I.O.S.

ANIMAL BURROWS IN DEEP-SEA SEDIMENTS

by

DAVID J HYDES

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CONTENTS

ABSTRACT

Recent improvements in the sampling of poorly compacted surface sediments from the deep sea, have allowed us to see that burrowing organisms have a marked effect on the sediment fabric. This report presents a practical guide to our current knowledge of such burrow structures. The different types of burrow are described, as are their known areas of occurrence. Recommendations for further work are made.

INTRODUCTION

The interest of the Chemistry Department at IOS in burrow structures in deep sea sediments was first aroused by the accidental discovery of open Trichichnus burrows in a Cape Basin red clay core (THOMSON et al., 1980). This was the first cruise on which the Hydrowerkstaten (Kiel) Kastenlot-box type corer was used for collecting sediment. With the Kastenlot-corer a relatively undistrubed sediment core is obtained in such a way that a much closer visual inspection of sediment stratigraphy is possible than with other coring systems (see KOEGLER 1963, for further details of the Kastenlot system). In most cores collected with this system inhomogeneities are seen in the sediment fabric, other than those caused by changes in the sedimentation regime. These are predominantly mottles resulting from the preservation of the infilled tunnels left behind by burrowing organisms. The most striking alteration of sediment fabric was seen at Station 10193 during RRS Discovery Cruise 110. At this station the Kastenlot core contained a number of open burrows of about a centimetre in diameter along the 2 metre length of the core.

An important question arises from these observations. To what extent do the inhomogeneities produced in the sediment by burrowing mean that a program of sediment sampling must be arranged to take account of burrows in order to provide an accurate and precise representation of the properties of the sediment being considered? A second question can be added to this - to what extent has data, previously classified as "bad", been produced as a result of sampling burrowed sediment? These questions can only be answered by sampling programs which take burrows into account and by measuring the differences between burrows and the bulk sediment. Such sampling has then to be put into the context of the world ocean in order to see how generally applicable its results might be. The first stage of this is to find out what is already known about deep burrowing in abyssal sediments and how extensive it might be - that is the aim of this report.

Burrowing, depending on the depth at which it takes place in the sediment, has two diametrically opposite effects on sediment structure. In the top layer where energy supply is greatest abundant shallow burrowing organisms tend to homogenise the sediment in what is usually considered to be the "bioturbated zone"; the constant reworking prevents the preservation of individual burrow structures. Below the bioturbated zone much of the food supply in the sediment utilizable by macro-organisms has been removed, so that penetration into this region is limited to a small number of specialized animals and as the frequency of burrowing is low the burrows formed will tend not to be obliterated by subsequent burrowing and are preserved in the sedimentary record, as so called "trace fossils".

Burrowing alters sediment physically and chemically. Physically, translation and grading of the sediment may lead to apparent hiatuses in the stratigraphic record or radiogenic age of the sediment. Micro-chemical environments can be formed in the sediment as a result of the concentration of organic matter in the burrow by the organisms, either in slimes produced by the organism to line the burrow wall or in fecal material. This organic matter becomes a "breeding ground" for bacteria. The growth of bacteria changes the chemical environment as the bacteria work through the spectrum of available electron acceptors as they metabolise the organic matter. Initially carbon dioxide is produced: later this carbon dioxide is utilised to produce methane.

Hard rock geologists have been aware for some time of the presence of fossilised burrow structures in consolidated formerly marine sediments. These and other trace fossils present can be used to identify the depositional environment of the sediment. The study of trace fossils is not the study of fossil fragments but of the imprints left by animal life in deformable sediment. As one is dealing only with the tracks of animals whose body parts have not been preserved there is no certainty about what made a particular track or whether identical tracks were made by non-identical animals. Conversely one animal could produce more than one type of trace. This problem is discussed by FREY et al. (1980) and indeed they show a Teichichnus burrow from an Eocene limestone which appears to be part of a Thalassinoides burrow system. It is this uncertainty which means that there is no officially sanctioned nomenclature for trace fossils; however as until recently only a limited number of people were working in this field a widely accepted nomenclature does exist. From the work on fossilised burrow structures in hard rock we know something about the three dimensional form and extent of burrows. Such information is not available from marine sediments where the diameter of the core section taken is in general less than the lateral extent of the burrow and observations can only be made on a limited number of faces sectioned through the core. For a graphical description of this problem see CHAMBERLAIN (1976) and BERGER et al. (1979).

The names and characteristic sizes of the trace fossil types described in the next section of this report are presented in Table 1.

This report presents a practical base for the further consideration of burrow structures. It is in no way an exhaustive review of the subject. In the following sections the major types of burrow structures which have been observed in deep sea sediments are described in terms of their physical appearance and place of occurrence. Observations of burrows in cores collected by the IOS Chemistry Department are also summarised. Recommendations are made for further work.

DESCRIPTION OF BURROW TYPES AND THEIR OCCURRENCE

DESCRIPTION

The major source of information on the appearance and occurrence of trace fossils in deep sea sediments is from samples collected by the Deep Sea Drilling Project. Descriptions of trace fossil assemblages have appeared irregularly in "Initial Reports of the Deep Sea Drilling Project". The best introductions to observations on DSDP cores are presented by CHAMBERLAIN (1975) and EKDALE (1977). The drawback of the DSDP work is that it is based on results from well-consolidated sediments which are not disturbed by the drilling process, and not the recent sediments we are interested in. The introduction of the hydraulic piston corer (HPC) into the DSDP program should mean that in the future information will be available from this source on structures in more recent sediments. The second source of the descriptions given here is the work of WETZEL (1979). This is a very useful source in that the ecology of the whole range of trace fossils is considered in recent sediments, between the sediment water interface and 5 metres depth in the sediment. The significance of this work is that the types of traces described are the same as those seen in the much older well-consolidated sediments sampled by deep sea drilling; also the three dimensional structure of the burrows revealed by X-ray photographs of serial sections of sediment appears to be similar to those found in hard rock studies. This uniformity suggests that it is valid to interpret observations in surface sediments on the basis of information from older sediments such as those sampled in the DSDP. However the applicability to other areas of the deep sea of Wetzel's detailed description of the ecology of trace fossils is probably restricted as he was dealing with an area of unusually high sedimentation rate off the coast of North West Africa. An example of our restricted ability to extrapolate his data to other areas is given by Wetzel. He found that the occurrence of _Zoophycos_ burrows off N.W. Africa decreases as the depth at which the sediment becomes anoxic increases and that they were not found in sediments which did not go anoxic. This contrasts with the situation in the Pacific where Zoophycos have been reported in apparently oxic sediments.

Observations of burrows in core sections is generally limited to the visual inspection of a single plane through the sectioned core. What can be seen in a core face are colour changes, holes, and gross changes in particle size and packing density. Where it is possible to take X-ray photographs of serial sections through a core as was done by Wetzel, a more detailed and three dimensional picture of burrows can be established. The fine details of particle packing density changes across burrows that were observed by Wetzel, made it possible for him to subdivide some of the different trace fossil types described by Chamberlain and Ekdale. For the limited geographical area considered by Wetzel his subdivisions appear valid in that changes in burrow type can be related to changes in the surrounding sediment. In the light of what we already know about the discrepancy in the behaviour of Zoophycos off N.W. Africa and the Pacific it is doubtful that Wetzel's subdivisions are of general utility to consideration of a wider range of sedimentary conditions. However details of Wetzels subdivisions are included here to illustrate the detail that can be obtained by X-ray observations, and for reference. Similarly Ekdale's subdivisions of Zoophycos structures are listed, although at the moment there is little evidence that they are of ecological significance rather than being products of differing regimes of sediment compaction or diagenesis.

