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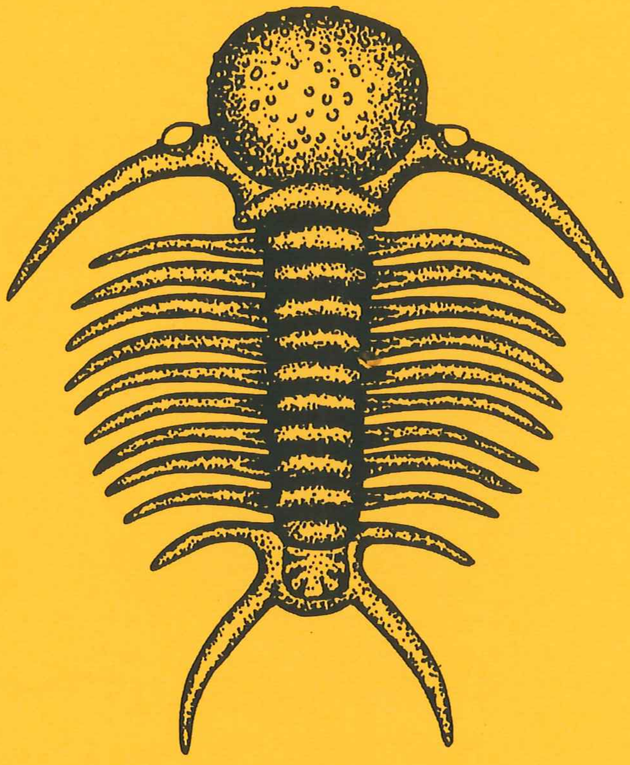

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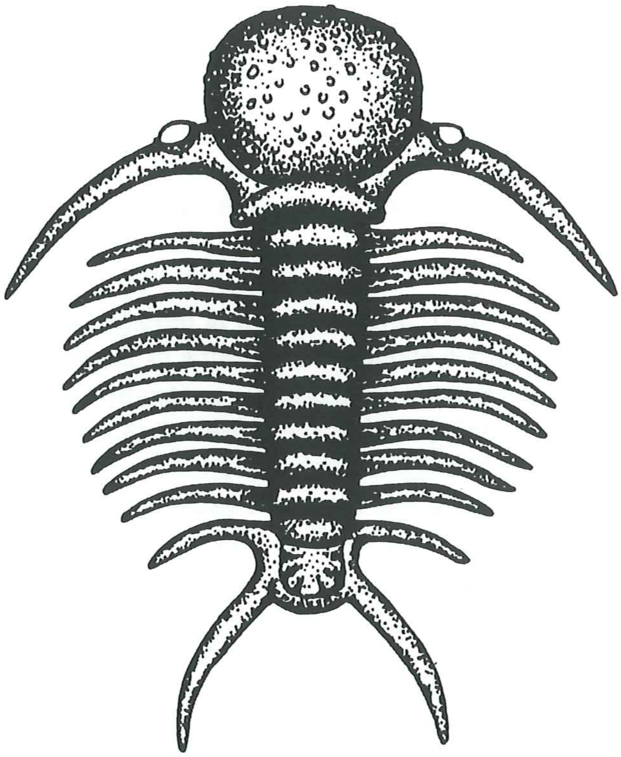

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HANNA CALNER

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The trace fossil assemblages exposed at the Armorano road section in the Monte Sporno unit, Northern Apennines, Italy, occur in a turbidite sequence composed of fine-grained limestones (mudstones) and argillaceous limestones (wackestones) together with coarser grained calcareous sandstones and claystones, both turbiditic and hemipelagic. Fodinichnial vertical burrows of post-depositional origin and pascichnial horizontal trails of pre-depositional origin alternates depending on lithology. The fine-grained beds of the section exhibit the greatest variety of ichnotaxa. Post-depositional burrows, such as *Chondrites* sp. and *Zoophycos* sp., occur herein frequently and the sediment is in some parts almost totaly bioturbated. In the coarser grained beds, vertical burrows are missing and a more monotonous ichnofauna occur, dominated by pre-depositional horizontal trails like *Taphrhelminthopsis* sp. Ichnotaxa such as *Helminthoida* (ichnosp. *Helminthoida labyrinthica*) and ?*Megagrapton* sp. are also present in the section together with six other ichnogenera, all reflecting a deep-sea community, and with characteristic elements of the *Nereites* ichnofacies. ❑ *Flysch deposits, trace fossils*, Zoophycos, Chondrites, Helminthoida labyrinthica, Taphrhelminthopsis, Nereites *ichnofacies, pre-depositional, post-depositional, Monte Sporno, Northern Apennines, Italy.*

