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Trace fossil assemblages of deep-sea fan deposits, Gurnigel and Schlieren flysch (Cretaceous–Eocene), Switzerland¹⁾

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RÉSUMÉ

Un inventaire des ichnofossiles répertoriés dans dix localités des Flyschs crétacé supérieur–éocène du Gurnigel et du Schlieren (Préalpes et Alpes suisses), est confronté aux interprétations des milieux de dépôt déjà proposés pour ces sédiments.

Les séquences de cône sous-marin interne chenalisé, montrent des traces «d'eau peu profonde», notamment *Arenicolites* et *Skolithos*, en l'absence de toute trace méandrique ou en réseau. Les dépôts de chenal principal (cône interne) sont pauvres en nombre et en variété de traces, alors que ceux de l'interchenal contiennent une abondance de formes «d'eau peu profonde» avec terriers verticaux et horizontaux. Les accumulations de l'interchenal (cône externe) montrent toutes les empreintes classiques d'eau profonde (radiales, méandriques, en spirale, en réseau) mais celles «d'eau peu profonde» sont manquantes. Dans les sédiments de lobe, les associations sont mixtes (formes profondes et «peu profondes»), mais les faciès de lobe distal, riches en formes réticulaires et méandriques, ne montrent pas de traces «peu profondes». Les empreintes sans connotation de faciès se retrouvent dans tous ces environnements. La diversité maximale se trouve là où les formes dites «peu profondes» étaient introduites par le courant, mais où la faune profonde pouvait se réinstaller après le dépôt de chaque turbidite, c'est-à-dire dans la partie chenalisée des lobes.

Il y a peu de relations entre les variations de l'ichnofaune d'une part, et soit les facteurs de préservation, soit les proportions sable/shale d'autre part. Mais la distribution des associations de traces montre une étroite dépendance de leur position sur le cône détritique sous-marin.

ABSTRACT

An inventory of trace fossils is given for ten localities in the Gurnigel and Schlieren flysch of the Swiss Prealps and Alpine front ranges. Distribution and relative abundance of ichnofossils are compared with the interpretations of depositional environment proposed by previous studies. The trace fossil associations, with different proportions of "facies crossing", "deep water" and so-called "shallow-water" traces, are shown to be related to the various depositional environments occurring across deep-sea sand fans, but not to preservational factors or simple variations of sand/shale ratios.

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1. Introduction

The thinning and thickening upward cycles shown in many turbidite sequences have been classically interpreted as reflecting either changes at source or variations in the distance between depositional environment and source. However, following the work of MUTTI & RICCI LUCCHI (1972) some of these same sequences have been reinterpreted as the deposits of deep-sea sand fans in which processes such as channel filling can lead to thinning upward sequences, and progradation of depositional lobes to thickening upward sequences (MUTTI 1977, RICCI LUCCHI 1975).

The main difference between these interpretations is that the older hypotheses invoke changes outside the immediate depositional area to explain the cyclicity while in the deep-sea sand fan model the same cyclicity is more closely related to changes in local depositional environment (e.g. lateral migration of a channel).

Trace fossils reflect animal behaviour and are therefore normally very sensitive to environmental change. If the thickening and thinning upward sequences represent changes taking place mainly outside the depositional area, the trace fossils should reflect a stable deep-sea environment with the ichnofauna dominantly controlled by preservational factors related to deposition of individual turbidite beds. If, however, deposition took place in a deep-sea sand fan with a variety of environments such as major fan valleys, distributary channels and depositional lobes, the ichnofauna should reflect local environmental conditions.

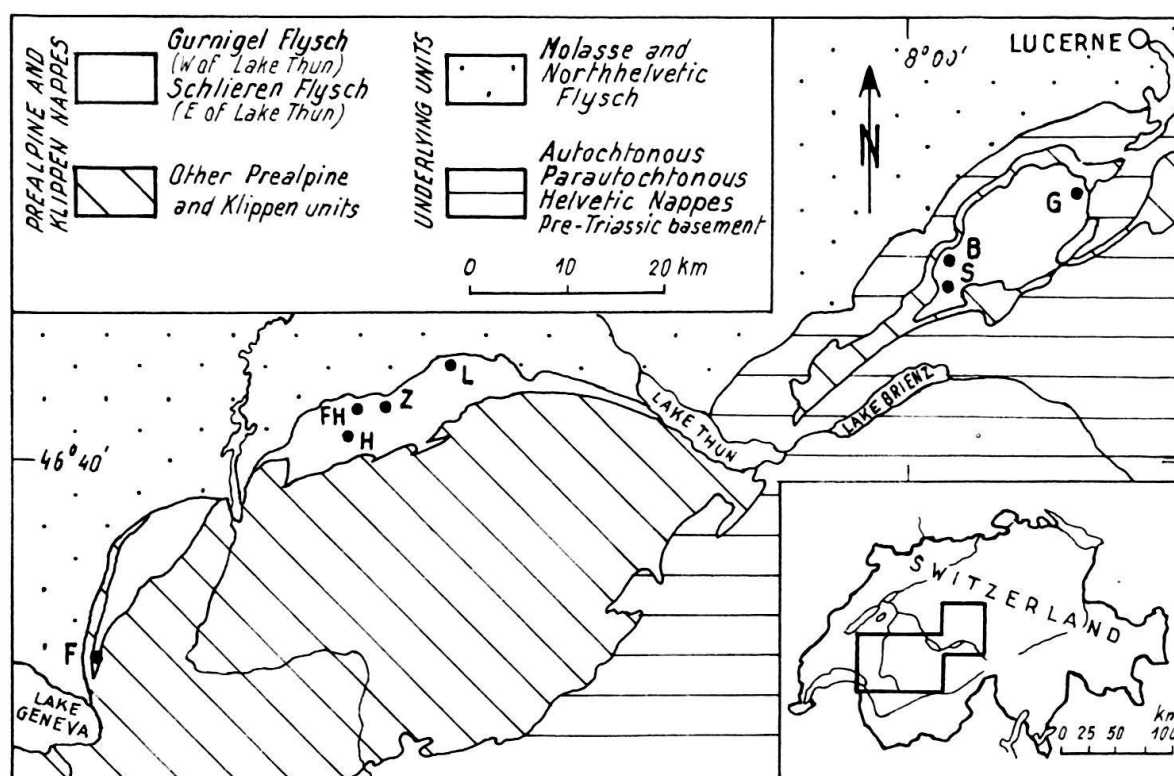


Fig. 1. Locality maps of the Gurnigel and Schlieren flysch, outcrops referred to in text.

F = Fayaux, both quarries; FH = Falli Hölli; H = Höllbach; Z = Zollhaus, both sections; L = Louetli; S = Sörenberg; B = Blattligraben; G = Guber.

There has been much taxonomic work on flysch trace fossils, particularly in Europe (see KSIĄZKIEWICZ 1970, 1977 and references therein) but there have, as yet, been fewer attempts to relate the trace fossil distribution to detailed sedimentological interpretation.

KSIĄZKIEWICZ (1970, 1975, 1977) suggested that there are changes in ichnofauna with increasing water depth within the Cretaceous–Oligocene flysch deposits of the Carpathian Mountains, Poland. The only papers attempting to relate trace fossils to a deep-sea sand fan model were by KERN (1978) working on the Cretaceous to Eocene flysch of Vienna, Austria, and CRIMES (1977) who showed that, in the Lower Eocene Jaizkibel fan of North Spain, the outer fan contained only deep water forms but the middle fan had, in addition, some ichnogenera normally found only in shallow-water successions.

The Upper Cretaceous–Eocene Gurnigel and Schlieren flysches outcrop at widespread localities within the Prealps and Front ranges of the Swiss Alps (Fig. 1) and accurate stratigraphic correlation between exposures has been made using nanofossils (VAN STUIJVENBERG et al. 1976, 1979, VAN STUIJVENBERG 1979, MOREL 1980, WINKLER 1980). These sequences have also been the subject of detailed sedimentological analysis and have been interpreted in terms of the differing environments of the deep-sea sand fan model (VAN STUIJVENBERG et al. 1976, VAN STUIJVENBERG 1979, MOREL 1980, WINKLER 1980). During these studies, trace fossils were found to be abundant in many outcrops. The present authors therefore combined to describe these trace fossils and establish any possible correlation between the interpreted environments and the ichnofaunas. The results can also be used to discuss critically the validity of the deep-sea sand fan concept.

2. Sedimentology

The Gurnigel flysch and the closely related Schlieren flysch show remarkable lateral continuity in facies. Composite sections of more than 1000 m thickness (Fig. 2) show a sandstone/shale basin plain sequence of Maastrichtian to Danian (Late Cretaceous–Early Paleocene) age overlain by a sand dominated Thanetian to Lower Ilerdian (Upper Paleocene–Lower Eocene) sequence interpreted as the deposit of prograding deep-sea sand fans in which younger more proximal depositional lobes are channelled. The development of these fans may have resulted from a sea level fall causing increased erosion and sand production (VAN STUIJVENBERG 1979). The top of the succession of Late Ilerdian to Lutetian (Early–Middle Eocene) age consists of a shale dominated channelled fan.

Within these sequences ten localities were investigated. Their stratigraphic horizon is indicated on Figure 2. Details of the sedimentological analysis can be found in VAN STUIJVENBERG et al. 1976, VAN STUIJVENBERG 1979, MOREL 1980, WINKLER 1980, and need only be summarized here.

Blattligaben

(Schlieren flysch, coord. 647.0/189.6). Coarse grained sandstones and granule conglomerates, typically in beds 3–4 m thick, with interbeds of variable thickness

and associated slumped shales. The computed sandstone/shale ratio is 0.4. The coarse grained sediments are not laterally continuous and are interpreted as infills of major fan valleys, with the slumped siltstones representing collapsed levée deposits. A proximal inner fan environment is therefore envisaged. The orientation of slump fold axes, and paleocurrent data suggest channels perpendicular to slope and therefore a slope or base of slope environment (WINKLER 1981).

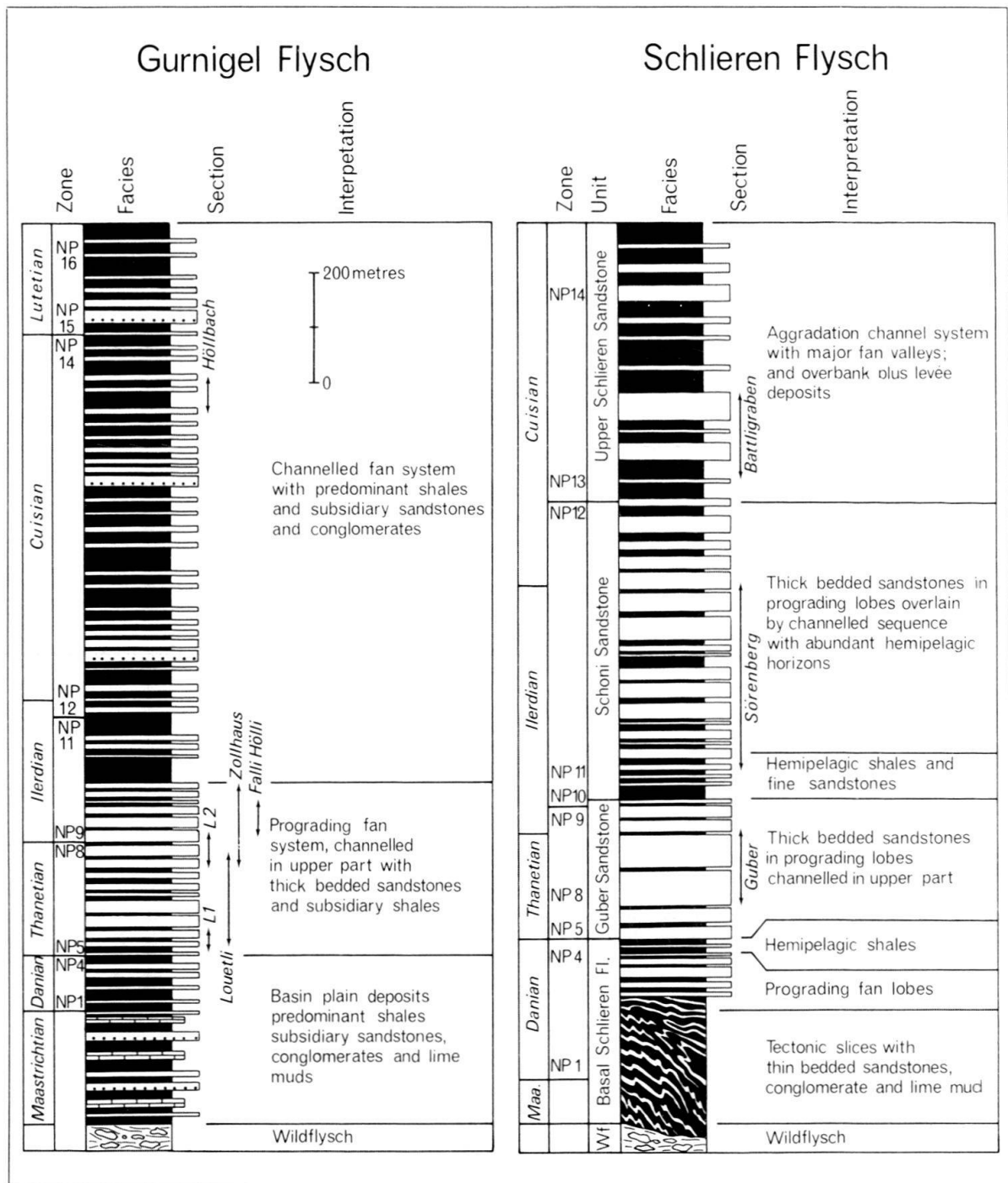


Fig. 2. Composite sections of the Gurnigel and Schlieren flysch based mainly on the localities shown in Figure 1 and described in the text.

Höllbach

(Gurnigel flysch, 585.5/170.7). The trace fossil bearing section consists of fine to medium grained sandstones mostly a few tens of centimetres thick, interbedded with shales, and has a sandstone/shale ratio of 0.8. This passes laterally into major channel-fill thinning upward sequences in which the channels are about 2 km wide and the fills more than 15 m deep. The Höllbach section is therefore interpreted as occupying a proximal position on the fan between major distributary channels.

Sörenberg

(Schlieren flysch, 647/187). A log of the Sörenberg section is shown in Figure 3. The sediments are mostly coarse grained sandstones to granule conglomerates in beds ranging from a few tens of centimetres to several metres thick, with subordinate shales. The sandstone/shale ratio is 5.5. Channelling occurs, particularly at the base of fining-up sequences, and there are also minor slumps. Thickening-up sequences also occur and the succession is interpreted as having been deposited on the inner fan across the boundary between areas dominated by distributary channels and depositional lobes.