OCCURRENCE

CHAMBERLAIN (1975) concluded that he was unable to find an association between any trace fossil and any particular lithology, although trace fossils were generally more common in biogenic sediments than in clastic ones especially abyssal muds, and more than twice as abundant in carbonate than siliceous sediments. EKDALE (1980) considers that pelagic biogenic facies are characterised by Chondrites, Planolites, Skolithos and Zoophycos, whereas in pelagic brown clay the dominant trace fossil is Planolites. EKDALE (1980) also concluded that although the benthic biomass is low in clay areas the intensity of bioturbation is just as high as in biogenic oozes where the benthic biomass may be two orders of magnitude higher. However in clays, burrows are easily deformed or destroyed by sediment flow and so the effects of burrowing may not be seen as clearly as in more competent sediments. Planolites and other pelagic clay burrows are commonly smeared. The frequency of occurrence of the main trace fossil types studied by EKDALE (1977) with respect to sediment type, total number of cores and ocean basin, are presented in Tables 2 and 3.

WETZEL (1979) gives a highly detailed account of where different burrow types are found within the limited area which he studies. As Table 4 shows, the trace fossil community was found to change with depth. However this apparent relationship with depth is probably a function of the dependence of sediment composition on depth. Few clear limitations on the occurrence of individual trace fossils are apparent. Scolicia and Lophoctenium tend to occur only in coarse-grained sediments, while Chondrites and Trichichnus which have narrow tubes only occur in fine-grained sediments. Zoophycos appears to be limited to clay-silt sediments which contain between 0.3% and 1.8% organic carbon.

Below, each of the burrow structures found in deep sea sediments is described. (The source of the information is noted in brackets after the name of the trace fossil.)

CHONDRITES (CHAMBERLAIN, EKDALE AND WETZEL) FIG. 1

Chondrites occur as plant-like systems of regularly ramifying tunnels which do not cross or anastamose, but radiate from a central vertical tube. The burrow size is from 0.5 mm to 3 mm, and one system may influence several 100 cm^3 of sediment. They are seen on core faces as infrequent branching tubes or as clusters of sub-circular tube sections. The wall is smooth, and is of uniform diameter. There is some indication that the burrow may be filled passively by sedimentation after it is deserted by the animal which created it. This is commonly seen in DSDP cores, especially where the burrows occur near an interface between two, different coloured sediments. Chondrites often cut across other burrows especially Planolites but are rarely cut across themselves. We can conclude from this that at the same depth in the sediment the Chondrites occurred later than the other burrows; and also assuming sedimentation to be continuous, that the animal making Chondrites burrowed deeper in the sediment than many of the other organisms in the infaunal community.

Wetzel distinguishes five types of Chondrites on the basis of the burrow diameter, whether or not a wall structure exists, and on how the burrow is filled.

TYPE A Tube diameter 3 mm. Wall structure not distinguishable. Visually paler than surrounding sediment. X-ray shows particles to be tightly packed in burrow.

Microscopically, packing appears to be in layers, made up of 2/3 quartz particles of greater than 20 microns.

TYBE B Tube diameter 2 mm. Wall structure not distinguishable by eye. Visually often uncoloured but also lighter or darker than surrounding sediment. X-ray shows interior to be less tightly packed. Outer coating of densely packed large unorientated particles. Inner filling up to 80% less than 6 micron particles built up in layers.

TYBE C Tube diameter 1 mm. Colour depends on overlying sediment. Inner tube packing similar to surrounding sediment. Outer wall composed of tightly packed particles - packing density decreasing towards centre of tube.

TYPE D Tube diameter 1 mm. Uncoloured. X-ray shows sharp well defined wall of tightly packed particles. Tubes often hollow, and when filled contain fine particles loosely packed.

TYPE E Tube diameter 1 mm. Coloured or uncoloured. X-ray shows wall with sharp outer boundary but diffuse towards centre. Structureless filling of fine material.

CHONDRITES - OCCURRENCE (WETZEL)

Chondrites are generally found in sediments well removed from the coast and deeper than 1000 m, which probably indicates a preference for finer grained sediments. Chondrites C and D occur much the most frequently, types A and B occur occasionally and E only occurs in water deeper than 3000 m. Below 2000 m they are typically associated with Zoophycos. The occurrence of Chondrites in a core section has nothing to do with Chondrites being contemporaneous with that section because of the deep burrowing of this trace fossil. Hence estimation of when Chondrites occur involves a "correction" by 15 to 35 cm in "core time".

HELMINTHOIDA (EKDALE, CHAMBERLAIN) FIG. 2

Helminthoida is a regularly meandering horizontal burrow with numerous parallel and closely spaced meanders. In vertical sections of cores it appears as a horizontal line of dots (about 0.5 mm diameter). Looped ends of meanders may also be evident. Chamberlain brackets Helminthoida with Helminthopsis (see below) probably because of their similar size and rarity however it would seem better to separate the two. Helminthoida are unbranching burrows in a wave or spiral pattern.

HELMINTHOPSIS (WETZEL) FIG. 2

The Helminthopsis burrow may be several dm in length, have a cross section up to 0.5 mm and a wall thickness of 0.1 to 0.3 mm. Attached to the main tube are short (cm long) dead end tubes. The burrow is filled with fine particles of less than 20 µm size. Helminthopsis is responsible for the formation of Chamberlain's "Composite Burrows" and is found in the interior of older larger burrows which are reworked presumably as a richer source of organic material than the surrounding sediment.

LOPHOCTENIUM (WETZEL) FIG. 3

The animals forming the three burrow structures already considered work the sediment to form simple distinct tubes. However in three burrow types Lophoctenium, Teichichnus and Zoophycos the sediment has been mined more efficiently by the formation of spreite (or tongue-like) structures. In this case the animal works through the sediment producing a series of overlapping tubes which give rise to a lamellar structure.

The Lophoctenium structure as can be seen in Fig. 3 is made up of a peripheral burrow which connects it to the sediment surface and the plane bounded by this burrow is worked out in an irregular manner. The irregularity of the working is what distinguishes this spreite most clearly from Teichnchnus of Zoophycos.

The spreite may be 20-50 cm long; 10-30 cm wide and 1-2 cm high. The peripheral tube may be 0.5 to 1.5 cm across and be several dm in length. Colour variations are seen across the spreite, and variations in packing are seen in X-ray pictures. The main body of the spreite is formed of fine grains. The thickness of the individual laminae varies from 0.5 to 2 mm. The laminae occur in groups of bands which do not stretch the full width of the spreite, usually not being more than 5 to 10 cm in length.

NEONEREITES (EKDALE)

Neonereites is a meandering trail of numerous irregular pods or pellets of sediment. The trail is generally horizontal and may appear elliptical or figure-eight shaped in cross section. It is rare-seen at one site by Ekdale. The elliptical tube was 1 mm wide; and appeared black in a pale coloured clay.

PLANOLITES, REDUCTION BURROWS AND SKOLITHOS (EKDALE, CHAMBERLAIN AND WETZEL) FIG.4

Planolites is the most common burrow type in deep sea sediments. In comparison to most other burrow types it lacks well defined characteristics. Planolites is a smooth-walled, cylindrical to subcylindrical sediment-filled tunnel. It is usually straight or slightly sinuous and internal structure is generally absent. In split core sections it most often appears as a solid coloured circle or ellipse ranging in diameter from 0.5 to 3.0 cm. Planolites is considered by Ekdale to be a horizontal burrow, and vertical burrows of the same morphology are referred to as Skolithos by EKDALE et al., (1978). This distinction is probably the result of shear stresses in slowly accumulating sediment tending to obliterate the vertical part of Planolites and other burrows before horizontal burrow sections are obliterated (BERGER et al., 1979). This more frequent observation of horizontal (Planolites) burrows giving the illusion they are different from the rarer vertical (Skolithos) burrows. Morphologically the so called "Reduction Burrows" are very similar to Planolites. The difference is that Ekdale defines Planolites as being darker than the surrounding sediment, whereas all or part of a "Reduction Burrow" is lighter than the surrounding sediment. Such a definition can only apply to an area of constant sedimentation where the lightening can be attributed to the mobilisation of metal oxides due to the formation of localised anoxic conditions within the burrow. HARTMAAN (1979) demonstrated that the colour change is due to the mobilization of manganese rather than iron oxides. Where sedimentation is not constant the colour change can be due to filling of the burrow with a surface sediment of different colour.