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Introduction

Flysch deposits, particularly those of Cretaceous to Tertiary time, are well known for their rich and diverse trace fossil content. As body fossils are rare in such deposits, trace fossils have become valuable for the reconstruction of ancient deep-sea environments (e.g. Ekdale *et al.* 1984). The deep-sea offers very special conditions for the animals. Quiet periods with continuous background sedimentation, and periods characterized by catastrophic event deposits (turbidites), alternate in a rather regular pattern. Different faunas, producing different trails and adapted for different environments, therefore successively replace each other vertically in a deep-sea sequence. Trace fossils in such deposits, for instance in the Polish Carpathians, the Guipúzcoan flysch and the Zumaya flysch of northern Spain and in Southern Apennines, Italy, are well documented and have been the topic for several articles (e.g. Ksiazkiewicz 1968, 1970, 1977; Crimes 1973, 1977; Roniewicz & Pienkowski 1977; D'Alessandro *et al.* 1986; Pienkowski & Westwalewicz-Mogilska 1986; Leszczynski & Seilacher 1991; Uchman 1991; Leszcynzski 1993*a*, 1993*b*). No previous work has, however, been carried out on the ichnofauna within the Monte Sporno unit in the Northern Apennines, Italy, which has become the subject for this research. The Monte Sporno trace fossil assemblages are well preserved and well exposed, and shows many characteristics typical for ichnocoenoses in flysch deposits.

Introduction to the outcrop

The examined sequence, that consists of Paleocene-Middle Eocene flysch deposits, is exposed at the Armorano road section in the Baganza Valley, near the village of Calestano, Northern Apennines, Italy (Fig. 1). The Armorano road section is part of the 1800 m thick Monte Sporno antiform (Bernini *et al.* 1994) which is tilted vertically with layers lower surfaces facing south. The Monte Sporno unit has been subdivided by Petrucci & Barbieri (1966) into a lower unit which is composed of about 200 m of clays and marls with rare sandstone intercalations, a middle unit that comprises 1300 m calcareous marls, sandstones and calcarenites with subordinate marls, siltites and shales, and, finally, an upper lithological unit that reaches a thickness of about 300 m dominated by marls and pelites. The Armorano road section belongs to the middle lithological subunit.

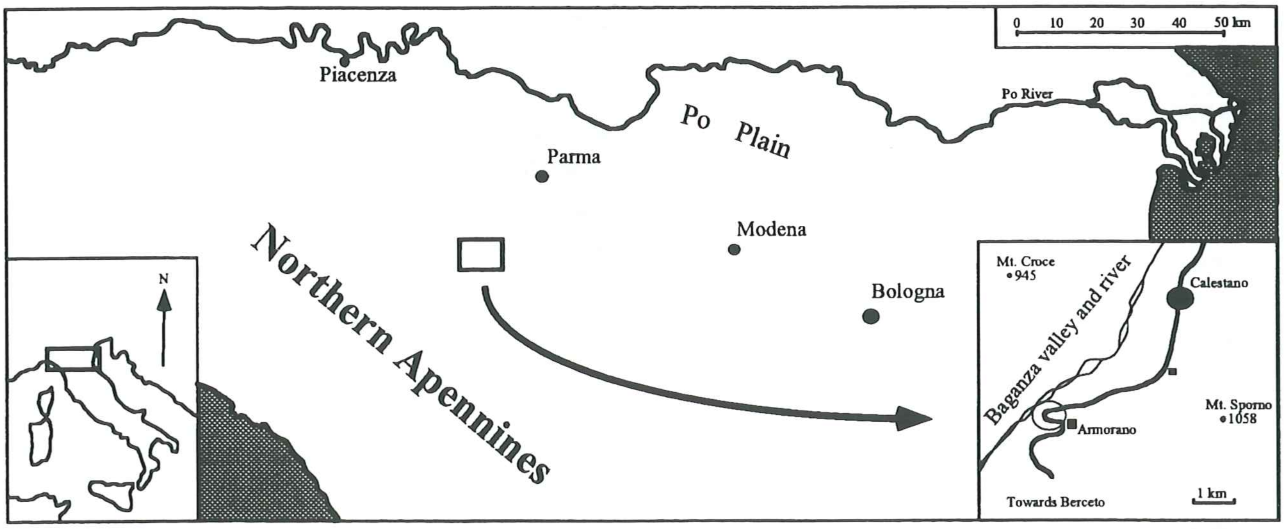


Fig. 1. The location of the Armorano road section (encircled) in the Po plain facing part of Northern Apennines. Simplified after Gasperi *et al.* (1986).