Guber

(Schlieren flysch, 660/198). A log of the Guber sandstone in the upper Guber quarry is shown in Figure 4. The sequence is dominated by medium to coarse grained sandstones, mostly 10 cm to 1.5 m thick and subordinate shales. The sandstone/shale ratio is 14. There are channels showing basal erosion of a few tens

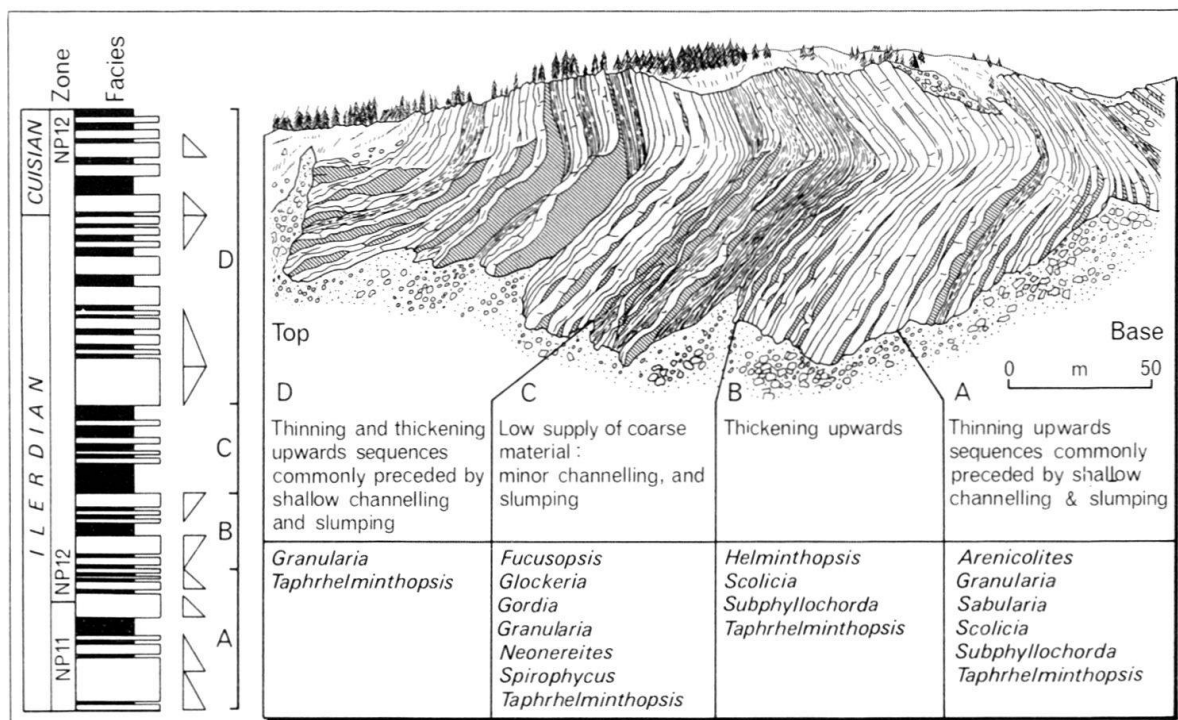


Fig. 3. Field sketch and log of Sörenberg section (Schlieren flysch) showing distribution of trace fossils.

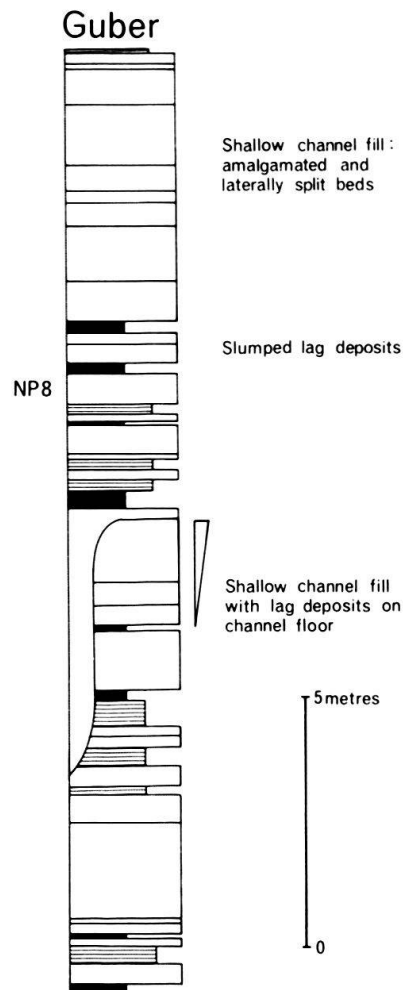


Fig. 4. Log of the section of the Schlieren flysch exposed in Guber quarry.

of centimetres to many metres and associated thinning-up sequences. Thickening-up sequences are also present and some beds show slumping. The section is interpreted as having been deposited on the channelled innermost part of a depositional lobe close to the interface with the channelized inner fan.

Lower and middle Zollhaus quarry

(Gurnigel flysch, 589.9/174.0). Part of the Zollhaus section is shown in Plate 1, Figure 1, and a log is presented in Figure 5. There are fine to medium grained sandstones, mostly 5–50 cm thick but some are several metres thick. The sandstones vary in thickness laterally and some are amalgamated. Shales are subordinate and the sandstone/shale ratio is 4.5. Some of the thicker sandstones have erosional bases which mark the start of thinning upward sequences, thus suggesting a channel infill origin. The sequence appears to have been deposited on the channelled inner part of a depositional lobe but perhaps not in quite such a proximal position as the Guber outcrop where bed thicknesses were greater and small scale channelling more pronounced. This impression may, however, be the result of sediment type and outcrop conditions.

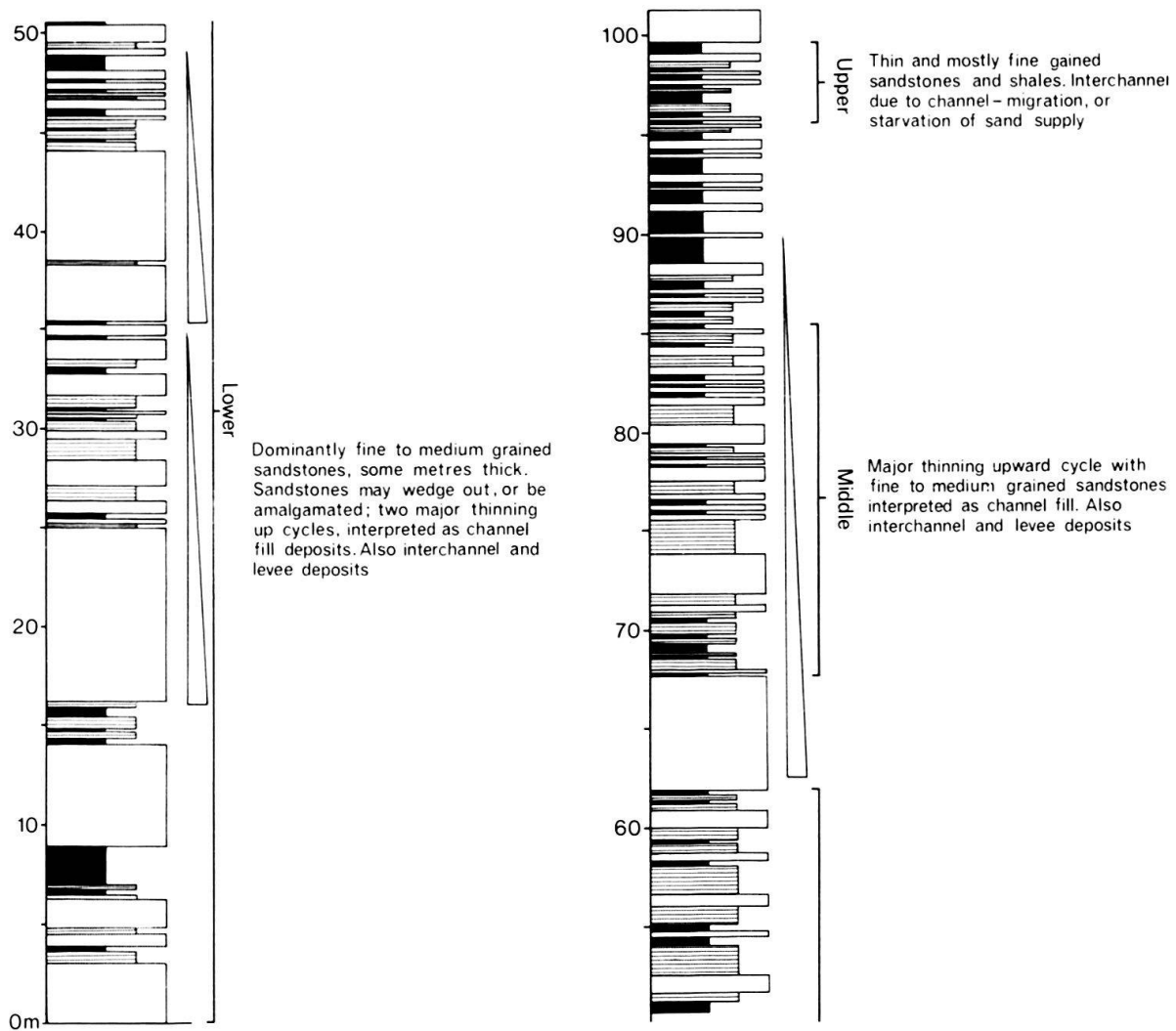


Fig. 5. Log of section of the Gurnigel flysch exposed in Zollhaus quarry.

Louetli

(Gurnigel flysch, 595.6/171.6). The Louetli quarry section (Pl. 1, Fig. 2) includes the top 50 m of a 155 m section and has been logged in detail. The upper part of the section examined for trace fossils is shown in Figure 6. It consists mostly of fine to medium grained sandstones, of varying thickness, often with erosive bases, and subordinate shales. The sandstone/shale ratio is 2.3. The sandstones are mostly arranged in thinning-upward sequences and represent channel fills in the inner to middle parts of depositional lobes.

Falli Hölli

(Gurnigel flysch, 585.3/173.8). The succession consists of fine to medium grained sandstones in beds a few centimetres to a metre thick, and shales. The sandstone/shale ratio is 3.5. There is little erosion at the base of the sandstones and, at the scale of the outcrop, organization into thickening or thinning-upwards sequences is not obvious. One sandstone bed shows extensive downward injecting sedimentary dykes oriented perpendicular to flutes. This sequence has been interpreted as mostly

interchannel deposits on a lobe and the dykes may represent tension caused by translation down the side of an elevated channel.

Fayaux L₂

(Gurnigel flysch, 560.0/146.5). This is a sandstone dominated succession with possible thickening or thinning-upward sequences with bed thicknesses of a few



Fig. 6. Log of the section of the Gurnigel flysch exposed in the Louetli quarry.

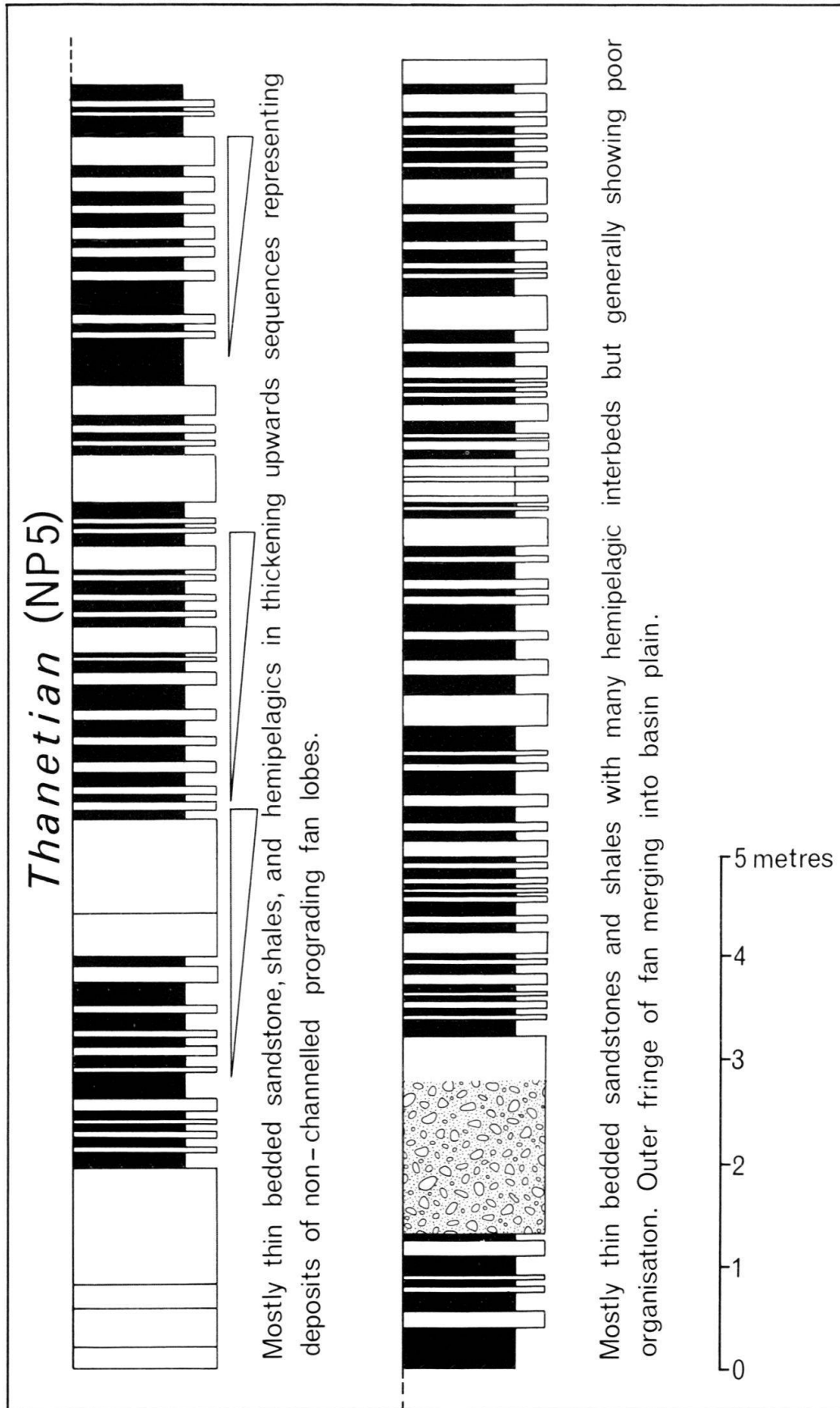


Fig. 7. Log of the section of the Gurnigel flysch exposed in the Fayaux quarry (L_1).

centimetres to about a metre. The sandstone/shale ratio is 7.0. It represents deposition at the central part of depositional lobes.

Upper Zollhaus quarry

(Gurnigel flysch, 589.9/174.0). This section consists mostly of thin bedded sandstones and predominant shales with a sandstone/shale ratio of 1.8. Organized sequences are not well developed. The section follows the channelled depositional lobe sequence of the Lower and Middle Zollhaus quarries and this facies may have resulted from sediment starvation.

Fayaux L₁

(Gurnigel flysch, 559.8/146.5). The section in the Lower Fayaux quarry is shown in Figure 7 and Plate 1, Figure 3. Fine to medium grained sandstones predominate, mostly in beds 5–50 cm thick. Shale partings are well developed. The sandstone/shale ratio is 1.6. The sandstones show marked lateral continuity and some are arranged in well-developed thickening upward sequences. This section is interpreted as a fan fringe to basin plain deposit and represents the most distal of the sequences discussed.

The sequences studied are interpreted in terms of 7 deep-sea sand fan environments:

- Major fan valleys (Blattligraben).
- Interdistributary channel areas (Höllbach).

