of Hole 442B.

### DISCUSSION

The "deep sea," which encompasses the abyssal and hadal realms of the oceans, at depths greater than 2000m (Bruun, 1957), imposes peculiar ecologic (including sedimentologic) conditions on its inhabitants. The lack of direct solar energy input precludes primary production, so benthic communities typically are dominated by detritus feeders — some of which graze on the sea bottom, some of which feed in the sediment, and all of which are potential trace-fossil makers. These creatures are rarely very selective in what they eat, and many are such trophic generalists that it is often difficult to distinguish between predator and scavenger (Dayton and Hessler, 1971). The absence of sunlight, seasonality, and significant bottom currents in the deep sea creates a monotonous environment in which to live. The behavioral responses of the bottom dwellers to these uniform conditions, as evidenced in their trace fossils, likewise are rather monotonous. Apparently, the behavior patterns of deep-sea burrowers have not changed significantly since the Cretaceous (Seilacher, 1974; Ekdale, 1978a). Consequently, trace-fossil assemblages in deep-sea sediments are distinctive.

Paleobathymetry of DSDP core samples can be inferred from benthic fossils and (or) sedimentary structures; trace fossils are both. The trace fossils preserved in Leg 58 cores aid our interpretation of the original water depth during deposition of the various lithofacies in the Philippine Sea. The three major lithofacies groups present in Leg 58 cores (terrigenous turbidites, biogenic ooze, and pelagic clay) are certainly of deep-water origin, and each contains a diagnostic suite of bioturbation features. Thus, there appear to be at least three different "deep-sea" ichnofacies.

In Seilacher's (1967) bathymetric zonation of ichnofacies, abyssal conditions are indicated by a diverse suite of highly patterned and dominantly horizontal deposit-feeder trails and burrows. These compose his "*Nereites* Ichnofacies" (after a common ichnogenus), which is commonly associated with well-bedded strata, such as distal turbidites. Although such clastic deposits are common in the deep sea, the characteristic trace fossils are predominantly horizontal structures and thus are rarely recognized in small-diameter DSDP cores. For this reason no definite ichnogenus have been identified

in the turbidites recovered on Leg 58, with the exception of *Chondrites*, an infaunal burrow system not confined to horizontal stratification planes. The bioturbated, hemipelagic, fine-grained sub-units of Leg 58 turbidites are thought to have been deposited on (and probably near the base of) a submarine slope. The bottom certainly lay below normal shelf depths (i.e., several hundreds of meters), but whether or not the sediments were deposited at truly abyssal depths is a question that cannot be answered by trace fossils alone.

The facies of pelagic ooze and clay probably were deposited at abyssal depths, because their sites of deposition had to be far enough removed from the base of the continental slope to avoid any terrigenous influx. The trace fossils in the calcareous biogenic ooze are diverse, exhibit good color contrast, have sharp, well-defined margins, and commonly exhibit a vertical (as well as horizontal) component of burrowing. The high carbonate content of the calcareous ooze indicates that it was deposited above the CCD. The trace fossils in the low-strength brown clay are not diverse, exhibit poor color contrast, have fuzzy margins, and commonly are smeared and stretched out; vertical burrows are extremely rare. The very low carbonate content of the clay indicates that it was deposited at or below the CCD. An approximate bathymetric zonation of the three deep-sea ichnofacies comprises, in order of increasing water depth, (1) the sharply defined bioturbated horizons of hemipelagic mud containing *Chondrites*, (2) the *Chondrites-Planolites-Zoophycos* association of biogenic ooze, and (3) the smeared *Planolites* of pelagic brown clay.