Material and methods

The field work was carried out during four days in June 1995, in cooperation with Mikael Calner, Lund University, Sweden, who examined the lithologies at the locality. For this study, the most trace fossil bearing part of the sequence was choosen and studied in detail. Totaly, a vertical sequence of 2.5 m was examined. It must, however, be mentioned that the layers are tilted vertically, and therefore, large areas of the layers lower surfaces are exposed. The trails were described morphologically and their position within the sequence was indicated. Some ichnogenera, such as *Zoophycos*, *Chondrites* and *Helminthoida* (ichnosp. *Helminthoida labyrinthica*), were identified in field, while others were collected and identified at the Department of Geology in Lund, Sweden. This is also the place where these samples are stored. Due to the well indurated sequence, there were some difficulties in examining the trails in cross section in field. However, collected specimens were cut vertically to the bedding to reveal possible vertical structures. Photographs were taken in field of trace fossils present in the different lithologies. Collected samples were photographically documented at the Department of Geology in Lund.

Sedimentology of the trace fossil bearing sequence

Details of the sedimentology are given by M. Calner (in press). Within the examined section, fine-grained limestones (mudstones) and argillaceous limestones (wackestones) dominate together with calcareous sandstones and claystones (turbiditic and hemipelagic) and the different lithologies alternate in a rather regular pattern representing several turbidite sequences (Fig. 2). The calcareous sandstones are brown to grey in colour and varies in thickness from 0.6 cm to 13 cm. Commonly, the sandstones have sharply defined erosional lower contacts scattered by flute casts. Primary structures within these beds are parallel lamination, graded bedding and cross lamination. According to M. Calner (Lund, personal communication 1995), between two and four of the Bouma (1962) divisions are present within the sandstone beds. The mudstones (classified after Dunham 1962) are greyish-blue in colour and between 16-25 cm in thickness showing a massive or slightly graded internal structure. Only one of the Bouma divisions is represented within the mudstone beds (M. Calner, personal communication 1995). The argillaceous wackestone at the top of the trace fossil bearing sequence (Fig. 2), representing one Bouma division, is similar to the mudstone beds, but contains a few more percentage of skeletal grains and has a lower $CaCO_3$-content than the mudstones (M. Calner in press). The calcareous claystones (of turbiditic origin) are yellow to grey in colour and lack of trace fossils. They occur as thin layers and represent the uppermost parts of the turbidites (M. Calner in press). Trace fossils are also missing in the green claystones (hemipelagic), which are present as thin layers between the turbidites. According to Prof. Parea (Modena, personal communication 1995) the sediments are considered to have been deposited below CCD (the calcium compensation depth). The turbidites have been divided by M. Calner (in press) into siliciclastic turbidite facies (the calcareous sandstones and the calcareous claystones) and carbonate turbidite facies (the mudstones and the argillaceous wackestone). A third facies has been referred to as hemipelagic facies (the green claystones). The changing facies is reflected in variations within the ichnofauna.