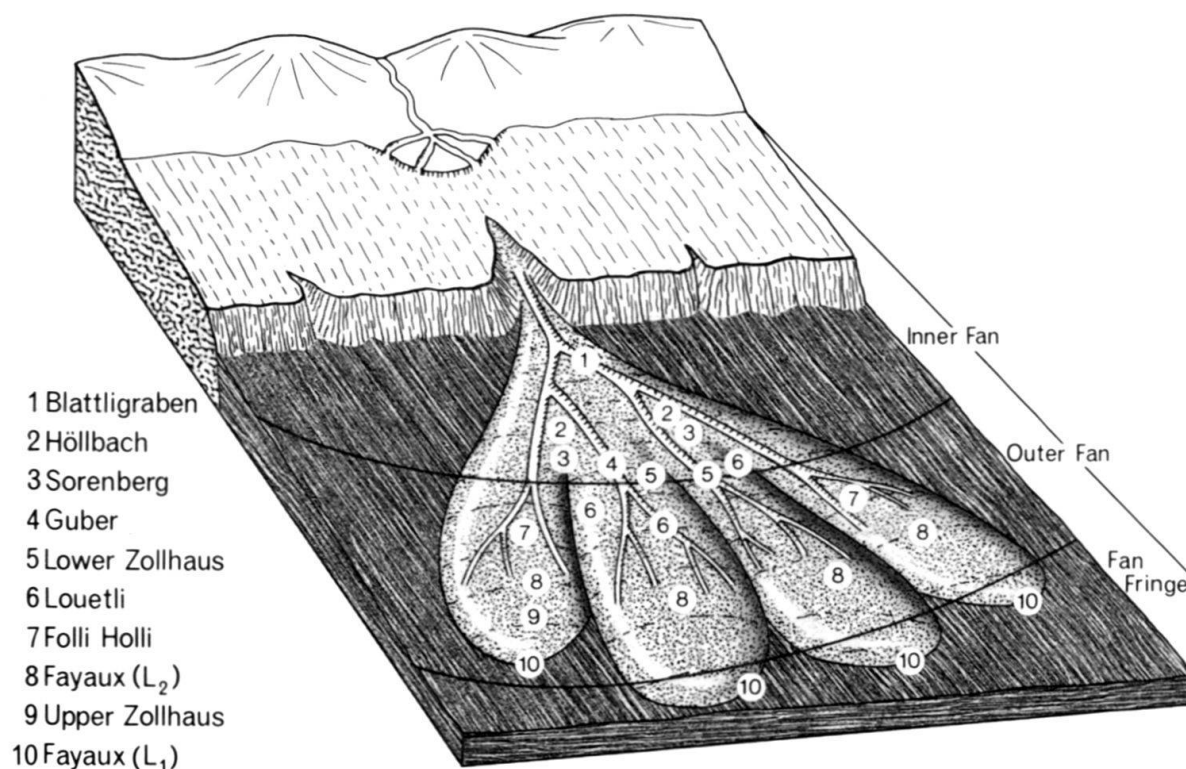


Fig. 8. Idealized deep-sea sand fan showing the relative positions of the sections described in the text.

- Distributary channel–inner depositional lobe (Sörenberg).
- Channelled depositional fan lobes (Guber, Lower and Middle Zollhaus, Louetli, Fayaux L₂).
- Interchannel area (Falli Hölli).
- Sediment starved lobe (Upper Zollhaus).
- Fan fringe – basin plain (Fayaux L₁).

The relative positions of the sections on an idealized deep-sea sand fan is shown in Figure 8.

The water depth on deposition of these sequences has been estimated on the basis of the faunas and calcium carbonate content of the hemipelagic shales as between 2500 and 5000 m (BROUWER 1965, VAN STUIJVENBERG 1979).

3. Environmental aspects of trace fossil distribution

SEILACHER (1964, 1967) suggested that a relatively small number of depth controlled marine trace fossil assemblages recurred throughout Phanerozoic time. Each assemblage was named after a characteristic trace fossil and they are, in order of increasing water depth: *Skolithos* (mainly littoral zone), *Cruziana* (littoral zone to wave base), *Zoophycos* (wave base to zone of main turbidite deposition) and *Nereites* (deep water turbidite zone). Later studies showed that, although this is a good working hypothesis, trace fossil distribution is related to many factors, including substrate type, energy conditions, food availability, and preservation potential, rather than just bathymetry (CRIMES 1970, 1975, FREY & HOWARD 1970). The significance of the *Zoophycos* assemblage has also been questioned because of the common occurrence of this trace fossil in most marine environments (CRIMES 1973, p.127). Nevertheless, there is general agreement that trace fossils of the *Skolithos* and *Cruziana* assemblages normally represent shallow water, while those of the *Nereites* assemblage are associated with deep water. Investigations on deep water turbidites by CRIMES (1970) from the Lower Palaeozoic sediments of Wales and Eire and by KSIAZKIEWICZ (1970, 1977) from the Cretaceous–Tertiary sediments of the Polish Carpathian Mountains showed that in more proximal, high energy environments with thick sand beds and high sandstone/shale ratios, trace fossils are uncommon while in more distal, lower energy environments, with thinner sandstones and lower sandstone/shale ratios, radiating and spiral trace fossils and then meandering forms become more abundant, and finally, patterned forms are found in the most distal deposits. KSIAZKIEWICZ (1975, 1977) later compared trace fossil distribution in the Carpathian flysch with bathymetry determined from foraminifera. He showed that while some trace fossils in the Carpathian flysch range from less than 200 m water depth to over 1500 m (e.g. *Gordia*, *Gyrochorte*, *Sabularia*, *Spirorhappe*, *Zoophycos*), the majority, particularly the meandering and patterned types, are most common between 600 and 2000 m. Relatively few are common at depths over 2000 m.

“Shallow water” (*Skolithos* and *Cruziana* facies) trace fossils have, however, been recorded from deep-sea turbidites in a number of sections. HAYWARD (1976) recorded *Skolithos*, “*Scalartuba*” and *Rhizocorallium* from a deep-sea (1–3000 m)

submarine canyon in the Miocene of New Zealand. KERN & WARME (1974) found *Ophiomorpha* and *Thalassinoides* in the thick bedded grain flow deposits of a deep-sea sand fan within the Upper Cretaceous Point Loma Formation in California. Also, CRIMES (1977) reported an extensive "shallow water" ichnofauna from the more proximal part of the Lower Eocene Monte Jaizkibel fan in North Spain for which foraminiferal evidence indicates a water depth of 1000–3500 m (KRUIT et al. 1972). The more proximal middle fan yielded *Arenicolites*, *Diplocraterion*, *Ophiomorpha*, *Pelecypodichnus*, *Rhizocorallium* and *Thalassinoides*, as well as many typically deep water trace fossils. In the outer fan "shallow water" trace fossils were exceedingly rare but deep water forms abundant.

4. Methods

Identifications were made in the field from bedding surfaces and loose material and where necessary checked later using collected material, photographs and sketches. The assemblages were not systematically related to individual beds or type of bed and for most sections the assemblage is therefore a total for the entire outcrop. On the other hand, at Zollhaus, the quarry divides the section into three separate locations investigated individually, and the long cliff at Sörenberg was also divided in an attempt to relate the assemblage to changing environmental conditions.

5. The trace fossils

The trace fossils have been associated into the so-called "shallow water" forms and then into the groupings proposed by KSIĄZKIEWICZ (1970) for trace fossils from the Polish Carpathian flysch, based on the manner of winding, meandering and branching. *Protopaleodictyon*, being an incipient network, has been included in that category. Distribution of the trace fossils in the various sections described here is considered further in part 6.

a) So-called "shallow water" forms

Arenicolites: These are observed as paired vertical burrows with no connecting spreite and most occur sandstone infilled on the base of turbidites. They presumably extended down into the underlying mudstone. Burrow diameters are commonly a few millimetres and burrow separation about a centimetre. These burrows have not been observed in vertical section and some may be the spreite lacking tops of *Diplocraterion*.

Diplocraterion: Examples occur as paired burrows of 1 to 3 mm diameter separated about 1 cm by spreite. The burrows and spreite are sandstone infilled and occur in mudstone. These *Diplocraterion* are smaller than most forms described from shallow water successions and are also smaller than those mentioned by CRIMES (1977, p. 76) from a deep water Eocene sand fan in North Spain.

Ophiomorpha: These trace fossils typically occur as oblique non branching burrows transgressing thick (> 1 m) sandstone beds. Each *Ophiomorpha* consists of a

central burrow with surrounding pellets. Compared with *Granularia*, the trace fossil is larger, the faecal pellets are larger relatively to the diameter of the burrow and branching is much less common. There are, however, intermediate examples in which differentiation is difficult if not impossible. The typical form compares well with *Ophiomorpha nodosa* and with examples and reconstructions of this species given by KENNEDY & SELLWOOD (1970, p.100) and KENNEDY & MCDUGALL (1969, p.460). No examples of meniscus fill (KENNEDY & MCDUGALL 1969, p.460, Textfig. 1) were noted.

In well-sorted shallow water sandstones *Ophiomorpha* is represented by highly inclined to vertical burrows which may or may not be accompanied by more nearly horizontal forms, whereas mostly horizontal systems occur in muddy siltstone or interbedded sandstones and shales (KENNEDY & MCDUGALL 1969, p.463, 464, KENNEDY & SELLWOOD 1970). In deep water Upper Cretaceous sandstones of the Point Loma Formation of California, vertical or oblique *Ophiomorpha* are similarly confined to clean sandstones (KERN & WARME 1974). Oblique and vertical *Ophiomorpha* also occur in deep water well-sorted sandstones in an Eocene deep-sea sand fan in North Spain (CRIMES 1977). A review of the environmental significance of *Ophiomorpha* has been given by FREY et al. (1978).

Associated with normal *Ophiomorpha* at Louetli and Sörenberg are trace fossils with numerous radiating straight burrows 2–6 mm in diameter but up to 35 cm long (Pl.1, Fig.4). The rays spread out from a poorly defined centre and are infilled with green pelleted mud set within a light coloured sandstone host rock. The pelleted nature of these burrows and their occurrence on the same slabs as *Ophiomorpha* suggests that they may be associated. KERN & WARME (1974, p.895, 896, and Fig.7a) also noticed thin straight mud filled burrows up to 40 cm long and 2–7 mm in diameter associated with *Ophiomorpha* in the Point Loma Formation. They concluded that they may have been made by small juvenile individuals burrowing out after hatching from the parents' burrow. CURRAN (1976) reported similar structures associated with *Ophiomorpha* in the marine Pleistocene beds at the Texas Gulf Mine, North Carolina. The tubes which were of 3–5 mm in diameter and extended for at least 25 cm are closely compared with those reported here. They were also filled with clayey sediment and stood out in marked contrast to the surrounding light coloured sandstone. The burrows met centrally at a clay lined bulb. CURRAN concluded that the bulb was a brood structure formed by an adult callianassid shrimp for the development of its young and the tubes were formed by post-larvae as they emerged from the bulb. This explanation seems appropriate to the structures described here even though the central bulb has not yet been found preserved.

Pelecypodichnus siliquaria (JAMES 1879): 25 examples of *P. siliquaria*, mostly very well preserved were found as sandstone infilled convex structures on the base of one 15 cm thick loose bed of sandstone quarried from Zollhaus quarry (Pl.1, Fig.5). They are almond shaped oblong bodies obtuse at each end but tapering to a sharp point (Pl.1, Fig.6). One end may be more obtuse than the other and they are mostly about 1.5 cm long and 0.8 cm wide at their maximum point. The surface is often broken but where preserved is either smooth or, less commonly, with a sharp

longitudinal crest. One specimen (Pl.1, Fig.7) shows a protrusion extending for about 0.5 cm at the broad end and perhaps representing the siphon. They compare directly with topotypes of *P. siliquaria* from the Ordovician of Kentucky (OSGOOD 1970, Pl.57, Fig.7). They are, however, slightly longer and more plump but not as plump as other examples figured by OSGOOD (1970, Pl.58, Fig.10). They show the overall almond shape and sharp point at each end more clearly than in examples from the Carboniferous of Kansas referred to *Pelecypodichnus* (= *Lockeia*) by HAKES (1976, Pl.6, Fig.3). *Pelecypodichnus*, interpreted as a pelecypod burrow or resting excavation (SEILACHER 1953, OSGOOD 1970, EAGAR 1974, HAKES 1976, 1977), is most typical of shallow water marine or deltaic sediments but examples, mostly a little longer (2–4 cm) and without such prominent terminating points, were figured by CRIMES (1977, p.75, and Pl.3c–d) from a deep-sea sand fan in North Spain.

The present examples show a marked degree of preferred orientation (Fig.9). This presumably reflects current orientation of the pelecypods. A similar current orientation also occurs in the examples from North Spain (Crimes, T. P., & Pegg, D., personal observations). In the Spanish material, the orientation is parallel to the trough axis and presumably reflects bottom current trends. The same may be true for the present examples but since the block was not found in situ the orientation cannot be used for this purpose.

Phycodes: This ichnogenus consists of a bundled, branched, burrow system. Two examples were found and one from the Zollhaus quarry is shown in Figure 10a. The specimens bear some resemblance to *Phycodes palmatum* (HALL 1852).

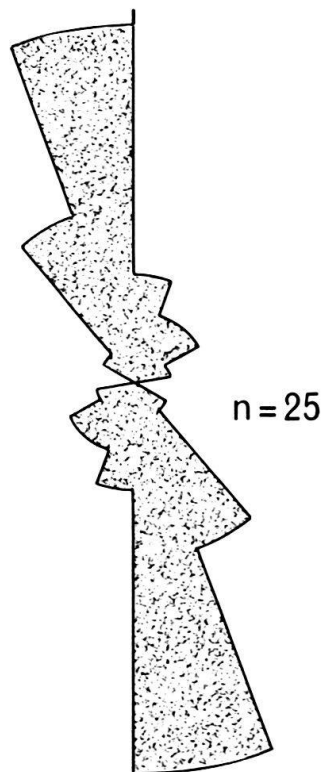


Fig. 9. Orientation of *Pelecypodichnus* on single fallen block in Zollhaus quarry. North assumed.

Rhizocorallium: Examples referred to *Rhizocorallium* were U tubes parallel to bedding 8–10 cm long and about 1.5 cm wide with spreite (Fig.10b). The spreite burrows are in some examples more than 1 mm in diameter. No branching was observed and the limbs of the U remain parallel even when turning. Separation of *Rhizocorallium* from some forms of *Zoophycos* is difficult. For example, parts of *Zoophycos insignis* SQUINABOL 1890 consist of U burrows with spreite. The spreite are, however, finer than in some of the present examples and commonly, the external burrow is well developed on only one side (see KSIĄZKIEWICZ 1977, Fig.16). Examples referred to *Rhizocorallium* showed markedly parallel, well-developed limbs and were not observed to be part of a more complex system as in *Zoophycos*.