Chamberlain and Ekdale consider three types of "Reduction Burrows":- halo, rind and solid. Only rind and solid burrows are considered to be "Reduction Burrows" by Ekdale. He considers that rind and solid burrows appear to have a burrow wall or rind which is not present with Planolites. A sharp boundary exists between the burrow and the bulk sediment and reduction appears to be progressive towards the centre of the burrow, a solid burrow being a form of rind burrow in which reduction has progressed to completion. Halo burrows on the other hand have a sharp boundary towards a central dark Planolites burrow and the reduction process appears to progress outwards into the bulk sediment.

Wetzel defines five types of Planolites each of which has structural variation when the cross section of the burrow is considered. All of these fall at the lower end of the size range noted by Ekdale and Chamberlain.

PLANOLITES A

Burrow diameter 8 to 15 mm, and up to several dm long. Surrounded by a thin skin of tightly packed grains. The interior of the tube is enriched in larger particles, and may contain up to 80% of sediment different from the surrounding sediment.

PLANOLITES B

Diameter of inner burrow 6-15 mm, with a wall structure which may be between equal or one half this, length up to several dm. The wall is made up of large particles with a sharp boundary to the inner burrow and diffuse into bulk sediment. Sediment from different levels is only seen in vertical sections.

PLANOLITES C

Burrow diameter 6-15 mm, and up to several dm long. Surrounded by a skin of tightly packed particles. Inner tube is enriched in shells of microorganisms, and can contain up to 60% foreign material.

PLANOLITES D

Diameter of inner burrow 2-5 mm with a wall structure one half up to equal this. Otherwise similar to type B.

PLANOLITES E

Diameter of burrow 2-5 mm. Otherwise similar to type C.

PLANOLITES - OCCURRENCE (WETZEL)

As with Chondrites the predominance of the different types of Planolites corresponds to changes in water depth and distance from land. In water depths between 1000 and 2000 m type B (occasionally A) is dominant, type D occurs infrequently at this depth. Helminthopsis are also commonly associated with planolites at this depth. As water depth increases the occurrence of types C and E increases and A decreases. Smaller structures become more common (as less food is available?) and Helminthopsis become less frequent.

Planolites communities generally occur in sediment with more than 50% of the silicate particles in the less than 2 micron grain size fraction. A changeover to a dominantly Scolicia population takes place where the sediment becomes coarser This changeover does not appear to be associated with other changes such as organic carbon content of the sediment. This may be because a trace-like Planolites is produced by a range of organisms and so the actual species producing the trace may change in response to a change in organic carbon without an apparent change in the preserved trace.

SCOLICIA (WETZEL) FIG. 5

This is the largest simple burrow structure, with a diameter of 2 to 5 cm. In cross section its shape is complex (see Fig. 5) being basically oval with identations with spiked edges top and bottom. The run of the burrows is irregular varying between straight and winding. No branching occurs. Visually the burrow is uncoloured, X-rays show it to be more tightly packed than the surrounding sediment. The outer area is rich in large particles, and possibly heavily slimed thereby attracting Helminthopsis burrowing. The interior is packed giving the impression of laminae 0.5 to 1 mm thick and 1 to 7 mm apart.

TEICHICHNUS (CHAMBERLAIN, EKDALE AND WETZEL) FIG. 6

Teichichnus is a wall-shaped spreite system connected to the surfaces by a U-shape tube. In core sections it appears as a vertical series of tightly packed, concave-up or more rarely concave down, crescent shaped laminae 0.5 to 2 cm wide and 2 to 15 cm high. The laminae are 0.25 to 1 mm thick and are composed of alternating layers of fine and coarse particles. In some cases the laminae are pelleted suggesting material is composed of faecal pellets. Wetzel distinguishes Teichichnus and "Teichichnus-like" burrows. The main distinguishing feature is that as the animal forming the "Teichichnus like" system burrows deeper into the sediment the laminae become wider. The Teichichnus is sharply defined in the sediment and is surrounded by a thin skin of tightly packed particles whereas the edges of the "Teichichnus-like" burrow are diffuse. The laminae may also be much thicker (up to 8 mm).

THALASSINOIDES (WETZEL) FIG. 7

Thalassinoides is a burrow network consisting of frequently branching, dominantly horizontal burrows and rarely branching, vertical burrows. Branching is typically y pattern, and the burrow is distended at the point of bifurcation. The system may extend to more than half a metre horizontally. Tube diameters vary between 0.5 and 3.5 cm. It appears that 60-100% of the sediment burrowed by the organism is transported to the sediment surface. Filling of burrow lacks typical structure, and the tubes may sometimes contain little or no filling. Where filled the colour of the burrow is usually that of the overlying sediment and the density of packing may be greater or less than that of the surrounding sediment.

TRICHICHNUS (WETZEL)

Trichichnus is a fine, dominantly vertical burrow. Occasional branching occurs. The tube is usually straight but may be winding. The diameter of the inner burrow ranges from 0.4 to 0.8 mm is surrounded by a wall of tightly packed grains which may be a quarter to half the thickness of the inner burrow. Filling of the burrow is often absent and when it occurs it is structureless. Up to 8 tubes may pass through 4 cm^2 horizontal plane. Two other types of structure occur in the sediment, which appear very similar to Trichichnus, but which are not biological trace structures.

TRICHICHNUS-LIKE STRUCTURE A

Is probably a de-watering channel. It is distinguished from Trichichnus in that it lacks such a well defined wall structure, although a thin skin of tightly packed grains is present. Tube diameter varies from 0.1 to 1 mm, and length to over 1 m. Branching can occur but always at a very sharp angle. It is usually found in slumped sediments.

TRICHICHNUS-LIKE STRUCTURE B

This occurs as fine threads of pyrite 0.1 to 1.5 mm in diameter and to more than 10 cm in length. Branching can occur at any angle. No wall structure exists. This structure is probably a direct product of microbial activity in the sediment and where a sediment section cannot be examined in detail, it is difficult to distinguish from Trichichnus burrows which have been pyritized.

ZOOPHYCOS (EKDALE AND WETZEL) FIG. 8

Zoophycos is the most conspicuous trace fossil in marine sediments because of its size and because as probably the most deeply burrowing organism it tends to be well preserved. It takes the form of variously shaped spreiten structures comprised of protrusive more or less J shaped burrows of variable length and orientation. The spreiten may be tubular in shape or arranged in hellicoid spirals. The periphery of the spreite is delimited by the last tunnel to be burrowed which truncates the distal ends of previous workings. This peripheral burrow may be left open. In vertical split core sections it appears as a series of crescents packed together to form a line of constant width. These crescents are made up of alternating layers of back-filling of mining spoil and faecal material. Ekdale differentiates four types of Zoophycos on the basis of the differing appearance of the cross sections of their spreiten in core faces.

ZOOPHYCOS - SIMPLE FORM (EKDALE)

The spreite is made up of thin crescents 1 to 2 mm thick packed tightly together to form a straight line of constant width 2 to 4 mm. This line is usually straight and close to horizontal. Series of up to nine parallel spreiten are seen in many cores, suggesting spiral coiling or vertical layering. The marginal tube is elliptical.

ZOOPHYCOS - CURVED FORM (EKDALE)

Closely similar to simple Zoophycos except that the spreiten are curved concave up. The marginal tube is circular. (Note: the shape of the marginal tube is most probably a function of compaction of the sediment).

ZOOPHYCOS - FAT FORM (EKDALE)

The crescents in the spreite cross section are irregular, thick (2 to 8 mm) and loosely packed together in a straight or curved line of varying width (3-6 mm), which may be inclined as much as 45° from the horizontal.

ZOOPHYCOS - PELLETED FORM (EKDALE)

The spreite is constructed entirely of tiny pellets (about 1 mm) presumably faecal in origin. The pellets are packed to form an irregular line of variable width (5 to 15 mm) and orientation. The marginal tube is elliptical in cross section.