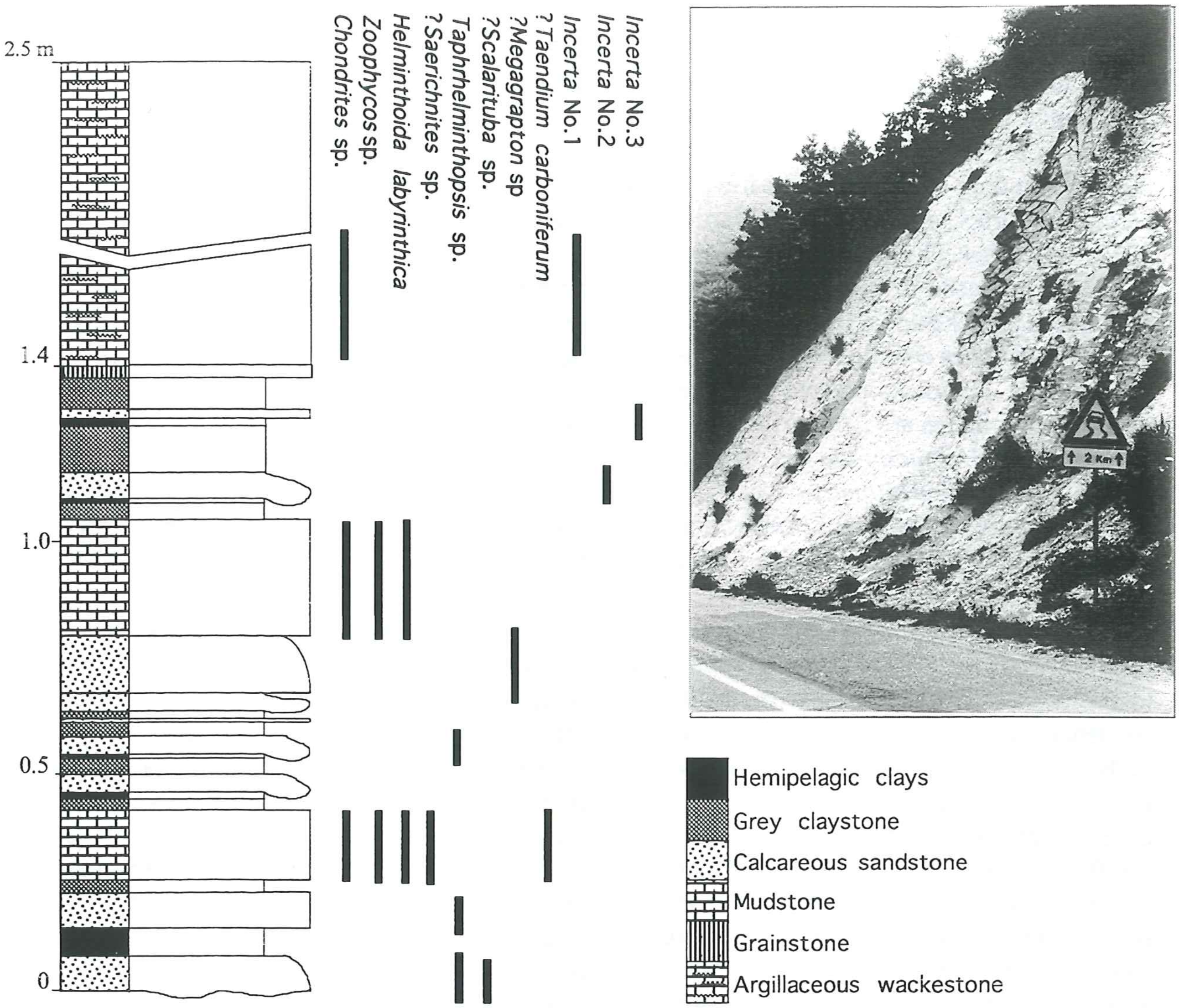


Fig. 2. The Armorano road section and the distribution of ichnotaxa.

Microfossil content

Details of the microfossil content are given by M. Calner (in press). Both benthic and planktic foraminifera are to be found in the section irrespectevly of the lithology, although planktic forms dominate.

Occurrence of the trace fossils

The trace fossils specific for the different lithologies are plotted in Fig. 2. Eight ichnotaxa have been observed, together with three biogenic structures that are distinctive morphologically but could not be identified using the existing nomenclature. More than half of the observed trace fossils were, however, only represented by one or two specimens.

The occurrence of the trace fossils is limited to the lower parts of the turbidite sequences. In general, the trails of the siliciclastic turbidite facies are visible as hypichnial (according to Martinssons 1970 toponomic classification) groove casts on the soles of the turbidites, composed of calcareous sandstone often with erosional base. The trace fossil assemblages in these parts contain *Taphrhel-*

minthopsis sp., ?*Scalarituba* sp., ?*Megagrapton* sp. and two unidentified ichnogenera herein named Incerta No. 2 and Incerta No. 3. The trace fossils of the carbonate turbidite facies commonly occur within the lower parts of the turbidites, as endichnial (Martinsson 1970) structures. The sediment in these parts is either composed of massive mudstone or argillaceous wackestone, in which the thick-bedded mudstones contain the greatest variety of ichnotaxa. Ichnotaxa present in the carbonate turbidite facies are *Chondrites* sp., *Zoophycos* sp., *Helminthoida* sp. (ichnosp. *Helminthoida labyrinthica*), ?*Saerichnites* sp., ?*Taendium* sp. (ichnosp. ?*Taendium carboniferum*) and a single unidentified ichnogenus herein named Incerta No. 1.

No body fossils which can be connected to the trace fossils have been found in the sequence. According to Ekdale *et al.* (1984) body fossils are rare in turbidites, and when present, they usually are allochthonous. The diversity of the trace fossil assemblages and the frequency of the specific trails, increase successively from the reference level to the middle parts of the section and then decrease again towards the top of the sequence. Finally, only large forms of *Chondrites* sp. sporadically occur.

Systematic ichnology

Terminology. - The various ichnotaxa described herein were identified according to Sacco (1888) and Häntzschel (1975). The ethological classification is according to Seilacher (1964) and the toponomic classification (Fig. 3) is according to Martinsson (1970). The various trace fossils, their occurrence, toponomy and preservation are listed in Table 1.

Ichnogenus *Chondrites* von Sternberg, 1833.

Chondrites ichnosp.

Plate I, Fig. A

Material and occurrence. - Numerous specimens encountered in the massive mudstone beds between 0.26-0.42 m and 0.82-1.08 m (Fig. 2), and in the argillaceous wackestone level between 1.36-2.45 m (Fig. 2). Rare occurrences of large forms of *Chondrites* sp. has also been recorded outside the described sequence where no other ichnotaxa have been found.