Skolithos: This ichnogenus consists of vertical burrows 1–3 mm diameter. The burrows are seen only as circular sandstone filled outlines where they intersect the bedding plane, but where they can be traced, they are mostly only 1–2 cm long. They occur as sandstone infilled in both sandstone and mudstone and vary in distribution from isolate to packed. Examples resemble *Skolithos linearis* HALDE-

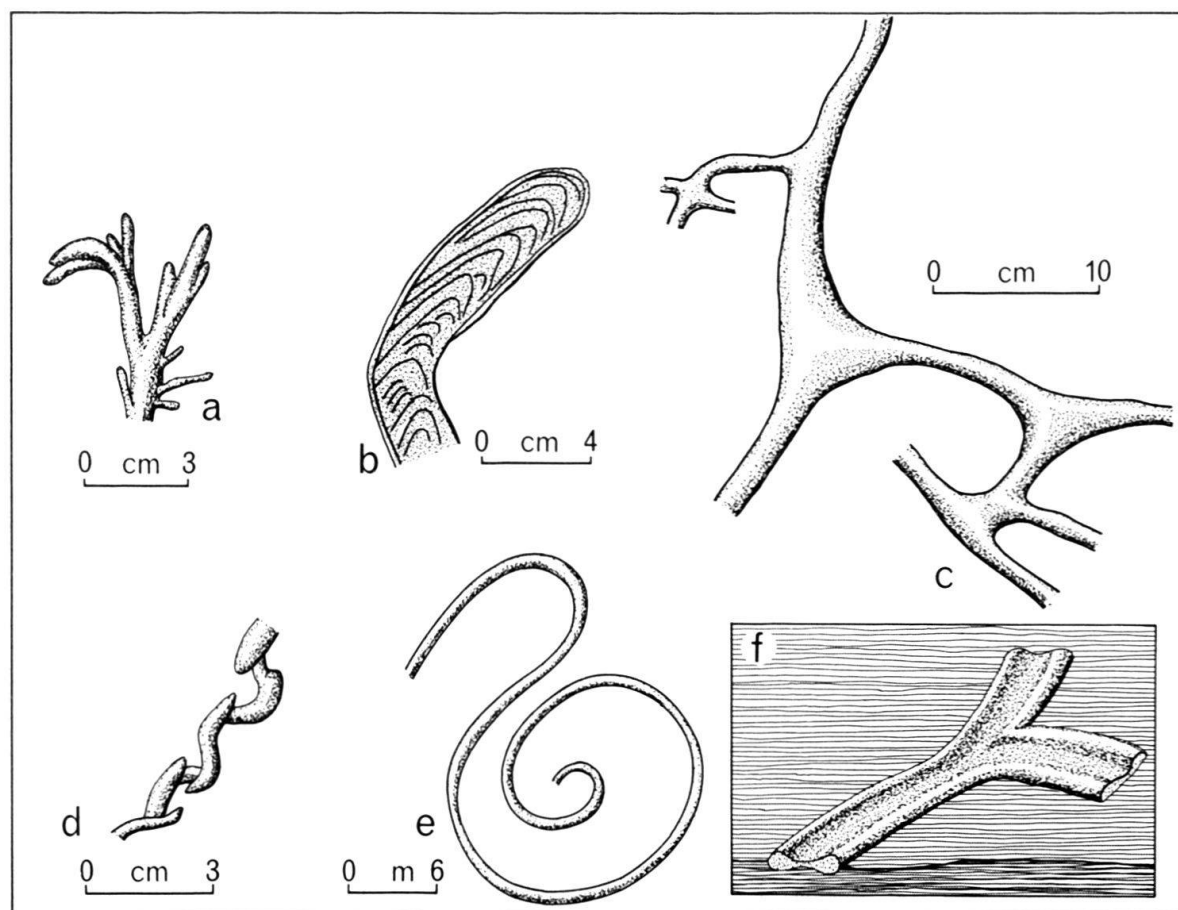


Fig. 10. Trace fossils from the Gurnigel flysch.

a = *Phycodes*, Paleocene, Zollhaus quarry; b = *Rhizocorallium*, Paleocene, Zollhaus quarry; c = *Thalassinoides*, Paleocene, Zollhaus quarry; d = *Treptichnus*, Paleocene, Fayaux (L₂) quarry; e = *Spirophycus bicornis* HEER, Paleocene, Zollhaus quarry; f = *Megagraption* showing three-dimensional form, Paleocene, Fayaux quarry (L₂).

MAN 1840 but most are of smaller diameter than 3–7 mm indicated in the diagnosis given by ALPERT (1974, p. 663).

Thalassinoides: Examples referred to this ichnogenus consist of horizontal, regularly branching systems with the burrows typically 1–3 cm in diameter and with swellings at the points of branching (Fig. 10c). Trace fossils of this type are normally ascribed to the activities of crustaceans (HÄNTZSCHEL 1975) and remains of callianassids have been found in some Upper Cretaceous and Miocene examples (EHRENBERG 1938, MERTINI 1941, GLAESSNER 1947, MÜLLER 1970, SELLWOOD 1971). *Glyphea* has been found in Jurassic examples of *Thalassinoides* burrow systems (SELLWOOD 1971, BROMLEY & ASGAARD 1972, FÜRSICH 1974, 9. 30).

Treptichnus: Only one example was found and it consists of a straight row of burrows of similar length and of about 0.5 cm in diameter arranged alternately to the right and left (Fig. 10d).

b) Straight branched and unbranched forms

Chondrites: This is common and occurs parallel to lamination planes within mudstones and fine sandstones and separation of laminae often reveals repeated examples. *Chondrites* is badly in need of systematic revision and separation of many of the described species is questionable (see also SIMPSON 1957). In the present investigation most examples were referred only to *Chondrites* sp. but exceptions were: a) *C. filiformis* FISCHER-OOSTER 1858 at Fayaux quarry (L₂) and Guber quarry, b) *C. arbuscula* FISCHER-OOSTER 1858 at Fayaux quarry (L₁) and Lower Zollhaus quarry (Pl. 1, Fig. 8) and c) *C. affinis* (BRONGNIART 1849) at Fayaux (L₁) and Guber quarries.

Dendrotichnium häntzscheli FARRES 1967: Only one specimen was found, in Fayaux quarry (L₂). Branches are 2–3 mm in diameter and alternate from a central burrow passing out at an acute angle, not a right angle as in *D. llarenai* (FARRES 1967). The trace fossil differs from *D. alternans* SEILACHER (1977) in that the meander shows no clear zigzag shape. A similar trace fossil was figured by MACSOTAY (1967, Pl. 5, Fig. 16) as an atypical *Chondrites* but should probably be included in *D. häntzscheli*. The Spanish examples of *Dendrotichnium* described by FARRES (1963, 1967) and SEILACHER (1977) are all from the Upper Cretaceous (Maastrichtian). The material described by MACSOTAY is also from this horizon but the example described here is of Late Paleocene (Thanetian) age. The known range is therefore Upper Cretaceous to Upper Paleocene.

Fucusopsis angulata PALIBIN 1932: These more or less straight, unbranched tubiform post-depositional burrows of 0.5–1.6 cm in diameter are often over 10 cm long and occur crowded on some sandstone soles with frequent crossings (Pl. 2, Fig. 1). They have 3 to 5 threadlike longitudinal or sublongitudinal ridges on each half of the burrow cross section. These ridges may continue for several centimetres but are then replaced by other ridges, some of which initially run parallel to the replaced ridge either inside or outside of it. These ridges form an integral part of the trace fossil and we doubt if any can be attributed to tension faulting as proposed for some examples by OSGOOD (1970, p. 380). There are also transverse step-like breaks

on the surface of the burrow and the burrow pinches and swells. One example from Lower Zollhaus quarry (Pl. 2, Fig. 2) shows higher relief and the typical threadlike longitudinal ridges at the sides are replaced inwards by a structure stuffed with pouch-like bodies of sediment arranged with slight imbrication. This is probably the structure of all examples of *F. angulata* but only specimens with fuller eroded relief will reveal the internal structure.

HAKES (1976, p. 27) has drawn attention to the similarity between *Scoyenia*, the typical trace fossil of the non-marine *Scoyenia* facies of SEILACHER (1967) and *Fucusopsis*, which is often found in flysch sediments. HAKES concluded that in *Scoyenia* the ridges are typically short and lanceolate as compared with the threadlike, often thick, ridges of *Fucusopsis*. However, the inner structure revealed here for *Fucusopsis* is paralleled by a similar sediment stuffed interior to *Scoyenia* (HÄNTZSCHEL 1975, p. W 106).

We doubt if the differences between these two merit separate ichnogenera. As FREY (1975, p. 16) has concluded none of the elements of the *Scoyenia* facies is by itself a reliable facies indicator.

Fustiglyphus: Only one example was found: a positive relief on a sandstone sole (Pl. 2, Fig. 3). It consists of a long central cylinder 2 mm in diameter and with 3 swellings. The cylinder shows traces of fine transverse annulation along part of its length. The swellings are like small V's in which the limbs are of similar width to the central cylinder. The full trace fossil is 7 cm long and the swellings are at intervals of 1.2 and 1.5 cm at one end. The specimen compares well with *Fustiglyphus annulatus* except that the swellings are present as plates rather than V's in that species. It also resembles the *Rhabdoglyphus* figured by KSIĄZKIEWICZ (1970, Fig. 1h).

Granularia: The definition of this ichnogenus is far from clear. HÄNTZSCHEL (1962, p. W194) gave as his synopsis "sediment-filled tubes; diameter up to about 1 cm walls coarsely dressed with clay particles". According to REIS (1909) clay pellets are also arranged at right angles to the burrow axis. However, KSIĄZKIEWICZ (1970, p. 287) used a much broader diagnosis and assigned to the group "all unsculptured tubes composed of sand grains and clay pellets". This broader definition was applied by CRIMES (1976, p. 62, 63) and CRIMES et al. (1974, p. 172, 173) who described branching sand-filled tubes from turbidites of the Cambrian of Ireland and Ordovician of North Spain under this name. WEBBY (1969, p. 88) seems also to have taken a liberal interpretation of the ichnogenus in describing specimens from the Silurian flysch of New South Wales, Australia. His traces have a marked tendency for sinuosity not seen in other examples. They are described as "sand filled tubes at least partly lined with mud particles", although mud pellets cannot be discerned on the figured material (WEBBY 1969, Pl. 10, Fig. 7). HÄNTZSCHEL (1975, p. 1064, 1065) referred to the burrows as twig-shaped with rather regular branching and walls originally lined with clay particles. Then, in contrast to his previous position, KSIĄZKIEWICZ (1977, p. 68) separated clay pelleted burrows as *Granularia* and erected a new ichnogenus *Sabularia* for straight or feebly curved, only rarely ramified burrows. In this he included sand-filled burrows of types he previously included under *Granularia*. This definition appears, however, to exclude the frequently branching twig-shaped burrows lined with small sand pellets which are so

common in Mesozoic and Tertiary flysch successions. Pending a detailed monographic treatment of this ichnogenus we have therefore here included in *Granularia* simple twig-like, often branching, burrows lined with small sand or mud pellets. Commonly, where the pellets are of sand, the pelleted nature can only be distinguished where preservation is good along at least part of the burrow (Pl. 2, Fig. 4). The pellets are seen where they are of mud (Pl. 2, Fig. 5) and they are commonly approximately perpendicular to the axis as reported by REIS (1909) but in these examples branching is less frequent. The last type compares closely with *Granularia* cf. *arcuata* SCHIMPER 1869 figured by HÄNTZSCHEL (1975, Fig. 40, 3a). The criteria used here would remove from *Granularia* the examples described by CRIMES (1976) and CRIMES et al. (1974), much of the material described by KSIĄZKIEWICZ (1970), and probably also the specimen described by WEBBY (1969). This would mean that occurrence of *Granularia* would be restricted to the Cretaceous and Tertiary as indicated by SEILACHER (1977, p. 290). We agree with SEILACHER (1977, p. 290, Pl. 1c) that *Granularia* may be made by crustaceans and can in this respect be related to *Ophiomorpha*.

Halymenidium: A single example was found as a positive post-depositional trace on a sandstone sole. It could be compared with *H. oraviense* (KSIĄZKIEWICZ 1961) as figured by KSIĄZKIEWICZ (1977, Pl. 3, Fig. 4).

Lophoctenium: This trace fossil occurs in low positive relief on sandstone soles and consists of bunches of thin (about 1 mm) closely spaced burrows with comb like branches (Pl. 2, Fig. 6). It is extensively developed on a few surfaces in Zollhaus quarry.

Neonereites: This trace fossil consists of single or double rows of post-depositional sandy pellets preserved in positive relief on sandstone soles. The single rows are referred to *N. uniserialis* SEILACHER 1960 and are commonly about 5 mm wide while the double rows are included in *N. biserialis* SEILACHER 1960 and have a width of normally about 1–2 cm. *Neonereites* is straight, or only gently meandering.

N. biserialis was found at Guber, Höllbach, Sörenberg and Lower Zollhaus while *N. uniserialis* was from Höllbach, Louetli, Sörenberg and Upper Zollhaus.

Sabularia simplex KSIĄZKIEWICZ 1977: These occur as gregarious full relief post-depositional burrows on sandstone soles (Pl. 2, Fig. 7). They are 3–8 mm in diameter and have no ornament, and although they tend to run parallel, crossings are not uncommon.

Saerichnites beskidensis PLIČKA 1974: A single example was found on a sandstone sole in Fayaux (L₂) quarry (Pl. 2, Fig. 8). It consists of a double row of alternating knobs each about 1 cm in diameter. Each knob is separated from the next in the same row by about 2 cm and the trace fossil is 13 cm long and approximately 3 cm wide. PLIČKA (1974, p. 81) suggested that the example he described from the Upper Cretaceous of Czechoslovakia was produced by an animal walking on the sea bottom. Similar trace fossils from the Eocene of North Spain were described as arthropod tracks by GOMEZ DE LLARENA (1946, Pl. 5, Fig. 8). CRIMES (1977, p. 81, Pl. 4a) and SEILACHER (1977, p. 308–309, Fig. 6k–l) described further examples from

the Upper Cretaceous and Eocene of Spain and both attributed them to burrowing rather than walking. CRIMES (1977, p.81) attributed the trace fossil with reservation to *Saerichnites* while SEILACHER (1977, p.309) placed them tentatively in *Hormosiroidea* and included *S.beskidensis* also in this ichnogenus. However, *H.florentina* SCHAFFER 1928, the type species, has only a single row of hemispherical knobs. *Saerichnites abruptus* BILLINGS 1866, the type species, has two parallel rows of closely spaced knobs. We therefore consider that these trace fossils and those described as ?*Saerichnites* by CRIMES (1977, p.81) and *Hormosiroidea beskidensis* by SEILACHER (1977, p.309) should be included in *S.beskidensis* which was described as having a double row of more widely spaced knobs. The trace fossil described here is clearly of burrow rather than surface walking origin and cannot be ascribed to arthropods.

c) Winding unbranched forms

Gyrochorte: Only one example was found, a filled burrow of 1.5 cm in diameter showing paired transverse oblique pads which, probably owing to inadequate preservation, do not meet medially (Pl.3, Fig.1). The specimen was not found in situ but the burrow is in positive relief on the sandstone and from associated structures it is probably on the sole. This is in agreement with material described by KSIĄZKIEWICZ (1977, p.113, 114) but contrasts with HALLAM'S (1970) material in which the pads are on the upper surface of the bed.

Scolicia prisca DE QUATREFAGES 1849: Complex traces 2–4 cm wide, bilobed on the upper surface, trilobed on the lower surface, with the central lobe bordered by two thin cylinders (strings) of sediment and backfilled with sediment. These trace fossils are common on or within sandstones and are identical with specimens collected recently by T.P. Crimes from the type locality for *Scolicia prisca* in North Spain. In our description we have followed KSIĄZKIEWICZ (1970, 1977) in separating *Scolicia* and *Subphyllochora*, although the latter may only be a sole surface expression of the former, as indicated by HÄNTZSCHEL (1975, p.W106). *Scolicia* has been variously interpreted as the trace of gastropods (GÖTZINGER & BECKER 1932, 1934), crustaceans (CHAMBERLAIN 1971), polychaetes (KSIĄZKIEWICZ 1977) or echinoids (SEILACHER 1977, p.293).

Subphyllochora: A sole trace with three lobes. The central lobe is bordered by thin strings of sediment and most show backfill laminae. The lateral lobes are faintly striated in some specimens. Most examples are 2 to 4 cm wide.

Taphrhelminthopsis: This is a bilobed trace fossil 2–3 cm wide on sandstone soles and often shows evidence of scour by currents. Many examples have transverse striations on the lateral ridges (Pl.3, Fig.2). They occur winding, meandering or coiling. KSIĄZKIEWICZ (1977) separated guided meandering examples with a tendency to coiling (e.g. Pl.3, Fig.2) as *Taphrhelminthoida*. *Taphrhelminthoida plana* KSIĄZKIEWICZ 1977 is distinguished from *T.convoluta* KSIĄZKIEWICZ 1977 by its subdued relief (KSIĄZKIEWICZ 1977, p.168, 169). The trace fossil figured in Plate 3, Figure 2, could therefore be included in *T.convoluta* but it is questionable whether guided meandering with a tendency to coiling necessitates a new ichnogenus. *Taphrhelminthopsis* has been attributed to gastropods (HÄNTZSCHEL 1975, p.W113),

acorn worms (BOURNE & HEEZEN 1965) and solenogasters (KSIĄZKIEWICZ 1977, p.137).

d) Radiating forms

Glockeria: This trace fossil is preserved in positive relief on sandstone soles. The ribs radiate from a centre which is commonly elevated. The overall diameter is from a few centimetres to over 10 cm. One of the best preserved specimens (Pl.3, Fig.3) can be assigned to *G. sparsicostata* KSIĄZKIEWICZ 1960. It consists of nine ribs each 2–4 cm long and about 2 mm wide and joined in the centre. The centre is elevated about 1 cm and some of the ribs show faint longitudinal striations. *Glockeria* is the post-depositional feeding burrow of an unknown animal.