Wetzel considered that ecologically the most important variation is in the marginal tube which may be described as U or J form. (a) U Form Back fill of the spreite is bounded on both sides by an open tube. This suggests the whole burrow was ventilated by a continuous tube connected to the sea floor by two holes. (b) J-form Only one side of the back fill is bounded by an open tube. The J form is found in oxygenated sediments whereas the U-form is found in anoxic sediments suggesting that the tube was used as an oxygen source.

Wetzel drew up the following Table (5) which gives a guide to the size of Zoophycos structures.

ZOOPHYCOS - OCCURRENCE (WETZEL)

Zoophycos was found in long cores from water depths greater than 2000 m. Clay-silt sediments are preferred, and it is absent in coarse-grained, rapidly accumulating sediments which tend to contain Lophoctenium and Thalassinoides. Zoophycos occurs in anoxic sediments containing between 0.3 and 1.8% organic carbon. In all cases the sediment is anoxic, in contrast to observations of Zoophycos in Pacific cores where it does occur in oxic biotopes. Between the Canary Islands and Cape Verde 80% of the Zoophycos observed were found in sediments laid down during periods of cold climate. As with Chondrites, because of the considerable depth to which it burrows a "correction" has to be made when estimating the time at which it occurred. When this is done the actual occurrence of Zoophycos is not as uniform as that of its burrows.

OBSERVATIONS OF BURROW STRUCTURES IN CORES COLLECTED BY I.O.S. CHEMISTRY DEPARTMENT DURING R.R.S. DISCOVERY CRUISES 108, 110, 125.

From Cruise 108 onwards the Chemistry Department has been photographing all cores collected, so that we have an accurate record of the appearance of those cores. In these photographs we can see that burrow structures are present in all 8 of the Kasten cores collected. Table 6 records the different types of burrows observed in these cores.

RECOMMENDATIONS FOR FUTURE STUDIES OF BURROW STRUCTURES

The major geochemical interest in burrows is the extent to which burrowing changes the overall chemical environment within a given sediment. To study this we need to be able to find the burrows which are there, and then quantify their affect on the chemical composition, mineral distribution and porosity of the sediment.

CHEMICAL STUDIES

Our understanding of the chemical processes involved in the early stages of diagenesis of deep sea sediments has increased rapidly in recent years. Almost all this effort has however been directed to a bulk explanation of the changes observed. The exceptional papers are those of HARRINGTON (1978) and HARTMANN (1979), in which the influence of burrows on sediment composition was investigated; and a number of papers by Berner, particularly BERNER (1969) in which the circumstances leading to the localised formation of pyrite are considered.

HARRINGTON (1978) briefly reports a first pass at using an electron microscope and microprobe to study Chondrites, Teichichnus and Zoophycos burrows observed during DSDP Leg 41. He could not find a consistent pattern of chemical depletion or enrichment in the burrows he looked at. HARTMANN (1979) looked at two core sections of Pacific pelagic sediment: a carbonate ooze and a carbonate-free, red clay, siliceous ooze. Yellowish coloured spots and the surrounding brown sediment were analysed for trace metals. Sequential leaching of the bulk brown sediment as also done. He concluded that: (1) the brown colour of these sediments was caused exclusively by manganese oxides (2) nickel and copper occur in intimate mixture or solution with manganese oxides, (3) slightly reducing conditions existed in micro-areas of these oxidised sediments for a limited period of time, during their early diagenetic history, mobilising a large fraction of those trace metals which are preferentially found in Mn noduels at the sediment surface.

In IOS cores collected at Discovery stations 10193 and 10400 structures occur in the sediment which appear to be produced by the formation of diagenetic pyrite. At station 10193, there are several diffuse vertical black bands, several cms long and about 1 cm wide. On a smaller scale several of the burrows appear to have associated with them black halos which are about 1 mm thick. These could be described as liesegang banding, the formation of which was discussed by BERNER (1969). At station 10400 in the base of the core we observed what appeared to be at first sight pyritized *Trichichnus* burrows (WETZEL, 1979). BERNER (1969) considered three models based on layered situations to illustrate the factors affecting the migration of iron and sulphur within recently deposited anaerobic sediments. In a low reactive-iron sediment, bacterial generation of H_2S in an organic-rich layer should lead to darkening by iron sulphide formation in the adjoining organic-poor sediment to a distance far greater than the thickness of the organic layer. In a high reactive-iron sediment, iron sulphide formation will be restricted to the organic-rich layer, which will be enriched at its boundaries by the diffusion of dissolved iron and sulphate towards the organic layer in which sulphide is produced. In sediments of intermediate reactive-iron content, the point at which the iron sulphide solubility product is exceeded may be some distance from the margin of the organic rich layer. Iron sulphide will be concentrated at this point and liesegang banding will form.

RECOMMENDED WORK

Analyses of sediment composition similar to those of HARTMANN (1979) should be carried out to see how generally applicable his conclusions are. It would seem likely that a broader spectrum of changes should be observed, in particular it would seem likely that in some burrows iron mobilisation will occur. Hartmann contended that localised mobilisation of manganese from burrows was a possible source of the manganese for the formation of manganese nodules at the surface of apparently well-oxidised sediment. It would seem to be worth testing this hypothesis quantitatively when more details on burrow occurrence and composition are available - preferably from Pacific manganese nodule belt cores.

The composition of the apparent "pyrite" structures observed in some IOS cores notably 10193 and 10400 should be investigated, and the sources of the components of the observed banding identified.

Work on the chemical composition of larger burrows can be done by standard wet chemical techniques. But for the smaller burrows, analyses can only be done by physical method such as Energy Dispersive X-ray Analysis in conjunction with a scanning electron microscope. Use of X-ray and electron microscope methods offers the advantage of being able to map the chemical composition of a sediment surface, without the need to be guided by colour changes. There is at present only a poor understanding of what produces colour changes in sediment and so the more objective approach available through the scanning electron microscope may enable a better identification of sources and sinks or chemical components in the sediment.

PREPARATION OF CORE FACES

At present the face of the Kasten core is prepared for visual inspection and photography by dressing with a pallet knife, to remove the layer of sediment which has been mixed along the inside of the core barrel during penetration. This does reveal major structures in the sediment, but smearing is not completely eliminated by this technique and structures of the scale of Chondrites and smaller will be obscured. The use of an electro-osmotic knife for core face preparation has been investigated for the preparation of core faces collected by the Geophysics Department of I.O.S. (P.J. Shultheiss). Figure 9 shows the much-improved definition that can be obtained with it. I would recommend that in future it be used for the preparation of all core faces which are to be photographed.

CORE PHOTOGRAPHY - VISIBLE LIGHT AND X-RAY

A report on the system used to photograph the cores using visible light is in preparation (P.S. Ridout).

X-ray photography reveals changes in the packing density within cores. In conjunction with visible signs of burrowing on the core surfaces it can give some indication of the three dimensional structure of the burrow within the core. More importantly it can reveal burrows which cannot be seen in visible light as they are the same colour as the surrounding sediment, or are not on the surface of the cut section. X-ray photographs will provide information on the packing density of the sediment which can be used to assess the influence of burrows on the porosity of the sediment.

On future cruises rectangular sections of core will be subcored from box cores (I.O.S. Box Corer) (J. Thomson) and will be examined by X-ray photography carried out at I.O.S. Taunton.

Table 1 (CHAMBERLAIN, EKDALE, WETZEL)

Trace Fossil Types

Name	Size Range (Diameter of cross section) cm
Simple Tubes	
Planolites	0.5 - 3
(Reduction Burrows)	
(Skolithos)	
Scolicia	2 - 5
Helminthoida	∿0.05
Branching Systems	
Chondrites	0.5 - 0.3
Helminthopsis	<0.1
Thalassinoides	0.5 - 3.5
Trichichnus	0.05 - 0.15
Spreite (tongue-like) Structures	
	(Thickness of tongue)
Lophoctenium	1 - 2
Teichichnus	0.5 - 2
Zoophycos	0.3 - 1.2

Table 2 (EKDALE)

Frequency of Occurrence with respect to Sediment Type

Trace	Red/Brown Abyssal Clay	Siliceous Ooze	Calcareous Ooze	Turbidite Helmipelagic
Chondrites		Occasional	Abundant	Occasional
Planolites	Common	Abundant	Abundant	Common
Teichichnus		Common	Common	
Zoophycos		Common	Common	Common
Reduction Burrows	Common	Occasional	Occasional	Occasional

N.B. Reduction burrows are rarely found in association with other burrow types.