Description. - Endichnial plantlike branched pattern of small cylindrical tunnel systems, in which the individual tunnels never cross each other. Each branch of an individual trail is connected to a common vertical shaft. The branches are straight to slightly curved, and mainly oriented parallel to bedding-plane. The branching tunnels are of uniform diameter within the same system. The specimens found in the Monte Sporno sequence can be divided into large and small forms, based on differences in tunnel diameter. Smaller forms are much more frequent in the sequence than larger forms. The diameter of the tunnels varies between 0.1 cm and 0.3 cm (small forms), plus a few with a diameter reaching 0.7 cm (large forms). The length of the branching patterns varies between 1.5 cm and 5.5 cm and the width between 1 cm and 9 cm. Smaller forms dominate in levels composed of mudstone, while larger forms dominate in the level composed of argillaceous wackestone. The tunnel fill of the traces consists of dark-coloured mud (mainly within the smaller forms) or green clay (mainly within the larger forms), which contrasts with the surrounding ligth-coloured mudstone or argillaceous wackestone.

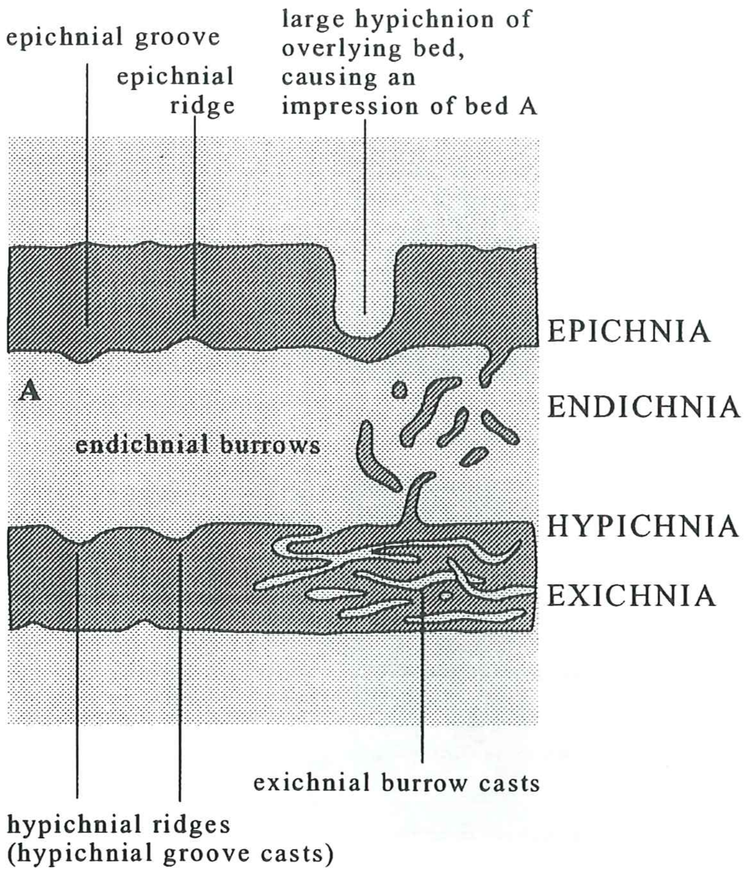


Fig. 3. Diagrammatic presentation of the toponomic classification of trace fossils, based on the main medium of preservation, simplified after Martinsson (1970). The four key terms to the right of the diagram refer to bed A.

Association. - *Zoophycos* sp., *Helminthoida labyrinthica*, and possibly also ?*Saerichnites* sp. and Incerta No. 1.

Remarks. - *Chondrites* has been interpreted as an open tunnel system in which the top of the vertical shaft is open to the sea-floor. *Chondrites* is suggested to have been produced by an infaunal deposit-feeding animal (Simpson 1956; Ekdale & Bromley 1983, 1984*a*), perhaps a worm, and it is classified as a fodinichnial trace fossil (Häntzschel 1975). The material of the fillings in *Chondrites* was probably derived from overlying sediments through the vertical shaft (Simpson 1956; Kotake 1991). Within the examined section, the *Chondrites* burrows show a post-depositional character. *Chondrites* occurs in all types of sediments since Cambrian time (Chamberlain 1975; Häntzschel 1975), including those deposited under anaerobic conditions (Ekdale & Bromley 1984*a*), and it has been represented in relatively deeper marine settings since the Ordovician (Simpson 1956; Häntzschel 1975; Ekdale 1977; Ekdale & Bromley 1983, 1984*a*; Bromley 1990). Typically, *Chondrites* represents the last trace fossil in a bioturbated sequence, which indicates that the burrow system was produced deep within the sediment in the anaerobic zone (Ekdale & Bromley 1984*a*).

Ichnogenus *Helminthoida* Schaufhäutl, 1851

Helminthoida labyrinthica Heer, 1865

Plate I, Fig. B

Material and occurrence. - Numerous specimens found on the sole of the massive mudstone bed between 0.26-0.42 m (Fig. 2) and a single observation on the sole of the massive mudstone between 0.82-1.08 m (Fig. 2).