Lorenzina: All examples of this trace fossil were from Fayaux quarry (L₂) preserved in positive relief on sandstone soles. The best preserved example (Pl.3, Fig.4) consists of a double elliptical ring, comprising an inner ring of 12 tubercles about 4 mm in diameter and an outer ring of 14 short ribs, about 2 cm in length and 4 mm breadth. Some ribs bear a distinct transverse annulation (Pl.3, Fig.5). This specimen can be compared with *Lorenzina (Bassaenia) moreae* RENZ 1925 in its double row of tubercles and in the tendency for the central ring to be more knob like but differs in the elliptical overall shape and in the tubercles being less regular in shape. It is therefore identified as *Lorenzina cf. moreae*.

Lorenzina has been variously interpreted as 1. feeding burrows (SEILACHER 1954, Fig.2), 2. excreta of crabs (NAWAK 1956), 3. holothurian tentacle impressions (SIMONELLI 1905) and 4. hydrozoan medusae tentacle impressions (KSIĄZKIEWICZ 1977). The fine transverse annulation in our specimen seems to rule out the possibility of it being produced from the excreta of crabs and the smooth central area and lack of any medusoid impressions elsewhere on the bedding plane make it difficult to interpret it as the result of a medusoid bending over and impressing its tentacles in the mud.

Sublorenzina: All examples of this ichnogenus were from Upper Fayaux quarry and are preserved in positive relief on sandstone soles. The areola is irregularly circular and surrounded by irregularly arranged ribs several millimetres wide and of variable length. Diameter of the traces is between 5 and 10 cm. One specimen could be compared with *Sublorenzina nowaki* (KSIĄZKIEWICZ 1970).

e) Spiral forms

Spirophycus bicornis (HEER 1876): Examples are thick (about 1 cm) tubes coiled at one end and preserved in positive relief on sandstone soles (Fig.10e). It has been attributed to polychaetes or acorn worms (HEEZEN & HOLLISTER 1971, KSIĄZKIEWICZ 1977).

Spirorhappe: The most common and distinctive is *Spirorhappe zumayensis* SEILACHER 1977 (Pl.3, Fig.6, 7). This occurs in Fayaux quarry (L₂) and the Lower and Upper Zollhaus quarries. The trace consists of narrow (1–2 mm) closely spiralling furrows in which the bottom of the furrows is inclined towards the centre of the spiral. Where preservation is good, fine dense, transverse striations can also be

seen. The diameter of the spirals is 5–25 cm. *S. zumayensis* occurs on the upper surface of sandstones but more commonly on the parting planes of shales. In the latter occurrence the trace fossils were abundant and seemed to occur densely on most parting planes. *S. zumayensis* was attributed to polychaetes by KSIĄZKIEWICZ (1977, p. 147).

Other examples of *Spirorhaphe* from Lower Zollhaus and Guber quarries were preserved in positive relief on sandstone soles and included as many as 20 turns (Pl. 3, Fig. 8). Unfortunately they did not have a well-preserved central area nor was it possible to follow the spiral around to determine if it was a one- or two-way spiral (cf. SEILACHER 1977, p. 302).

One example of *Spirorhaphe* from Lower Zollhaus quarry showed a collapsed tube thus indicating an open burrow origin as inferred by SEILACHER (1977, p. 302).

f) Meandering forms

Cosmorhaphe: Two specimens of burrows preserved in positive relief on sandstone soles with first and second order meanders were found and both were poorly preserved, with only a small part of the trace fossil present.

Helminthoïda crassa SCHAFHÄUTL 1851: Although found in five localities this trace fossil was always rare. It consists of tightly compressed meanders preserved in positive relief on sandstone soles. The diameter of the strings of some forms was several millimetres but a form with strings only about 1 mm was found at Lower Zollhaus, Falli Hölli and Louetli. SEILACHER (1977, p. 300) assigned *H. crassa* to *Helminthorhaphe* and gave a diagnosis as “meanders widely spaced relative to burrow diameter, but rather irregular and poorly guided”. This diagnosis contrasts with the figure of SCHAFHÄUTL’s type of *H. crassa* in which the meanders are tightly compressed (see also KSIĄZKIEWICZ 1977, Fig. 34a). *Helminthorhaphe* was erected by SEILACHER (1977) to emphasize the contrast between *H. crassa* and *H. labyrinthica*; apart from the error in diagnosis it is doubtful if such a differentiation is necessary.

Helminthoïda labyrinthica HEER 1865: Preserved within shales and in positive relief on sandstone soles, this trace fossil consists of burrows about 1 mm in diameter forming tight densely packed meanders.

Helminthopsis: The irregularly winding normally smooth walled burrows are found in positive relief on sandstone soles and are commonly a few millimetres in diameter (Pl. 4, Fig. 1). In one example from Guber quarry the burrow was stuffed with faecal pellets for part of its length. The diameter of the pellets was close to the burrow diameter but they were surrounded by a thin cylindrical sheath of sediment. This suggests that in the usual preservation the sheath is seen and only if it were removed would the pellets be exposed.

Paleomeandron aff. *robustum* KSIĄZKIEWICZ 1968: A single example of this trace showing the diagnostic quadratic second order meanders was found, preserved in positive relief on a sandstone sole. The burrow was about 5 mm in diameter.

g) Network forms

Desmograpton: Several specimens were found with the characteristic closely spaced parallel burrows but designation as *Desmograpton* sp. could only be made in one example where the diagnostic perpendicular cross burrows were also present. The specimen was described in positive relief on a sandstone sole.

Megagrapton: A single specimen of *Megagrapton tenue* KSIAZKIEWICZ 1968 was found at Fayaux quarry (L₂) and consists of a large network of irregular polygons preserved in positive relief on a sandstone sole. Another burrow of similar preservation from the same locality was referred to *M. irregulare* KSIAZKIEWICZ 1968 and consisted of strings 3 mm in diameter forming an irregular net about 4 cm across. This specimen (Pl.4, Fig.2) was of particular interest because the burrows were banana shaped in transverse section (Fig.10f) and were quite clearly collapsed over the entire network, thus partly confirming SEILACHER's (1977, p.290) view that *Paleodictyon* and similar networks were open burrow systems and not sediment stuffed burrows.

Paleodictyon: This trace fossil has been found at five localities but at none was it common. The best preserved example is from Lower Zollhaus quarry and can be identified as *Paleodictyon miocenicum* forma *pleurodictyonoides* KSIAZKIEWICZ 1977. It is a positive sole trace consisting of a 4 mm long mesh composed of elliptical or circular riblets or knobs about 1 mm diameter (Pl.4, Fig.3). The mesh passes laterally and at a higher level into a normal *Paleodictyon* network. This is in contrast to similar specimens described by SEILACHER (1977, p.2c) where the transition to a normal network was at a lower level where erosion had cut deeper.

Protopaleodictyon: There were several examples of rudimentary *Paleodictyon* nets which might be included here but only one, more characteristic example has been so designated. It is a specimen of *Protopaleodictyon bicaudatum* SEILACHER 1977 from the Fayaux quarry (L₂) and is illustrated in Plate 4, Figure 4. This specimen is of particular interest because it shows the typical two appendages per undulation which is the critical feature of SEILACHER's diagnosis of *P. bicaudatum* but followed clockwise it passes into a trace fossil conforming with *Paleomeandron biseriale* SEILACHER 1977 in which the longitudinal elements are pronounced, so that they appear as two series of longitudinal bars in alternate position. SEILACHER (1977) gives two figures of *P. biseriale* (1977, Fig. 7b, 8c) and chose the trace fossil figured in Figure 8c as holotype. The characteristic of *Paleomeandron* is the quadratic second order meanders but there is nothing in the type of *P. biseriale* to confirm its assignment to *Paleomeandron*. The evidence for quadratic second order meanders in SEILACHER's other figure (1977, Fig.7b) is also poor. It is therefore possible that *P. biseriale* may be an inadequately preserved part of a *Protopaleodictyon* net.

Urohelminthoida: Preserved in positive relief on sandstone soles, these trace fossils consist of tightly coiled meandering burrows 2–3 mm thick with apices at the turning points.

h) Spreite forms

Phycosiphon incertum VON FISCHER-OOSTER 1858: Antler like U-shaped loops usually less than 1 cm long and a few millimetres wide, mostly within siltstones and shales and parallel to bedding.

Polykampton alpinum OOSTER 1869: This was found at Fayaux quarry (L₂) but is also known from Falli Hölli. Specimens have been collected by workmen during quarrying but we were unable to locate the exact horizon for the material and our description is based on material kindly provided by Mr. Krebs of Blonay and the type material in the Berne Museum re-examined by one of us (R. G.).

The specimens show a central burrow (Pl.4, Fig.5) with feather like bunches arranged at frequent intervals on each side. Sediment within successive bunches on the same side is imbricated and, while there is a featherlike internal structure to the bunches, it is not as prominent in the recently quarried material we examined as in the figure given by OOSTER (1869, Pl.4). The structure was originally interpreted as a hydrozoan and does bear resemblance to certain pennatulid anthozoans. SEILACHER (1959, p.1070) considered it as a feeding burrow with alternate fan-like fields. It occurs on some slabs intimately associated with *Zoophycos* (Pl.4, Fig.6) with which it has features in common.

Zoophycos brianteus MASSALONGO 1855: This is a circular or elliptical radiating spreite (Pl.4, Fig.7) with, in some specimens, a burrow around part of the periphery. It occurs within sandstones. Commonly the diameter of the trace fossil is 25–50 cm and several radiating spreite may be stacked vertically. The origin of *Zoophycos* has been much discussed but it is now generally agreed to be a trace fossil (see KSIĄZKIEWICZ 1977, p.108, 109, for an up to date summary of the discussion).

i) Other trace fossils

“Circling trace fossils”: These consist of burrows or trails about 1 cm wide and inscribing a full circle of 3–6 cm in diameter. The trace fossil is without ornament and the same as that figured by KSIĄZKIEWICZ (1977, Fig.32) as a “scribing trace” but not described. The origin of this form is obscure.

Gordia molassica (HEER 1865): A meandering post-depositional burrow about 2 mm diameter in positive relief on sandstone soles and with many crossings (Pl.4, Fig.8). The meanders occur at more than one level as noted for material from the Carpathian flysch by KSIĄZKIEWICZ (1977, p.156). In most of our material the burrow is thinner than in HEER’s type (HEER 1865, Fig.327) but corresponds well to some of the specimens described by KSIĄZKIEWICZ (1970, Pl.20, Fig.6). We have separated this from other meandering forms because of its marked tendency to cross its own burrow, a feature absent in all other meandering trace fossils described here.

Mammilichnis aggeris CHAMBERLAIN 1971: Preserved in positive relief on sandstone soles, most specimens consist of a deep tyre-like ring with a teat like central tubercle. The ring diameter is 8–12 mm and the teat diameter 1–2 mm, the trace fossils are about 5 mm deep. The rings vary from granulated (Pl.4, Fig.9) to smooth and several show evidence of current scour and form the apices of long low

flute casts (Pl.4, Fig.10). Our material compares closely with that figured by KSIĄZKIEWICZ (1977, Pl.1, Fig.1) from the Oligocene Krosno Beds of the Polish Carpathian flysch. In one specimen (Pl.4, Fig.9) the ring is surrounded by a circular elevated rim with radial ridges. These structures have been claimed to be resting traces (CHAMBERLAIN 1971), perhaps of an anthozoan (KSIĄZKIEWICZ 1977, p.52). Interpretation as an anthozoan is strengthened by the specimen with an outer rim with radial ridges while the fluting demonstrates the predepositional nature of these structures.

6. Distribution of trace fossils

The distribution of trace fossils in the various sections discussed above is shown in Table 1 where the 10 sections have been arranged from left to right in order of increasing distality based on sedimentological criteria. The trace fossils have also been assigned to "shallow water" types *Skolithos* and *Cruziana* facies (S), deep water types (*Nereites* facies) (D) and facies crossing types (F). For the 10 sections, the numbers of trace fossils of the various groups are shown in Table 2. In Table 3 we show the relative abundance of the different morphological groupings of trace fossils. The trace fossils' occurrences in the different sections and their environmental interpretation will now be discussed.

Blattligraben

Only 5 ichnogenera have been found and these include 3 facies crossing types together with one "shallow" and one deep water type. This paucity is not surprising in a major fan valley environment with much coarse grained detritus and intermittently fast flowing currents which would erode recently produced surface or near surface traces. A similarly restricted ichnofauna was reported by HAYWARD (1978) from a canyon filled with Miocene turbidites in New Zealand.

Höllbach

Trace fossils are more abundant in this section and there is a predominance of "shallow water" and facies crossing types; deep water types are represented only by *Subphyllochorda*, *Helminthopsis* and *Halymenidium*. Of these, *Subphyllochorda* is probably only a preservational variant of the facies crossing *Scolicia* and, occurring as it does on turbidite soles, it owes its existence to exhumation by erosive turbidity currents. *Halymenidium* is tentatively claimed by KSIĄZKIEWICZ (1977) to prefer water depths of 600–2000 m. The "shallow water" ichnogenera include vertical burrows into sands, typical of high energy regimes (*Arenicolites*, *Skolithos*) but also horizontal burrows such as *Rhizocorallium*, *Thalassinoides* and *Phycodes* normally taken to indicate lower energy conditions (SEILACHER 1967, AGER & WALLACE 1970, FÜRSICH 1975).

The low sand/shale ratio (0.8) and interbedding of relatively thin sands and shales might be expected to provide ideal preservational conditions for an extensive suite of deep water trace fossils. The paucity of deep water trace fossils is therefore an indication that few were produced and suggests that the basic control at this

Table 1: Distribution of the trace fossils in the described sections.