Table 3 (EKDALE)

Frequency of observation with respect to total number of cores examines and ocean basin in which observations were made. Atlantic - A, Indian - I, Pacific - P, Caribbean - C, Red Sea - R, Gulf of Mexico - M.

Trace		% of Total Cores	Where Noted
Chondrites		42	All areas
Heminthoida		3	P
Neonereites		1	P
Planolites		60	All areas
Teichichnus			C I P
Zoophycos	Simple	38	C A I P
	Curved	1	P
	Fat	8	R I P
	Pelleted	20	M R I P
Reduction Burrow			
	Rind	69	A M R I P
	Solid	43	A P I C

Table 4 (WETZEL)

Trace Fossil	Type	Water Depth, m	Percentages of cores at that depth which contains that Trace Fossil
Chondrites	A	2500 - 3500	20%
	B	1000 - 3000	20%
	C	1000 - 3000	25%
		3000 - 3500	50%
		Maximum occurrence at Pleistocene Holocene Boundary.	
	D	1000 - 2000	25%
		2000 - 4000	50%
		Maximum occurrence at Pleistocene Helocene Boundary.	
	E	3000 - 4000	<30%
		>4000	>30%
		Prefers fine grained sediments.	
Helminthopsis		600 - 800	∿ 40%
		800 - 1000	∿ 60%
		>1000	>80%
Lophoctenium		1000 - 3000	50%
		Prefers coarse silt-fine sand sediments.	
Planolites	A	1000 - 2000	100%
		2000 - 3000	∿ 60%
		3000 - 4000	<50%
	B	All cores deeper than 1000	
	C	1000 - 3000	60%
		3000 - 4000	>80%
		>4000	100%
	D	<2000	<20%
		2000 - 3000	∿ 80%
		>3000	100%
Planolites	E	2000	20%
		2000 - 3000	60%
		3000 - 4000	80%
		4000	100%

Scolia Sp	A	Occasional examples at 660 m	
		900 - 1000	20%
		1000	80%
		Favours coarse predominantly aeolian sediments.	
Teichichnus		600 - 2000	30%
		2000 - 3000	10%
		3000 - 4000	30%
Teichichnus like		1000 - 2000	75%
		2000 - 4000	50%
Thalassinoides		500	20%
		500 - 1000	40%
		1000 - 2000	60%
		2000 - 3000	25%
		3000 - 3500	10%
Trichichnus		<1000	50%
		>1000	90%
		Not found in silts or sands	
Trichichnus	A	Mostly in association with slumps	
Trichichnus	B	1000 - 3500	90%
Zoophycox		>2000	100%
		2500-3500	most common

Table 5 (WETZEL)

	Size in mm	
	Minimum	Maximum
Total vertical extent of structure	200	1,100
Vertical extent of shaft before burrowing becomes dominantly horizontal	100	400
Cross section of central structure		
long axis	40	90
short axis	4	12
Vertical separation of spreite layers	20	120
Thickness of spreiten	3	12
Cross section of marginal tube	2	10
Horizontal extent of burrowing	150	1,000

Table 6

Core Number	Position	Water Depth	Sediment Type	Burrow Type
Cruise 108 Nares Abyssal Plain				
10163#6K	23°43.5'N 59°41,7'W	5871	Dark Fawn Clay	Smeared Planolites between 12 and 18 cm.
10164#1K	26°14.0'N 60°20.7'W	6135	Fawn Clay	Open Trichichnus burrows - at 180 cm, seen in fractured surface.
Cruise 110 East Pacific Ocean				
10189#2K	9°58.4'S 102°35.3'W	4452	Reddish yellow red radiolorian ooze. Oxyhydroxide rich.	Large (>1cm) smeared mottles (Planolites/Solid Reduction) in top 50 cm Below 50 cm smaller (<1cm)
10190#1K	7°36.5'S 104°11.6'W	3743	Buff sandy ooze	Ring burrows white 1.5 cm OD 1.02ID interior greenish.
10191#1K	4°49.7'S 105°57.2'W	3737	Foram ooze	Numerous pale mottles along length of core $\sim$ 1 cm. At 119-132 cm large compound structure, 10 cm sq.
10193#1K	2°09.5'S 95°33.4'W	3334	Red brown ooze down to 35cm overlying yellow green yellow clay.	Extensive Zoophycos burrowing including open holes. Spriete width 1cm. Planolites and ring burrows in red brown ooze. Black streaks in sediment in association with Zoophycos.
10194#4.SG	1°31.3'N 86°48.8W	2711	Dark yellow red yellow marly clay to 20cm, above yellow green yellow clay.	Numerous large smeared mottles up to 3cm across Zoophycos at 88 and 48cm.
Cruise 125 N.E. Atlantic				
10399#7K	25°15.9'N 25°26.1°W	5235	Red clay with some carbonate	Extensive Planolites, along length of core.
10400#8K	25°41.7'N	5965	Red clay	Planolites along length of core. At end of core 190cm on fracture faces are extensive fine, black Trichichnus Type B burrows, size 0.1 to 0.5mm. Possibly open.

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Fig. 1A Chondrites

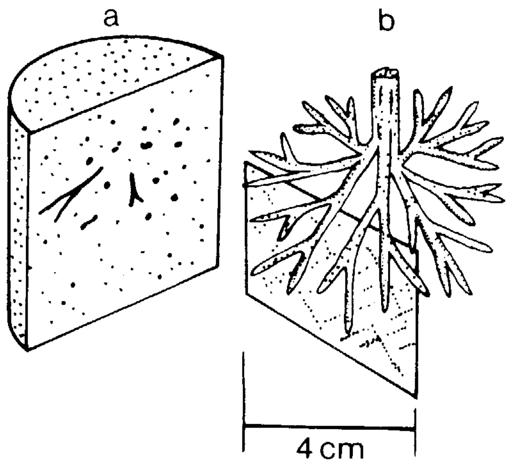

Fig.1B Interior structure of the different types of Chondrites

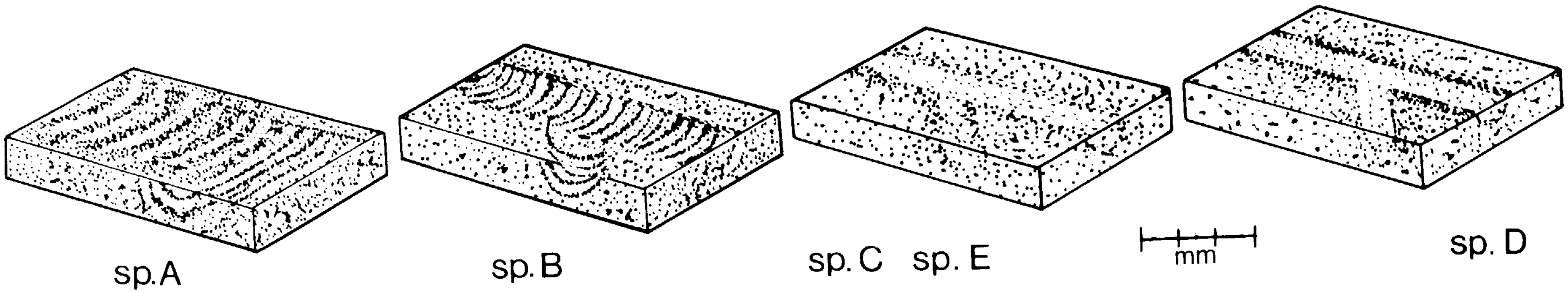

Figure 1 Chondrites

(A) Chondrites as seen in a core face, and a sketch of the three dimensional structure showing how it would appear in a core face at a particular section.

(B) Wetzel's sketches describing his 5 subdivisions of the Chondrites classification.