Description. - Hypichnial unbranched, regularly meandering tunnel-trails, which loop

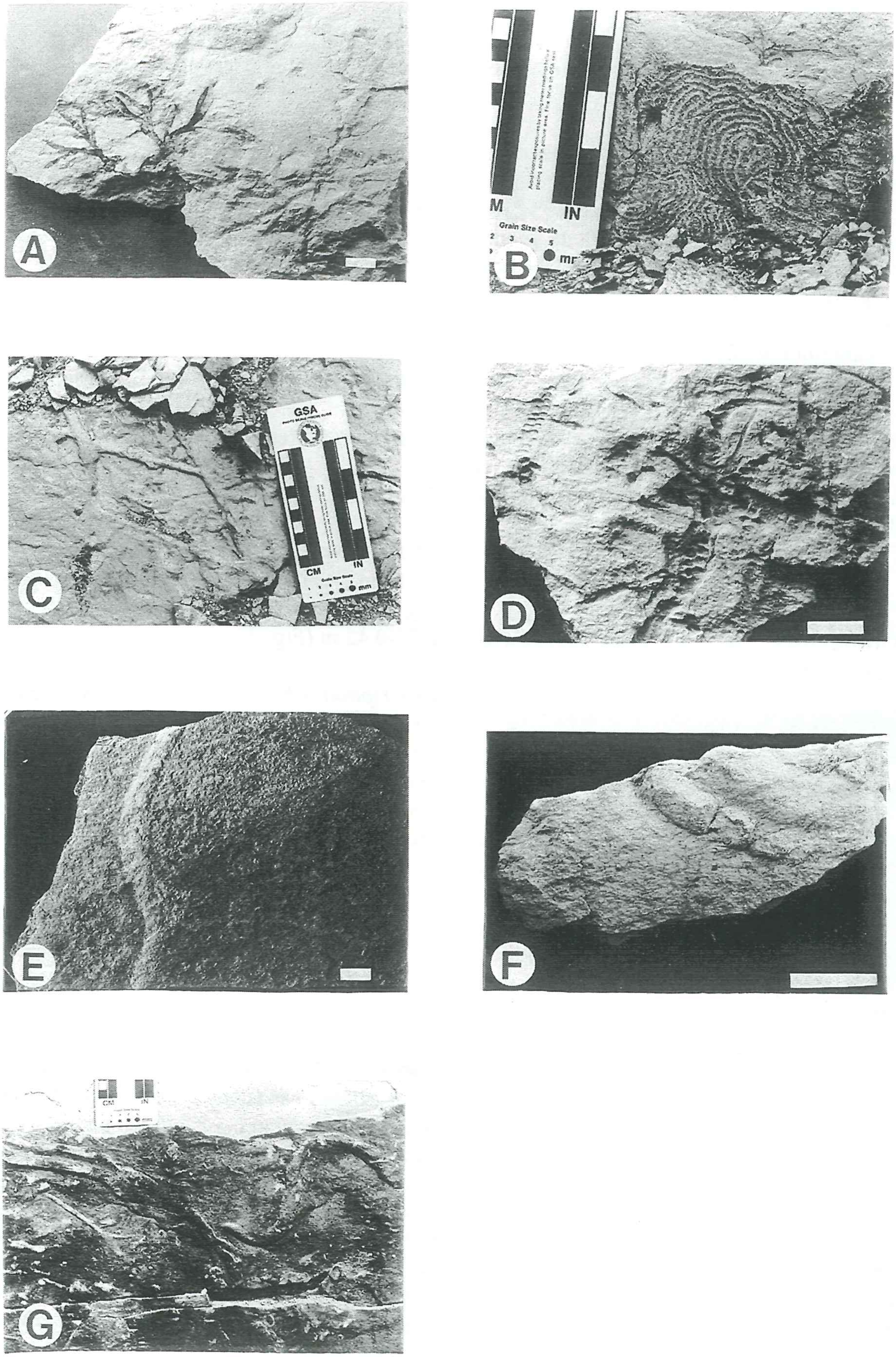
Table 1. Trace fossils recorded in the Armorano road section and their occurrences with respect to facies.

Trace fossil	Toponomy	Facies	Preservation
Chondrites sp.	endic hnia	carbonate turb. facies	post-depositional
Zoophycos sp.	endic hnia	carbonate turb. facies	post-depositional
Helminthoida lab.	hypichnia	carbonate turb. facies	pre-depositional
Taphrhelminthopsis sp.	hypichnia	siliciclastic turb. facies	pre-depositional
?*Scalarituba* sp.	endichnia	siliciclastic turb. facies	post-depositional
?*Megagrapton* sp.	hypichnia	siliciclastic turb. facies	pre-depositional
?*Saerichnites* sp.	?endi chni a	carbonate turb. facies	uncertain
?*Taendium carb.*	endichnia	carbonate turb. facies	post-depositional
Incerta No.1	?endi chni a	carbonate turb. facies	uncertain
Incerta No.2	hypichnia	siliciclastic turb. facies	pre-depositional
Incerta No.3	hypichnia	siliciclastic turb. facies	pre-depositional