	<i>Blattliggraben</i>	<i>Höllbach</i>	<i>Sörenberg</i>	<i>Güber</i>	<i>Zollhaus (L.)</i>	<i>Louetti</i>	<i>Falli Hölli</i>	<i>Fayaux L₂</i>	<i>Zollhaus (U.)</i>	<i>Fayaux L₁</i>	<i>Type</i>	
<i>Arenicolites</i>		X	X	X	X	X					S	"Shallow Water" forms
<i>Diplocraterion</i>					X			X			S	
<i>Ophiomorpha</i>			X			X		X			S	
<i>Pelecypodichnus</i>					X						S	
<i>Phycodes</i>		X			X						S	
<i>Rhizocorallium</i>		X			X	X					S	
<i>Skolithos</i>	X	X	XX		XX						S	
<i>Thalassinoides</i>		X		X	X	X		X			S	
<i>Treptichnus</i>								X			S	
<i>Chondrites</i>	X	XX	X	XX	XX	XX	X	XXX	X	XXX	F	Straight, branched and unbranched
<i>Dendrotichnium</i>								X			D	
<i>Fucusopsis</i>		XX	X		X	X	X		XX		F	
<i>Fustiglyphus</i>										X	D	
<i>Granularia</i>	X	XXX	X	XX	XX	XXX	XXX	XXX	XXX	XXX	F	
<i>Halymenidium</i>		X									D	
<i>Lophoctenium</i>					X				X		F	
<i>Sabularia</i>			X		X					X	F	
<i>Saerichnites</i>								X			D	
<i>Neonereites</i>		X	X	X	X	X			X		F	
<i>Gyrochorte</i>					X						F	Winding, unbranched
<i>Scolicia</i>	X	X	X		XX	X	XXX	XXX	XXX		F	
<i>Subphyllochorda</i>		X	X		XXX				XXX		D	
<i>Taphrhelminthopsis</i>	X		XX	X	X			X			D	
<i>Glockeria</i>			X		X	X	X	X	X		D	Radiating
<i>Lorenzina</i>								X			D	
<i>Sublorenzina</i>								X			D	
<i>Spirophycus</i>			X	XX	X	X	X	X	X		D	Spiral
<i>Spirorhaphe</i>				X	XX		X	X	XXX		D	
<i>Cosmorhaphe</i>					X			X			D	Meandering
<i>Helminthoida crassa</i>					X	X	XX	X	X		D	
<i>H. labyrinthica</i>				X	XX	X	X	XX	X	XX	D	
<i>Helminthopsis</i>		X	X	X	X	X	X	XX	X	X	D	
<i>Paleomeandron</i>										X	D	
<i>Desmograption</i>								X			D	Networks
<i>Megagraption</i>								X			D	
<i>Paleodictyon</i>					X	X	X	X		X	D	
<i>Protopaleodictyon</i>								X			D	
<i>Urohelminthoida</i>					X	X					D	
<i>Phycosiphon</i>					XX		X	X		X	D	Spreite
<i>Polykampton</i>								X			D	
<i>Zoophycos</i>				XX	X	X	X	XXX	X	XX	F	
"Circling Trace"					X	X	X	X			D	Other
<i>Gordia</i>		X	X						X		F	
<i>Mammilichnis</i>			X		X	X		X		X	F	

X = rare, XX = average, XXX = common.

locality was environmental rather than preservational. The sediments were deposited in a proximal position on the fan between distributary channels. The presence of high energy "shallow water" vertical burrows into the sandstones cannot be explained as a response to a turbidity current since the current had already passed before the animals burrowed into the sand. It may however suggest that the area was affected by down canyon non-turbidity bottom currents. Such currents are known to operate at frequent intervals in modern deep sea canyons.

Sörenberg

In the ichnofauna from this locality, facies crossing types are the most common, but deep water forms predominate over "shallow water" forms. The log (Fig.3)

Table 2: Percentage of ichnogenera of deep water, "shallow water" and facies crossing types in the described sections.

	% Facies crossing	% Deep water	% Shallow water
Blattligraben	60	20	20
Höllbach	43	21	36
Sörenberg	50	31	19
Guber	36	45	18
Lower Zollhaus	33	43	23
Louetli	37	42	21
Falli Hölli	36	64	0
Fayaux (L ₂)	21	64	14
Upper Zollhaus	53	47	0
Fayaux (L ₁)	45	55	0

Table 3: Number of trace fossil types observed in the described sections.

	Blattligraben	Höllbach	Sörenberg	Guber	Zollhaus (L.)	Louetli	Falli Hölli	Fayaux L ₂	Zollhaus (U.)	Fayaux L ₁
"Shallow water" forms	1	5	3	2	7	4		4		
Straight, branched and unbranched	2	5	5	3	6	4	3	4	5	4
Winding unbranched	2	2	3	1	4	1	1	2	2	
Radiating			1		1	1	1	3	1	
Spiral			1	2	2	1	2	2	2	
Meandering		1	1	2	4	3	3	4	3	3
Networks					2	2	1	4		1
Spreite				1	2	1	2	3	1	2
Other		1	2		2	2	1	2	1	1

represents a changing environmental picture. In the lowest beds examined (A) are four channel fill, thinning upwards sequences and these contain the "shallow water" types *Arenicolites* and *Skolithos* together with deep water *Subphyllochora* and *Taphrhelminthopsis* as well as facies crossing types such as *Granularia*, *Sabularia* and *Scolicia*. *Arenicolites* and *Skolithos* are vertical burrows typical of high energy environments and may again indicate non-turbidity bottom currents especially since they occur in channel fill sequences.

Overlying the channel fills are two thickening upwards sequences (B) representing prograding lobes and these contain only deep water types (*Helminthopsis*, *Subphyllochora*, *Taphrhelminthopsis*) and one facies crossing type (*Scolicia*).

There follows 35 m of thin bedded sandstones and shales (C) with a low sand/shale ratio (0.6–0.9) and no clear facies sequences. This contains an ichnofauna which is relatively abundant but similar in variety to the channel fill sequences. The main difference is the absence of "shallow water" forms with the ichnospectrum restricted to deep water elements (*Glockereria*, *Spirophycus*, *Taphrhelminthopsis*) and facies crossing types (*Fucusopsis*, *Gordia*, *Granularia*, *Neonereites*). Sedimentologically, this part of the succession is interpreted as a quiet period when supply of coarse sediment was much reduced. The absence of "shallow water" trace fossils may indicate that the area was cut off from bottom currents as well as sediment laden turbidity currents. The highest part of the succession (D) including thickening upward sequences and thinning upward channel fill sequences displays relatively little area of sole exposed and many of the sandstones are thick bedded and coarse grained with a sand/shale ratio of 6.5. The only trace fossils found are *Granularia* and *Taphrhelminthopsis* but this paucity is probably a function of exposure and preservation potential.

Guber

The outcrop is a vertical quarry face which prevented systematic collection, and the trace fossils were mainly examined in fallen blocks. There are two "shallow water" ichnogenera (*Arenicolites*, *Rhizocorallium*) but deep water types including meandering and spiral forms predominate in the ichnospectrum.

The mixed assemblage is consistent with the environmental interpretation of the succession as mainly representing a series of channel fills and prograding lobes. The low diversity probably results from the thick sandstone beds, high sandstone/shale ratio (14.0) and inability to examine many beds in situ.

Lower Zollhaus

This sequence contains an ichnofauna of greater diversity than any of the others. Deep water types predominate but there are 7 "shallow water" types including *Arenicolites*, *Diplocraterion*, *Pelecypodichnus* and *Skolithos*, all typical of high energy conditions. The *Pelecypodichnus* were formed on the ocean floor mud and are markedly current oriented, indicating the activity of non-turbidity bottom currents. Deep water network forms make their first appearance in the ichnospectrum. The environmental interpretation of the sequence as the inner channelled part of a depositional lobe would explain the presence of trace fossils typical of high

energy environments, since such conditions could be provided by down channel bottom currents. The increase in variety of deep water trace fossils and the appearance of network types are also consistent with a slightly more distal position than for the Guber sequence.

Louetli

The ichnofauna is very similar to that of Lower Zollhaus, although diversity is slightly lower. The two sections are sedimentologically very similar.

Falli Hölli

The most conspicuous feature of the ichnofauna is the absence of shallow water forms. Despite alternating thin to medium bedded sandstones and shales, failure to find a single trace fossil typical of high energy shallow water conditions suggests little or no fast flowing bottom current activity. The most common trace fossils are deep water types including spiral, meandering, radiating and network forms. The ichnospectra of low energy deep water types agrees with the sedimentological interpretation of the succession as deposited mostly in interchannel areas on fan lobes.

Fayaux (L₂)

The ichnofauna is dominated by deep water types with radiating, meandering, spiral and network forms all being represented. There are, however, four "shallow water" ichnogenera (*Diplocraterion*, *Ophiomorpha*, *Thalassinoides* and *Treptichnus*). Although the *Diplocraterion* are vertically oriented, the *Ophiomorpha* are all oblique and *Thalassinoides* and *Treptichnus* are horizontal. *Diplocraterion* is normally associated in shallow water with high energy, often channelled sequences (FÜRSICH 1975, CRIMES et al. 1977, Fig. 10) while the oblique and horizontal forms are more common in lower energy situations (SEILACHER 1967, AGER & WALLACE 1970, FÜRSICH 1975). The increased percentage of deep water forms including 4 network types and the nature of the "shallow water" types suggest a lower energy, perhaps slightly more distal environment. This is also indicated by the sedimentology pointing to a position towards the centre of a lobe.

Upper Zollhaus

This sequence lacks the "shallow water" trace fossils present in the underlying channelled sequence of the Lower Zollhaus quarry. Instead; the ichnofauna has deep water and facies crossing types in approximatively equal abundance. The deep water forms are mainly spiral or meandering; no patterned type has been recorded. Sedimentologically this sequence was interpreted as the result of sediment starvation over an inner lobe environment. This would explain the absence of "shallow water" high energy trace fossils. The reason for an absence of patterned types is not clear, but could be the paucity of the soles available for inspection in this section.

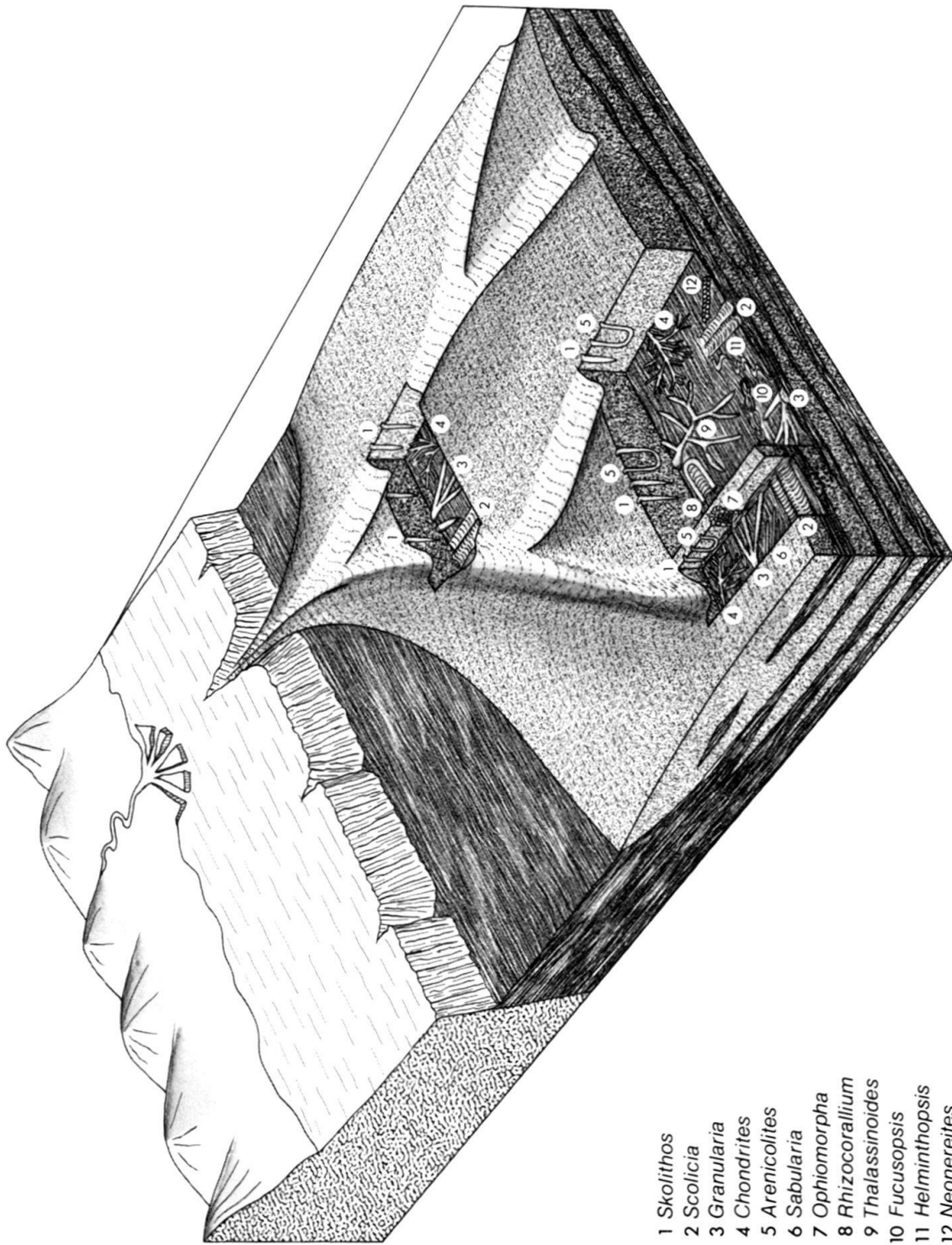


Fig. 11. Trace fossils of the inner fan showing occurrence in major fan valleys (Blattigraben) and intertributary channel areas (Höllbach).

Fayaux (L₁)

The absence of shallow water trace fossils, the lack of spiral and radiating types typical of the more proximal parts of deep-sea environments, and the occurrence of meandering and network forms point towards an outer fan/basin plain environment. This is consistent with the sedimentological analysis.

7. Discussion

The distribution of ichnofacies in the Gurnigel and Schlieren flysch shows that there are variations in ichnofauna dependent on the position within a deep-sea fan.

Those sequences which represent channelized inner fan facies (Blattligraben, Höllbach, Sörenberg) all have “shallow water” trace fossils, with vertical burrows such as *Arenicolites* and *Skolithos* prominent. There are also some deep water types but, with the exception of *Helminthopsis*, they lack the meandering and network types. *Helminthopsis*, although typically a deep water trace fossil, is also known to occur on the outer open shelf as in the Devonian sequence described by GOLDRING & LANGENSTRASSEN (1979). Sequences deposited within or adjacent to major fan valleys (e.g. Blattligraben) have a low diversity. Interchannel areas within the inner fan (e.g. Höllbach) have a diverse “shallow water” ichnofauna including vertical

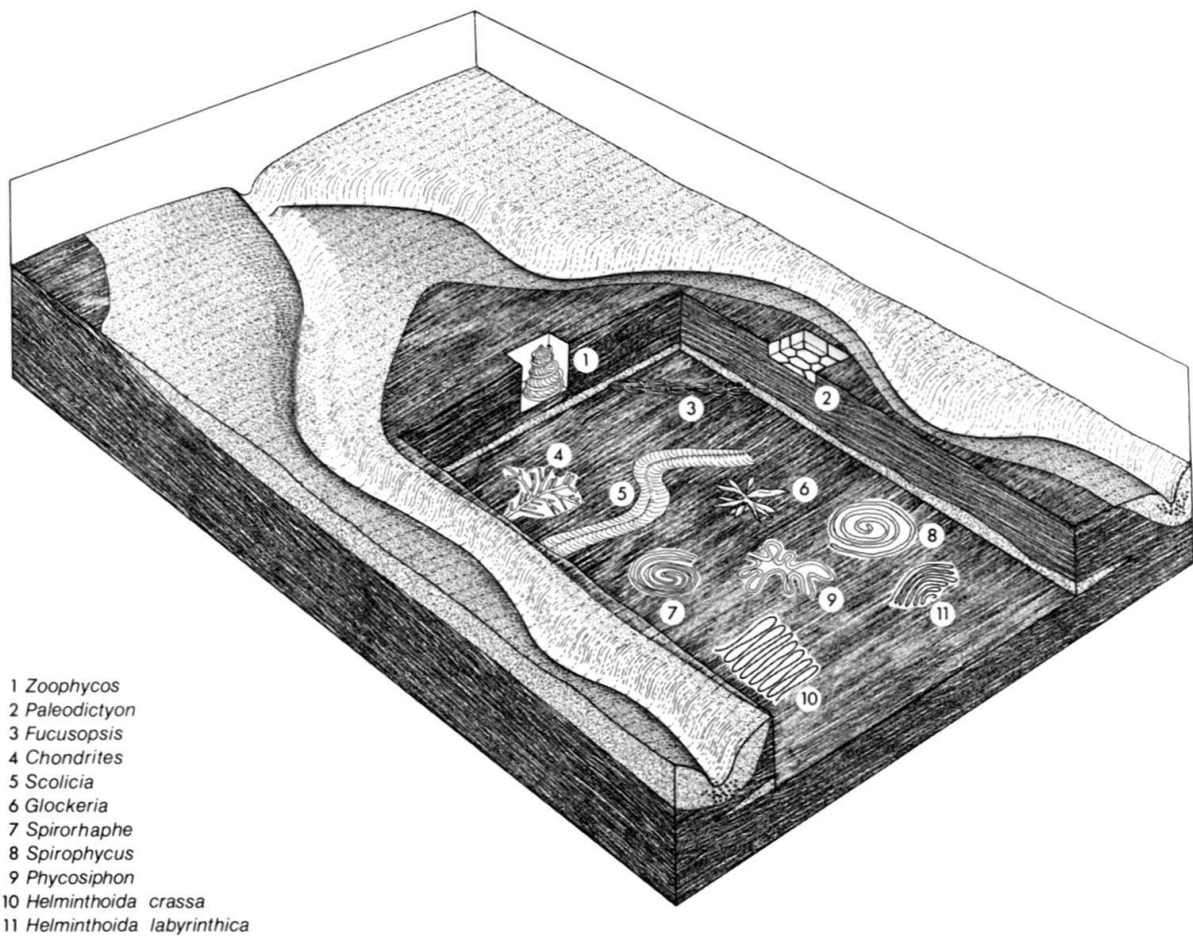


Fig. 12. Trace fossils of the interchannel areas of the outer fan (Falli Hölli).

and horizontal burrows but deep water types are rare. The relationship between trace fossils and depositional environment in the inner fan is shown in Figure 11.