Fig. 2A Helminthoida

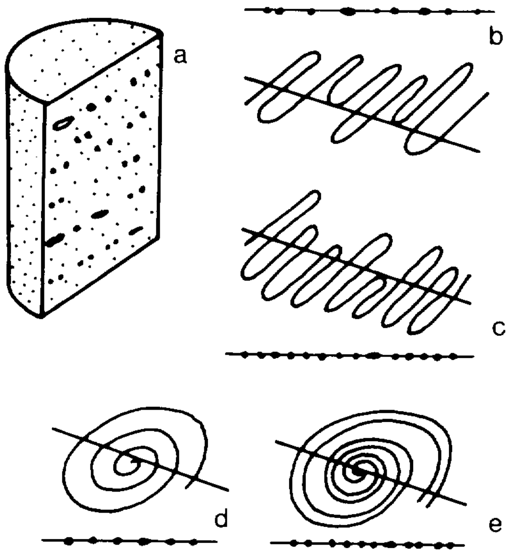

Fig. 2B Helminthopsis

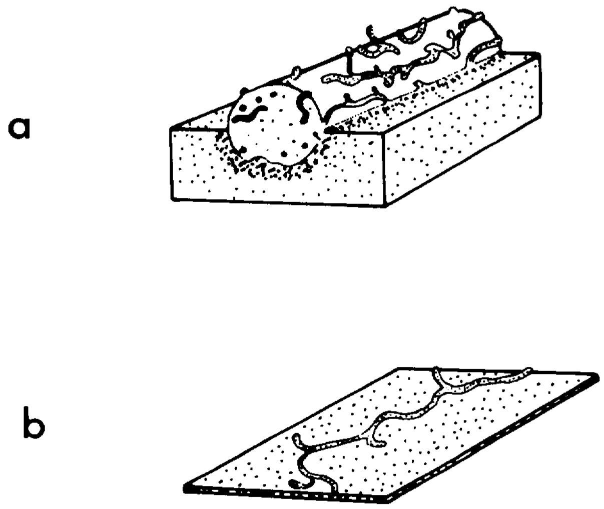

Figure 2 Helminthoida and Helminthopsis

(A) Helminthoida in a core face and how various looping or spiral trails may appear in section.

(B) Helminthopsis as seen forming a composite burrow (Chamberlain) and as seen at the interface between two sediment horizons. Note the short side shoots which distinguish it from Helminthoida.

Fig. 3 Lophoctenium

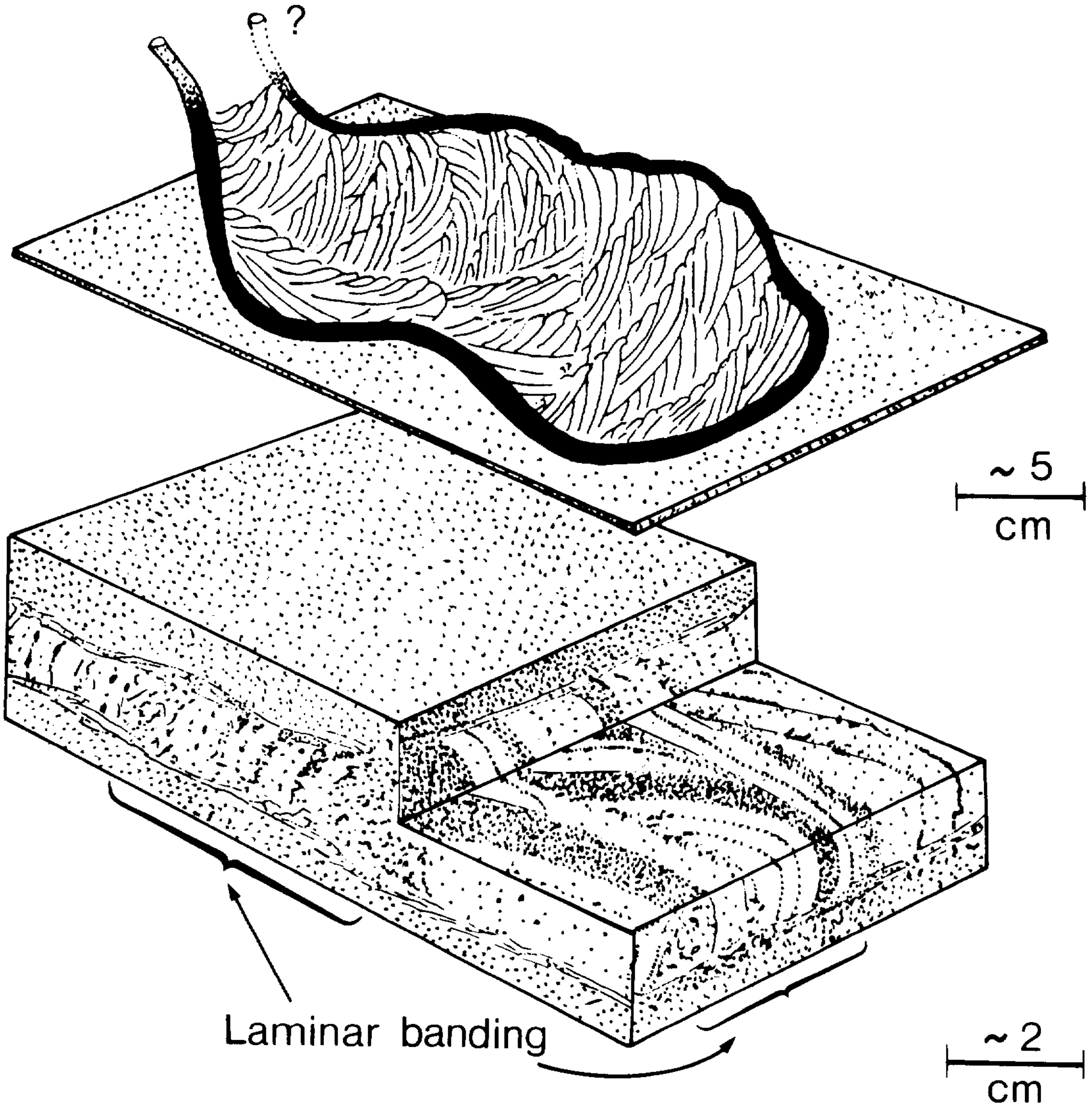

Figure 3 Lophoctenium

Note the highly irregular banding which distinguishes it from Zoophycos.

Fig. 4A Planolites Cross Sections

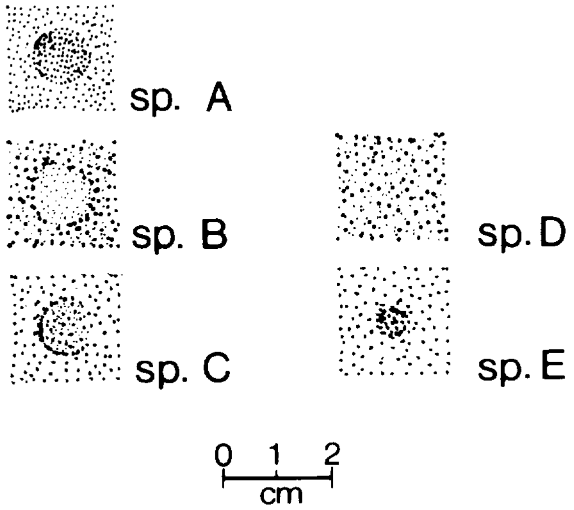

Fig. 4B Reduction Burrows

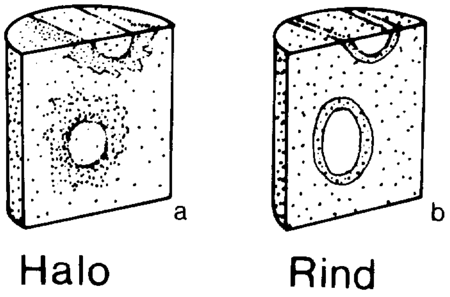

Figure 4 Planolites and Reduction Burrows

(A) Shows the differences in packing density that distinguish Wetzel's 5 classes of Planolites.