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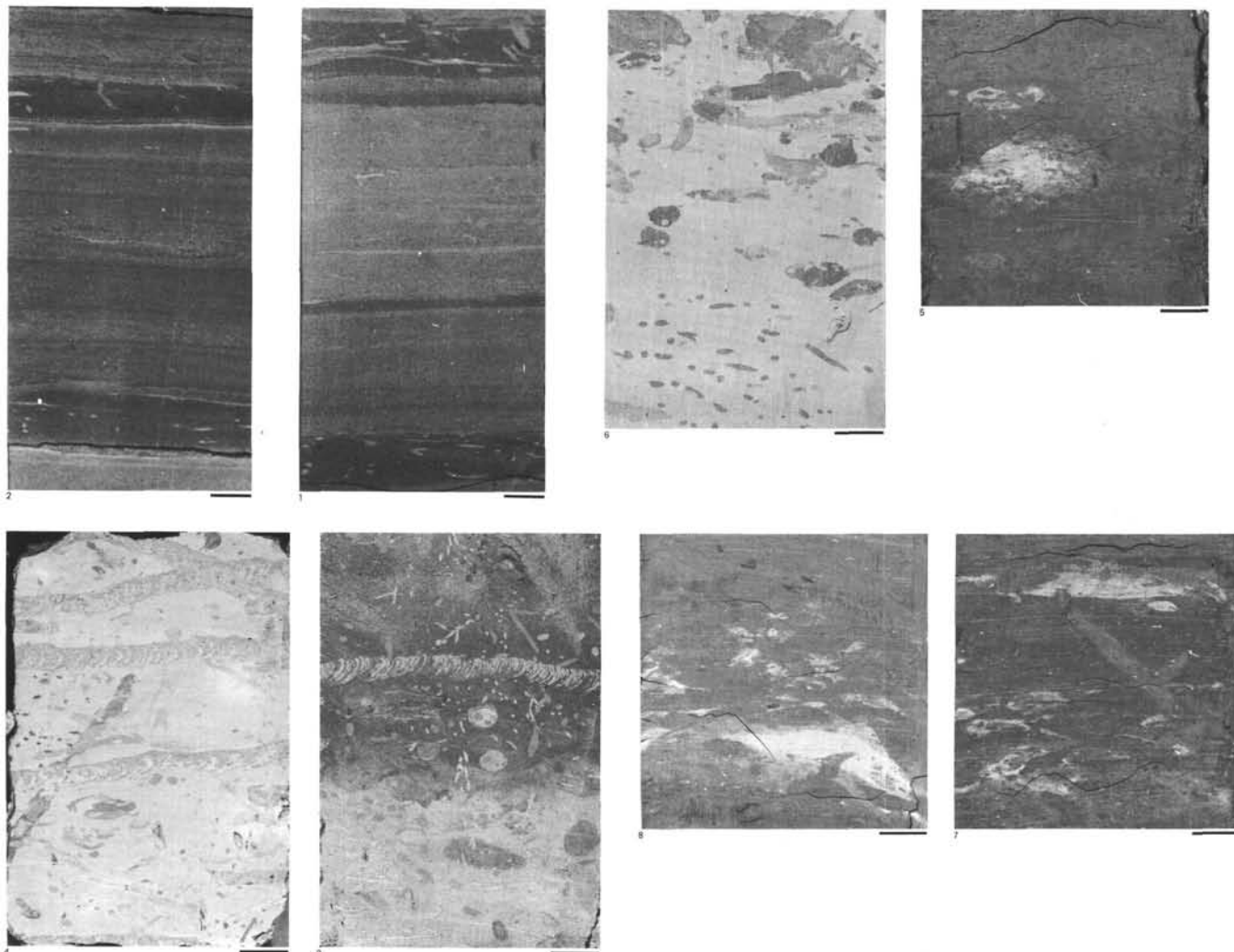
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## PLATE 1



Typical Trace Fossils in DSDP Leg 58 Cores  
(bar equals 1 cm)

- Figure 1 Bioturbated horizons interbedded with laminated horizons in middle-Eocene hemipelagic mud. 445-74-2, 120-131 cm.
- Figure 2 Bioturbated horizons interbedded with laminated horizons in the middle-Eocene hemipelagic mud. 445-74-2, 82-93 cm.
- Figure 3 Deformed burrows with fuzzy margins in Miocene pelagic clay. 442B-2-5, 17-24 cm.
- Figure 4 *Chondrites* and *Planolites* in upper-Miocene calcareous ooze. 445-28-1, 34-33 cm.
- Figure 5 *Chondrites*, *Planolites*, and *Zoophycos* in upper-Miocene calcareous ooze. 445-25-6, 1-10 cm.
- Figure 6 *Chondrites*, *Planolites*, and *Zoophycos* in upper-Miocene calcareous ooze. 445-23-1, 4-13 cm.
- Figure 7 Deformed, smeared *Planolites* in Miocene pelagic clay. 442B-2-5, 81-88 cm.
- Figure 8 Deformed, smeared *Planolites* in Miocene pelagic clay. 442B-2-5, 60-67 cm.