Interchannel areas (Fig.12) within the outer fan (Falli Hölli) lack "shallow water" types but include all the main deep water forms (radiating, meandering, spiral, network).

In the depositional fan lobes (Guber, Zollhaus, Louetli, Fayaux L₂) there is a mixed ichnofauna. In the fan fringe (Fayaux L₁) "shallow water" trace fossils are absent whereas deep water types occur including meanders and networks. The relationship between trace fossils and depositional environment in the outer fan (lobes and fringe) is shown in Figure 13.

Facies crossing trace fossils are approximately evenly distributed in all environments.

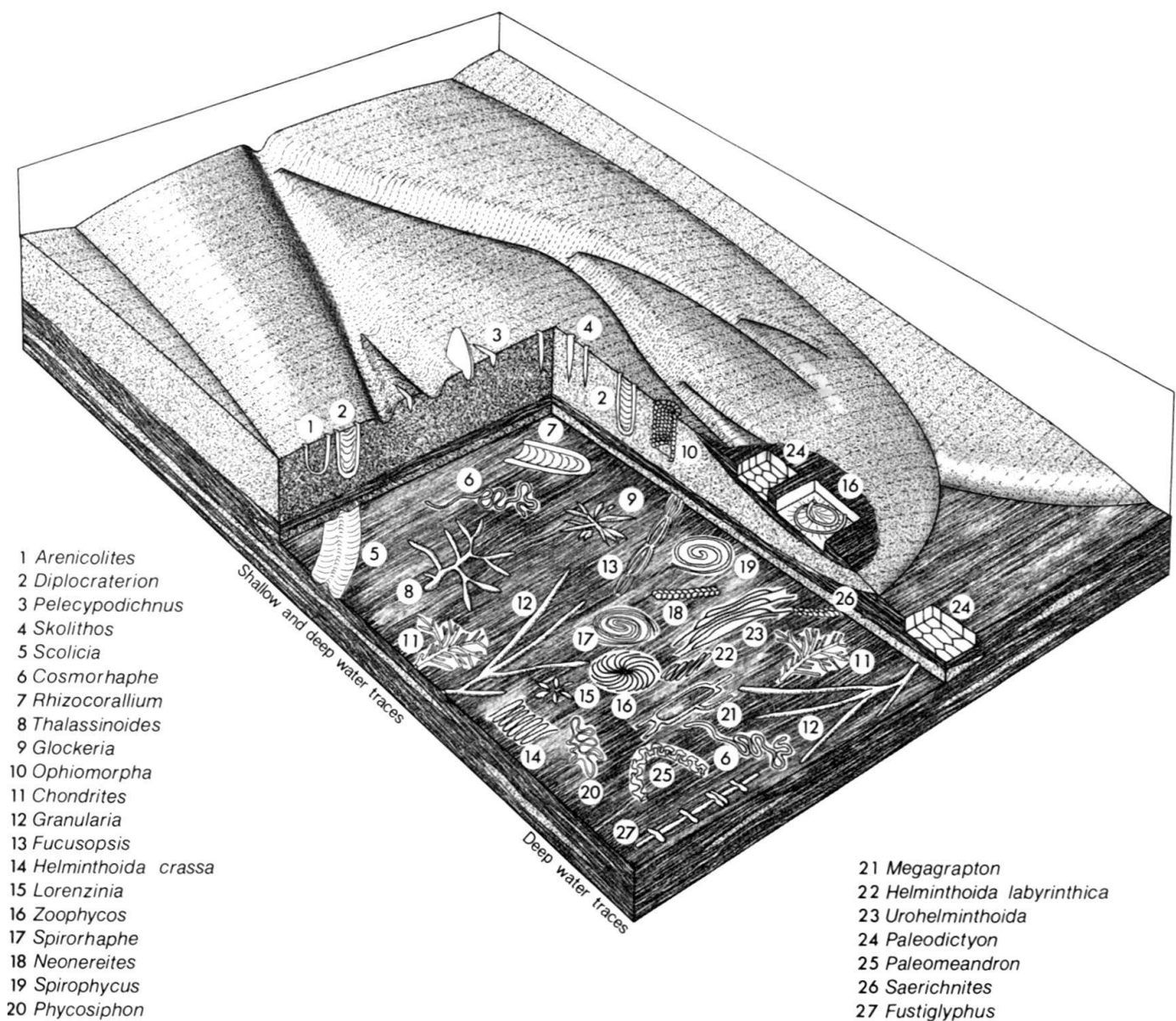


Fig. 13. Trace fossils of the outer fan depositional lobes (e.g. Guber, Zollhaus, Louetli, Fayaux L₂) and fan fringe (Fayaux L₁).

Maximum diversity is reached at sites where "shallow water" forms were introduced and to where deep water colonizers readily returned and were not removed by the following turbidity current or inhibited by currents flowing between turbidity events. Such sites are the channelled part of the depositional lobe. How applicable these results are to Palaeozoic turbidites with their lower diversity of deep water traces (CRIMES 1974, SEILACHER 1974) remains to be seen.

The variation in ichnofauna within an idealized sand fan parallels that reported by CRIMES (1977) from the Eocene Jaizkibel deep-sea fan in North Spain where channelized lobes have mixed shallow and deep water trace fossils, while in the outer fan fringe "shallow water" forms are exceedingly rare and deep water forms common.

It is difficult to relate the variations in ichnofauna between the different sections simply to preservational factors or variations in sand/shale ratios. Most deep water trace fossils lie parallel to bedding and are formed at the sediment/water interface or only a few centimetres down in the mud. Rarity of these types in more proximal areas could, at least in part, be preservational and brought about by erosion of the top few centimetres of mud by fast flowing turbidity currents. However, neither the variation in forms of deep water trace fossils nor the absence of shallow water vertical and horizontal burrows in the outer fan fringe can be so ascribed. Nor does the sand/shale ratio have much influence. Indeed, if Table 2 is rearranged with the sections in order of their sand/shale ratio no consistent variations in ichnofauna can be demonstrated.

The trace fossil distributions can therefore be more satisfactorily explained in terms of the various environments of the deep-sea sand fan model than simply by changes of sediment supply at source and preservational factors. In addition, this provides independent support for the validity of the deep-sea sand fan model, and the evidence for persistent high energy conditions in the channel sequences suggests that non-turbidity bottom currents issuing from canyons may play a significant role in the more proximal fan environments.

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Plate 1

- Fig. 1 Section in lower part of Zollhaus quarry with thinning upward sequences of Upper Paleocene (Thanetian and Ilerdian) age forming part of the Gurnigel flysch.
- Fig. 2 Louetli quarry with Upper Paleocene (Thanetian) sediments forming part of the Gurnigel flysch.
- Fig. 3 Part of the section exposed in the Lower Fayaux quarry (L₁) showing sediments of Upper Paleocene (Thanetian) age forming part of the Gurnigel flysch.
- Fig. 4 Radiating trace of *Ophiomorpha* burrows possibly representing a callianassid shrimp brood structure.
- Fig. 5-7 *Pelecypodichnus*, Upper Paleocene (Thanetian or Ilerdian), Zollhaus quarry.
- Fig. 8 *Chondrites arbuscula* FISCHER-OOSTER 1858, Upper Paleocene (Thanetian or Ilerdian), Lower Zollhaus quarry.

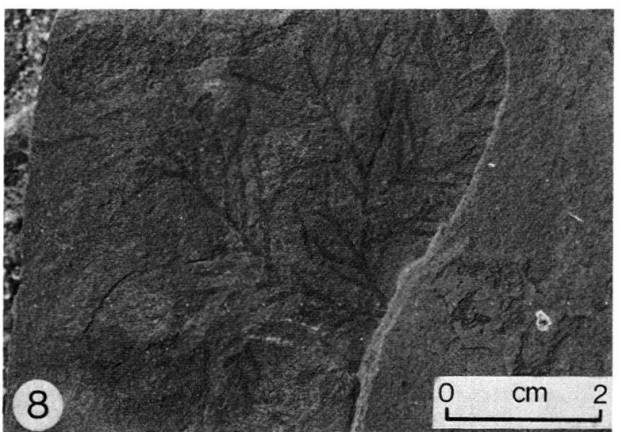
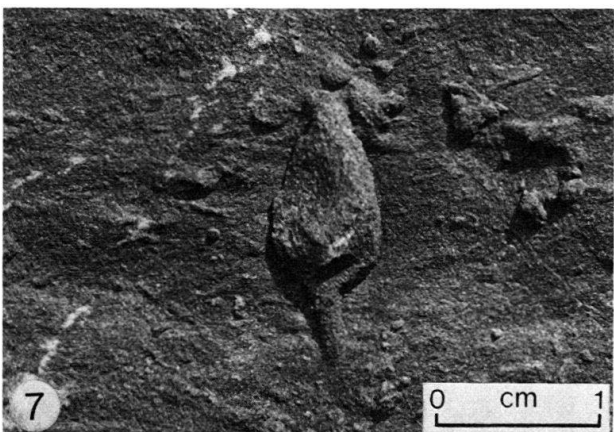
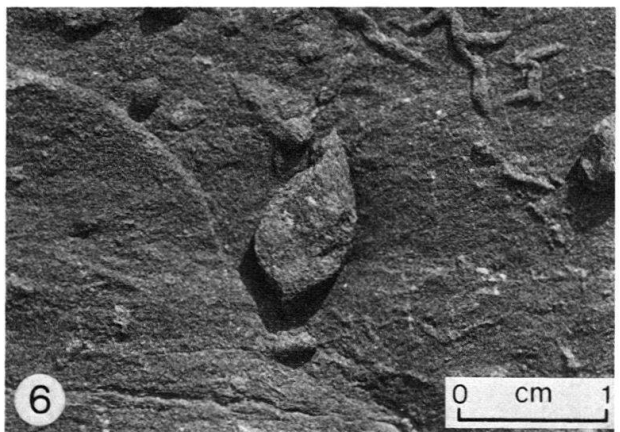
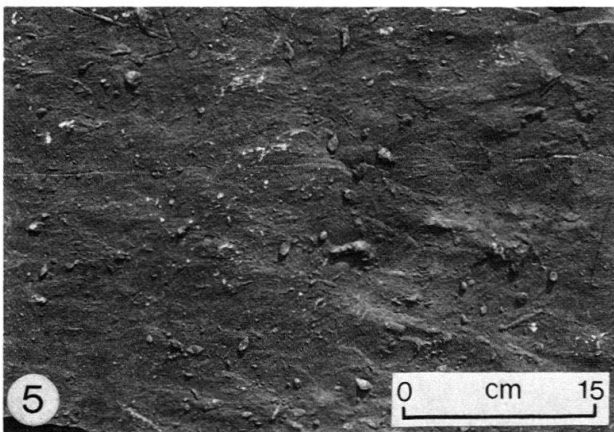
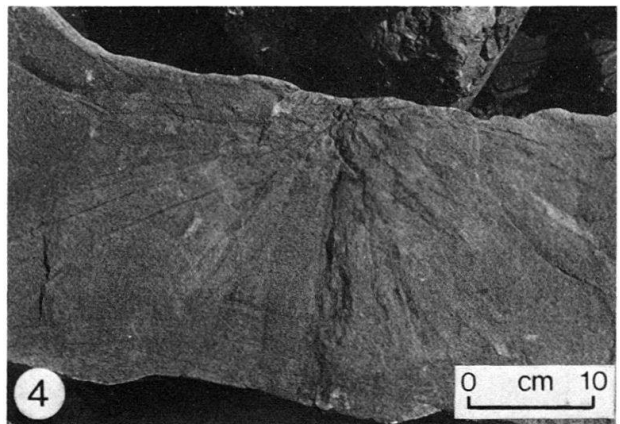
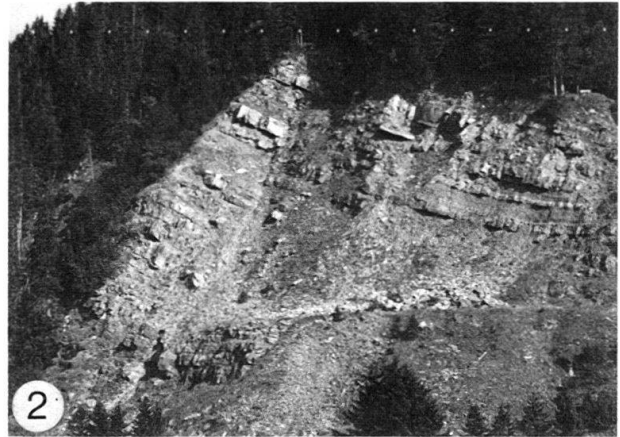


Plate 2

- Fig. 1 *Fucusopsis angulata* PALIBIN 1932, Upper Paleocene (Thanetian or Ilerdian), Zollhaus quarry.
- Fig. 2 *Fucusopsis angulata* PALIBIN 1932, showing internal sediment stuffing, Paleocene (Thanetian or Ilerdian), Zollhaus quarry.
- Fig. 3 *Fustiglyphus* sp., Upper Paleocene (Thanetian), Lower Fayaux quarry (L₁).
- Fig. 4 *Granularia* sp. showing fill of grains coarser than overlying bed, Upper Paleocene (Thanetian), Lower Fayaux (L₁).
- Fig. 5 *Granularia* sp., Upper Paleocene (Thanetian or Ilerdian), Zollhaus quarry.
- Fig. 6 *Lophoctenium* sp., Lower Eocene (Ilerdian), Zollhaus quarry.
- Fig. 7 *Sabularia simplex* KSIAZKIEWICZ 1977, Upper Paleocene (Thanetian), Lower Fayaux quarry (L₁).
- Fig. 8 *Saerichnites beskidensis* PLIČKA 1974, Upper Paleocene (Thanetian), Upper Fayaux quarry (L₂).