(B) (a) A halo burrow in which reduction of sediment takes place starting at the burrow boundary and diffuses out into the sediment. Whereas in (b) rind burrow reduction takes place in a sharply defined band of sediment.

Fig. 5 Scolicia

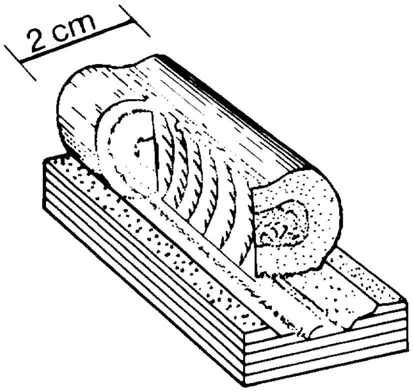

Figure 5 Scolicia

Note the complex cross section of this burrow.

Fig. 6A Teichichnus

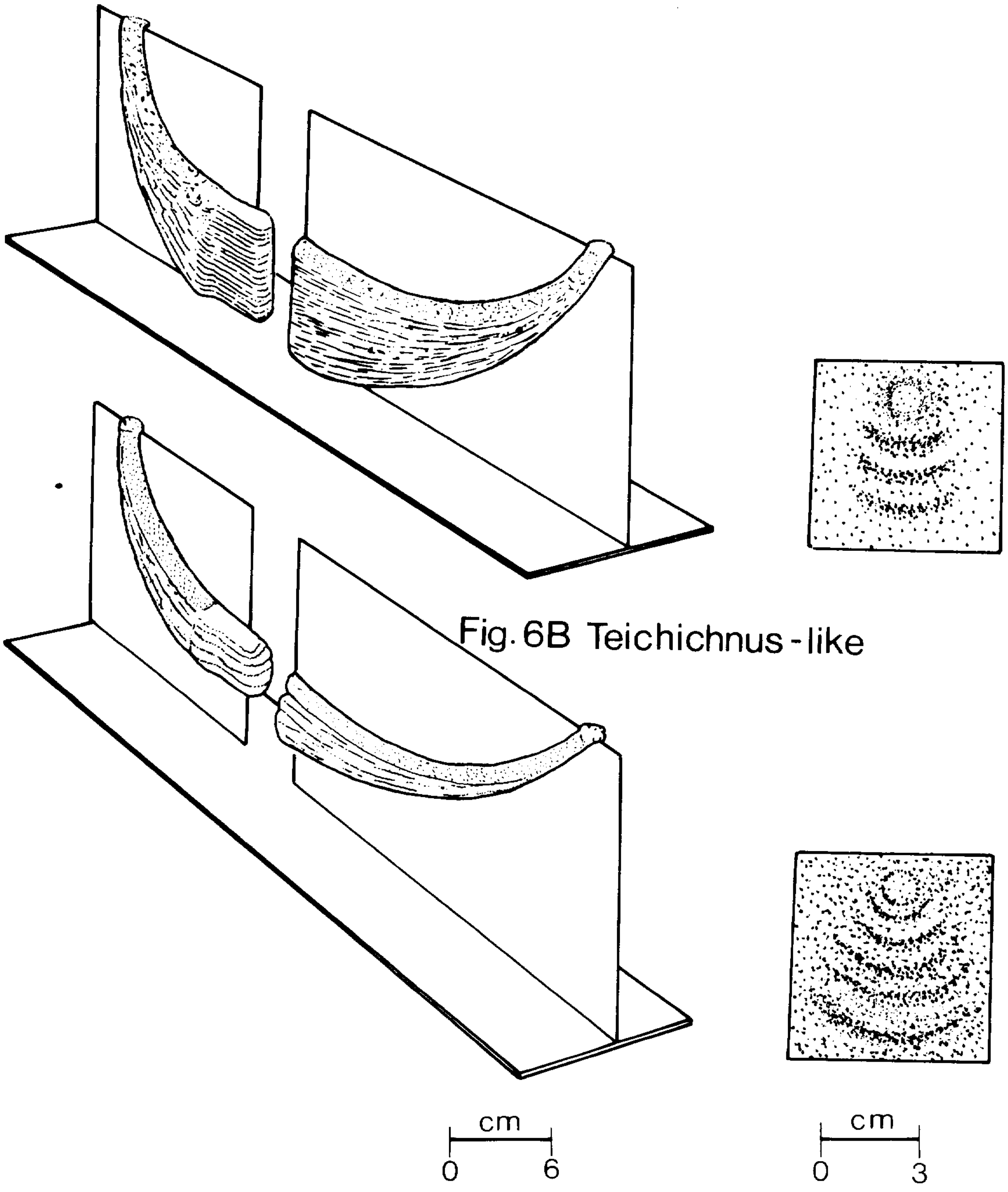

Fig. 6B Teichichnus-like

Figure 6 Teichichnus

Fig. 7 Thalassinoides

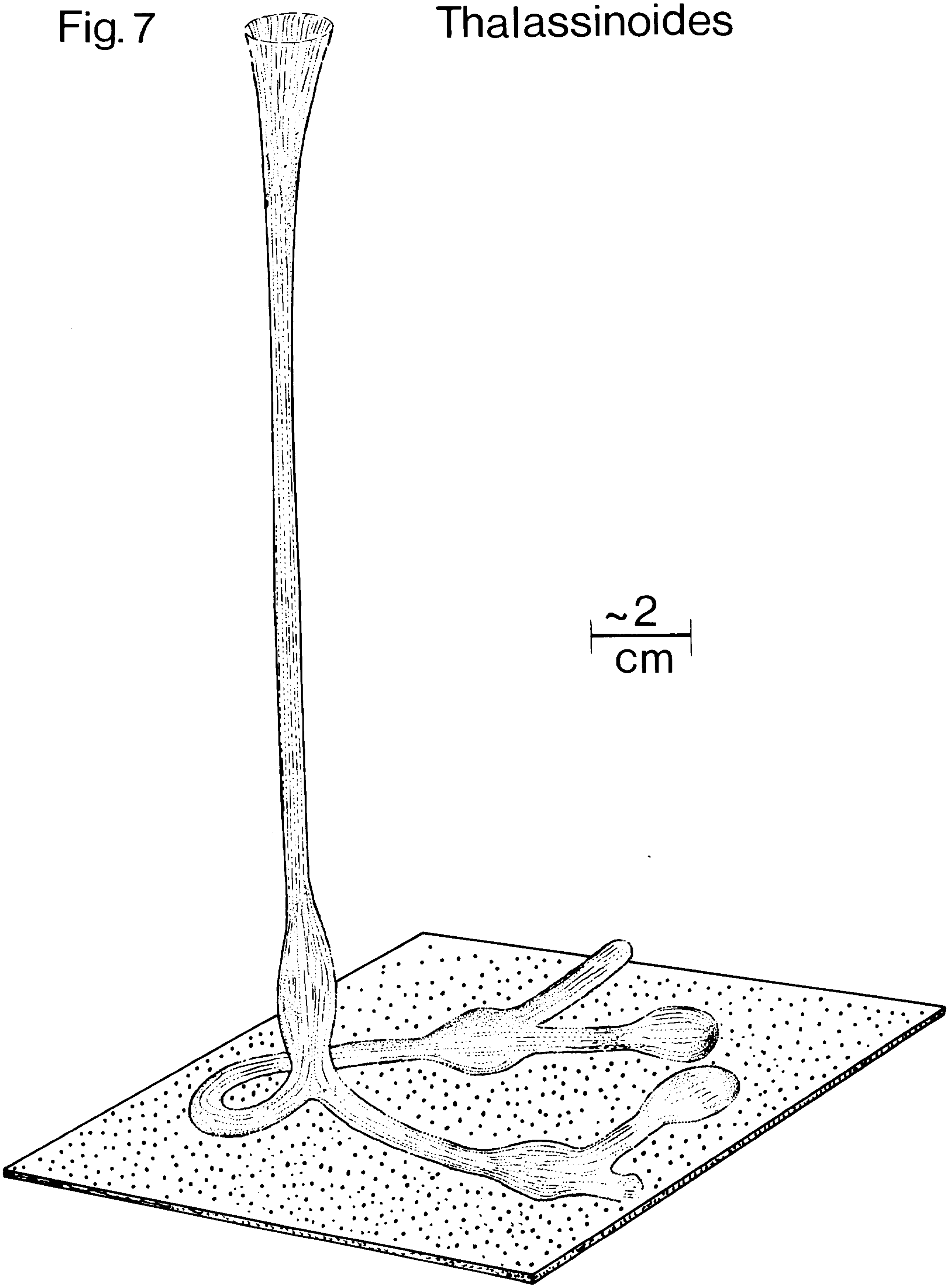

Figure 7 Thalassinoides