back and forth, closely spaced in almost parallel patterns. Parallel to bedding-plane, and where they occur, they often cover areas about 1 m^2 and sometimes more. The trails vary in size. The diameter of the smallest tunnels is about 0.1 cm and the diameter of the larger forms, 0.5 cm. The amplitudes varies between a few millimetres up to 7 cm and the distance between two neighbouring tunnels is about 0.1 cm in the smaller forms and 0.5 cm to 0.8 cm in the larger forms. Smaller and larger forms occur together. Because the trails are closely spaced, they are difficult to delimit from each other. The trails form a wide variety of patterns.

→

Plate I. **A.** *Chondrites* sp. in the mudstone bed between 0.82-1.08 m. **B.** *Helminthoida labyrinthica* in the mudstone bed between 0.26-0.42 m. **C.** *Megagrapton* sp. on the sole of the calca reous sandstone bed between 0.70-0.83m. **D.** ?*Saerichnites* sp. in the debris material. **E.** ?*Scalarituba* sp. in the calcareous sandstone bed between 0-0.08 m. **F.** ?*Taendium carboniferum* in the argillaceous wackestone bed between 1.36-2.45 m. **G.** *Taphrhelminthopsis* sp. on the sole of the calcareous sandstone bed between 0.15-0.23 m. Scale bar 1 cm.


A
B
M
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Grain Size Scale
C
GSA
CM
IN
D
E
F
G

Association. - *Chondrites* sp., *Zoophycos* sp., and probably also ?*Saerichnites* sp. and Incerta No. 1.

Remarks. - The ichnogenus *Helminthoida* has been observed in flysch deposits from Cretaceous to Tertiary time (Häntzschel 1975). It is regarded as a grazing trail, pascichnia, produced by mobile epibenthos, economically searching for food upon the sediment surface, covering as much ground as possible but with the minimum of effort (Clarkson 1994). *Helminthoida* should be classified as a pre-depositional trace fossil, in the sense that it has been preserved during a process of minor erosion and by sudden burial as semirelief casts on the sole of the overlying turbidite (Bromley 1990).

Ichnogenus ?*Megagrapton* Ksiazkiewicz, 1968

?*Megagrapton* ichnosp.

Plate I, Fig. C

Material and occurrence. - Observations in field on the sole of the calcareous sandstone level between 0.70-0.83 m (Fig. 2).

Description. - Hypichnial, sub-cylindrical strings, about 0.5 cm to 1 cm wide, in some parts swollen. At various intervals branching at nearly right angles forming a network of more or less complete irregular rectangles, not closed.

Association. - No other ichnotaxa have been observed in the sequence in association with ?*Megagrapton* sp.

Remarks. - The size of the trails found in the Monte Sporno sequence, does not agree with the general size of the ichnogenus *Megagrapton*, described by Ksiazkiewicz (1968), in which the diameter of the strings is between 0.1 cm and 0.3 cm. *Megagrapton* is widely recognized in Upper Cretaceous to Upper Tertiary flysch deposits in Japan and Europe (Häntzschel 1975). The trails show a pre-depositional character within the examined section. The abrupt breaks in the strings may have been formed when the animal left the interface and descended into the clay (Ksiazkiewicz 1968).

Ichnogenus ?*Saerichnites* Billings, 1866

?*Saerichnites* ichnosp.