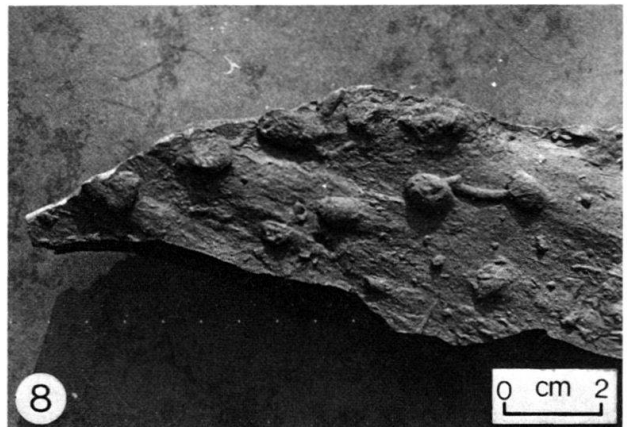
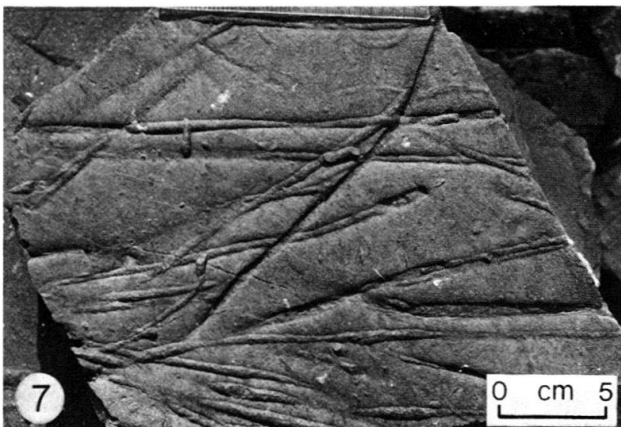
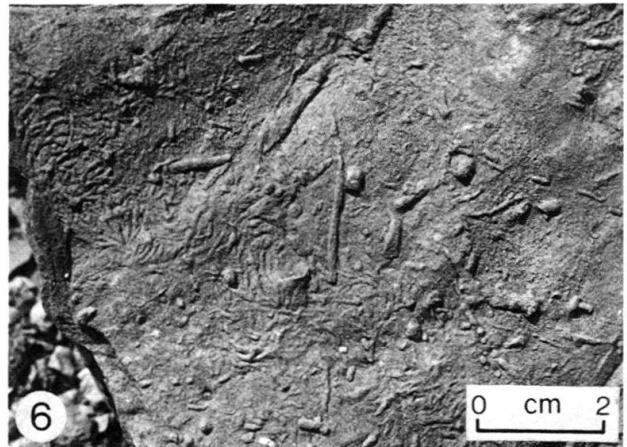
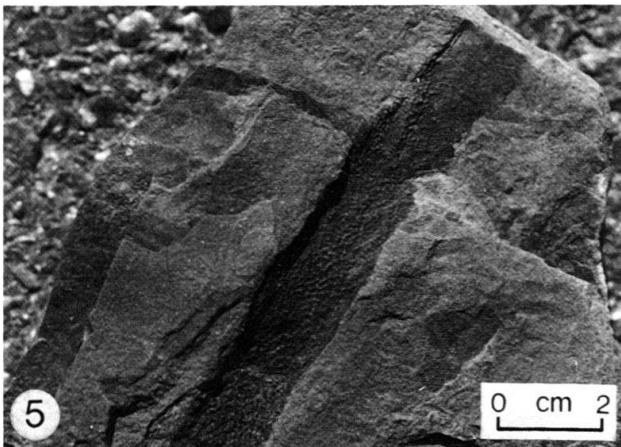
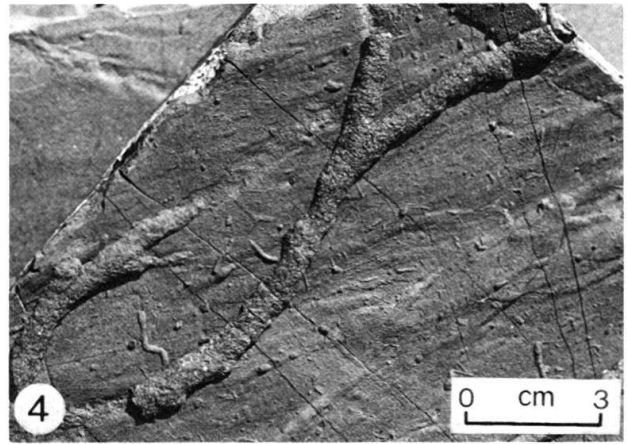
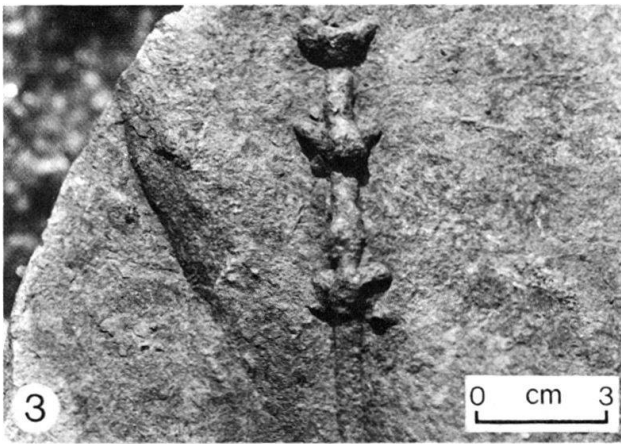
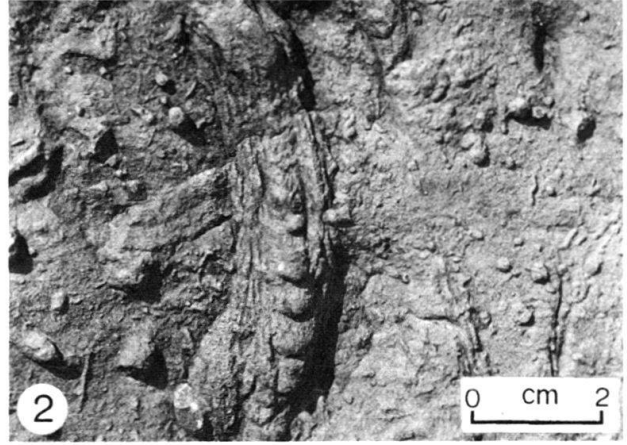
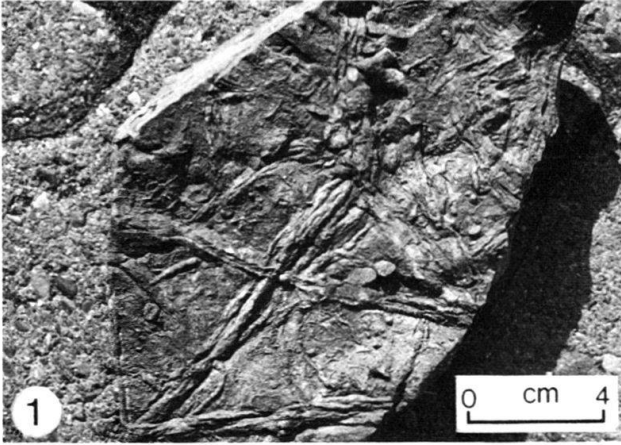


Plate 3

- Fig. 1 *Gyrochorte* sp., Upper Paleocene (Thanetian or Ilerdian), Zollhaus quarry.
- Fig. 2 *Taphrhelminthopsis* sp., Upper Paleocene (Thanetian or Ilerdian), Zollhaus quarry.
- Fig. 3 *Glockeria sparsicostata* KSIAZKIEWICZ 1968, Upper Paleocene (Thanetian), Upper Fayaux quarry (L₂).
- Fig. 4 *Lorenzina* cf. *moreae* RENZ 1925, Upper Paleocene (Thanetian), Upper Fayaux quarry (L₂).
- Fig. 5 Close up of rays of *Lorenzina* cf. *moreae* to show their annulated form.
- Fig. 6 *Spirorhaphe zumayensis* SEILACHER 1977, Upper Paleocene (Thanetian or Ilerdian), Zollhaus quarry.
- Fig. 7 *Spirorhaphe zumayensis* SEILACHER 1977, Lower Eocene (Ilerdian), Zollhaus quarry.
- Fig. 8 *Spirorhaphe* sp., Lower Eocene (Ilerdian), Zollhaus quarry.

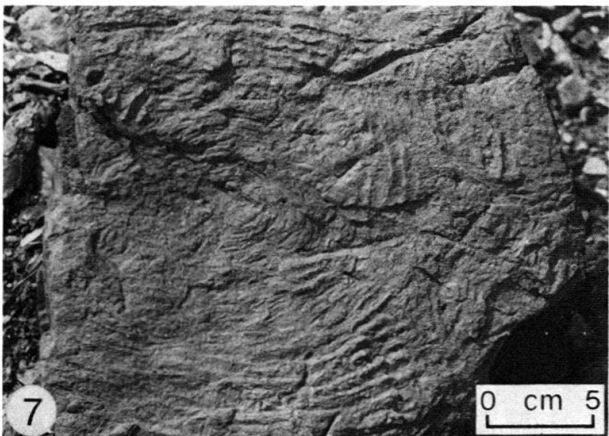
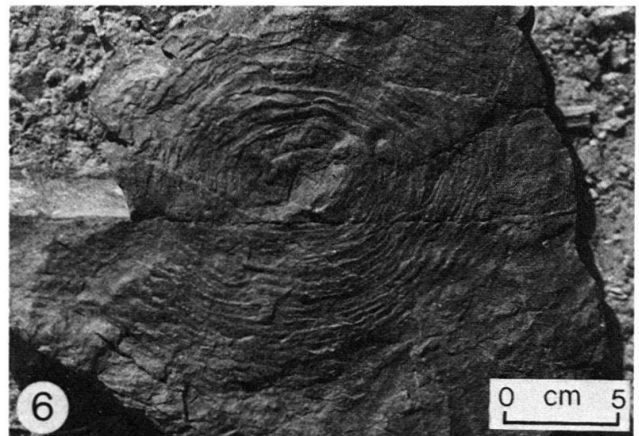
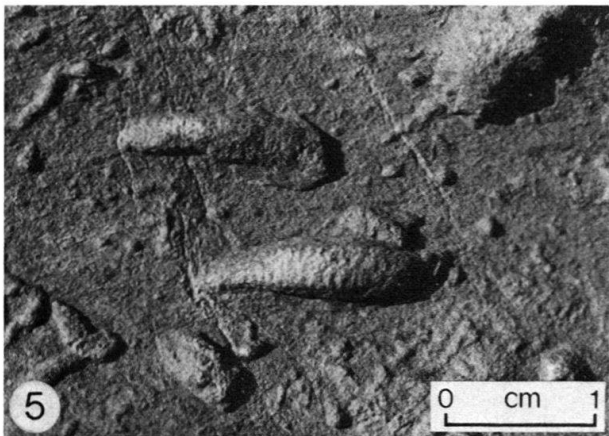
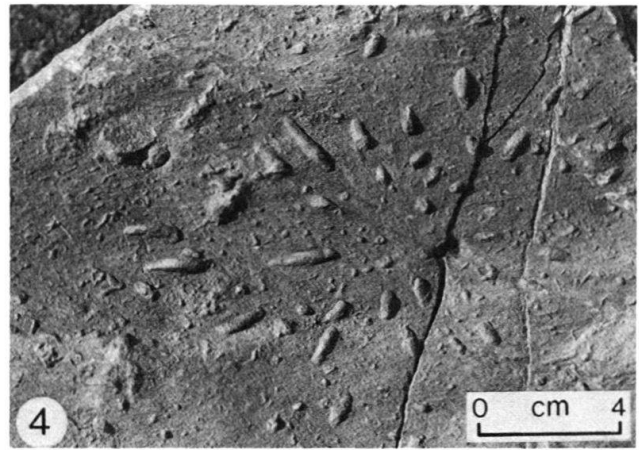
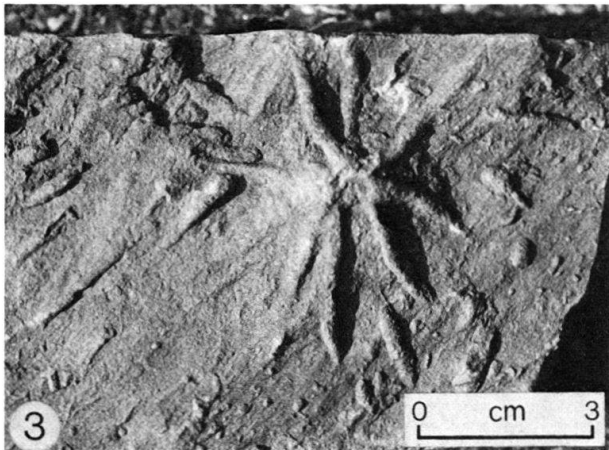
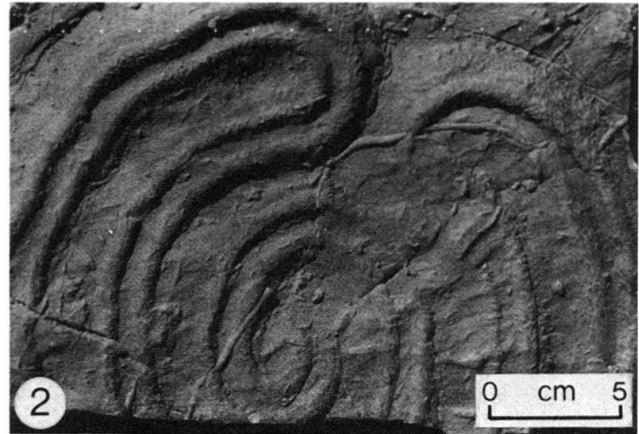
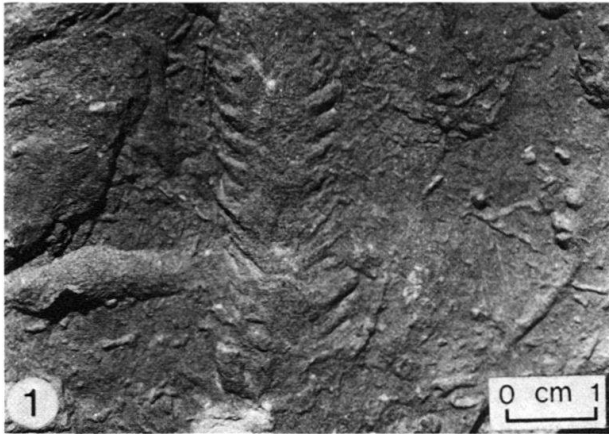


Plate 4

- Fig. 1 *Helminthopsis* sp., Upper Paleocene (Thanetian), Upper Fayaux quarry (L₂).
- Fig. 2 *Megagraption irregulare* KSIAZKIEWICZ 1968, showing collapsed burrows thus demonstrating that they were open tunnels, not sediment stuffed burrows, Upper Paleocene (Thanetian or Ilerdian), Upper Fayaux quarry (L₂).
- Fig. 3 *Paleodictyon miocenicum* forma *pleurodictyonoides* KSIAZKIEWICZ 1977, Upper Paleocene (Thanetian or Ilerdian), Zollhaus quarry.
- Fig. 4 *Protopaleodictyon bicaudatum* SEILACHER 1977, Upper Paleocene (Thanetian), Upper Fayaux quarry (L₂).
- Fig. 5 *Polykampton alpinum* OOSTER 1869, Upper Paleocene (Thanetian), Upper Fayaux quarry (L₂).
- Fig. 6 *Polykampton alpinum* OOSTER 1869, with *Zoophycos*, Upper Paleocene (Thanetian), Upper Fayaux quarry (L₂).
- Fig. 7 *Zoophycos brianteus* MASSALONGO 1855, Upper Paleocene (Thanetian), Upper Fayaux quarry (L₂).
- Fig. 8 *Gordia molassica* (HEER 1865), Eocene (Cuisian), Höllbach.
- Fig. 9 *Mammillichnis aggeris* CHAMBERLAIN 1971 showing granulated structure, Upper Paleocene (Thanetian), Upper Fayaux quarry (L₂).
- Fig. 10 *Mammillichnis aggeris* CHAMBERLAIN 1971 showing elevated rim and current scour, Upper Paleocene (Thanetian), Upper Fayaux quarry (L₂).