Fig. 8 Zoophycos

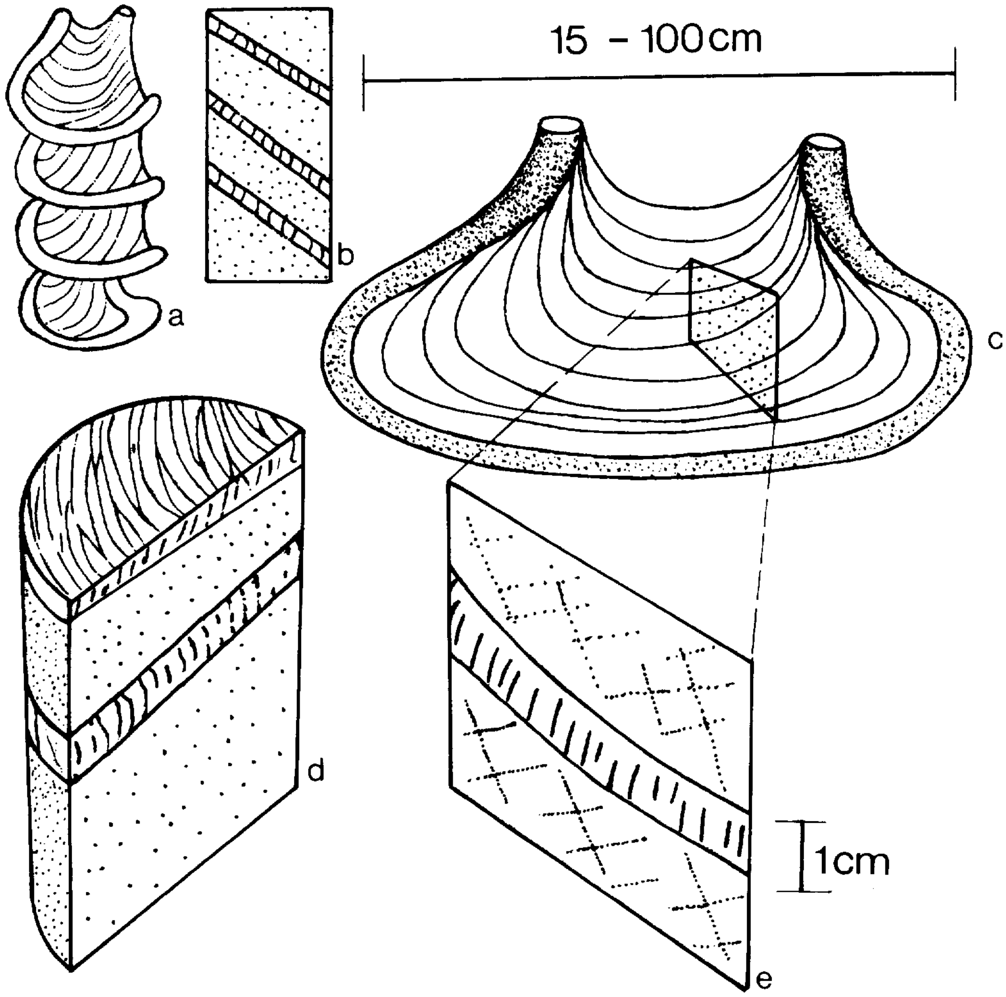

Figure 8 Zoophycos

Sketches of helically wound Zoophycos and a single spreite and how they might appear in core sections. Zoophycos is distinguished from Lophoctenium by the regular structuring of the spreite.

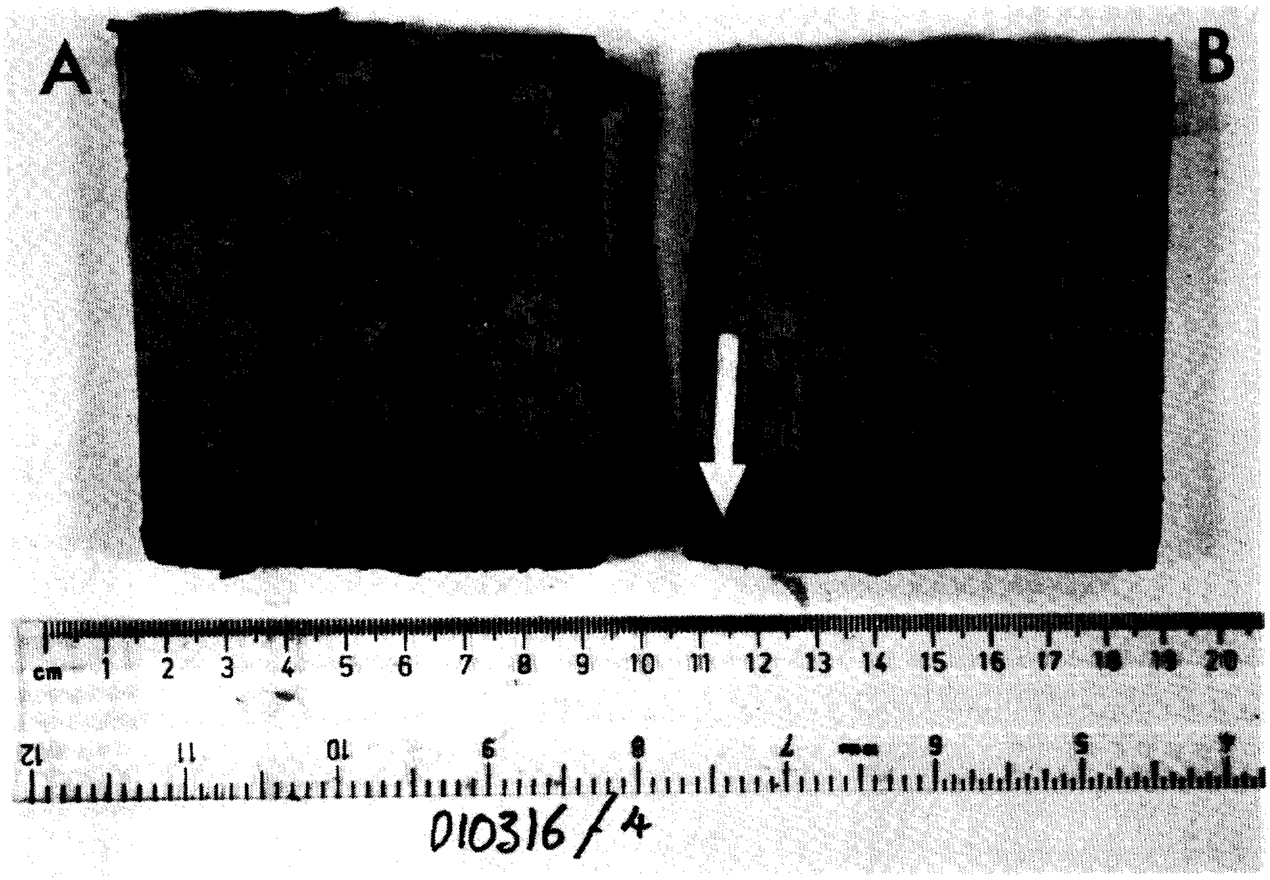

FIGURE 9

The photographs above show the improvement in the definition of sediment structures that is obtained when the sediment surface is prepared with an electro-osmotic knife (A) as compared to a palette knife (B).