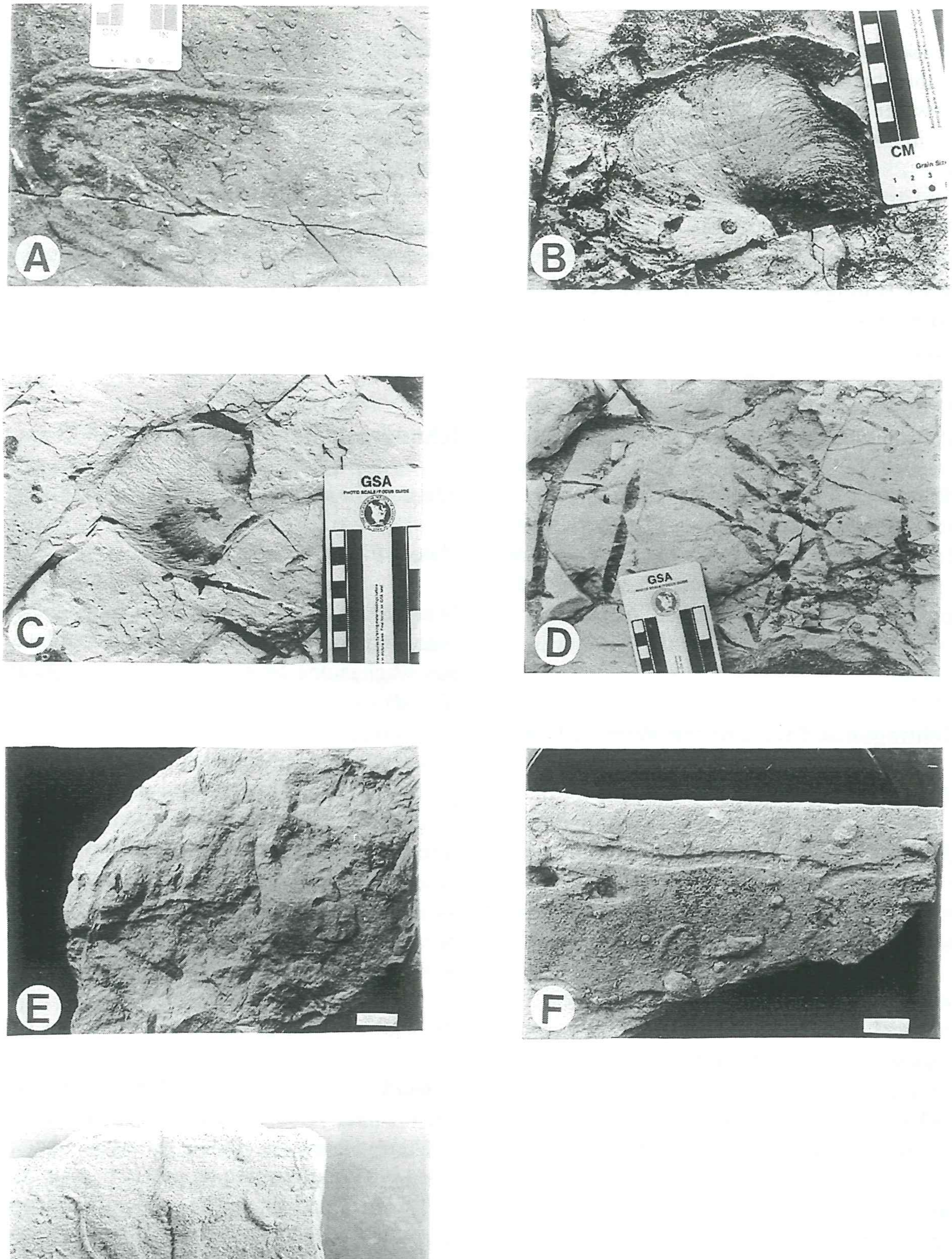
Plate I, Fig. D

Material and occurrence. - Nine trails were found in the debris material, probably belonging to the massive mudstone bed between 0.26-0.42 m (Fig. 2).

Description. - Endichnial? trace fossils consisting of two parallel furrows containing semicircular rows. Each row is between 0.2 cm and 0.5 cm in diameter. The length varies between 2 and 3 cm and the outer margin of the trails is straight to slightly curved.

→

Plate II. **A.** *Taphrhelminthopsis* sp. on the sole of the calcareous sandstone bed between 0-0.08 m. **B.** *Zoophycos* sp. in the mudstone bed between 0.26-0.42 m. **C.** *Zoophycos* sp. in the mudstone bed between 0.82-1.08 m. **D.** backfill structures in the mudstone bed between 0.82-1.08 m. **E.** Incerta No. 1. in the debris material. **F.** Incerta No. 2. in the calcareous sandstone bed between 1.13-1.19 m. **G.** Incerta No. 3. in the calcareous sandstone bed between 1.26-1.28 m. Scale bar 1 cm


A
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Association. - Ichnogenus Incerta No. 1, and if they belong to the massive mudstone level between 0.26-0.42 m, also *Zoophycos* sp., *Helminthoida labyrinthica* and *Chondrites* sp.

Remarks. - There are lots of similarities between these trails and the ichnogenus *Saerichnites* Billings, 1866, although *Saerichnites* with rows reaching 1.5 cm in diameter (Häntzschel 1975), is a bit larger. Further, *Saerichnites* occurs in the geological record in Ordovician settings (Häntzschel 1975), while the trails described above are found in a sequence of Paleocene-Middle Eocene age. *Saerichnites* is regarded as tracks from molluscs, perhaps cephalopods (Teichert 1964). It cannot be deduced whether ?*Saerichnites* sp. within the examined section are of pre-depositional or post-depositional origin.

Ichnogenus ?*Scalarituba* Weller, 1899

?*Scalarituba* ichnosp.

Plate I, Fig. E

Material and occurrence. - One fragmentary trail found within the calcareous sandstone level between 0-0.08 m (Fig. 2), a few centimeters above the base of the bed.

Description. - Endichnial, sinuous, sub-cylindrical burrow, 0.7 cm in diameter, parallel to bedding. The fragmentary specimen found in the sequence is 8 cm long and the burrow is marked by poorly preserved transverse ridges situated at distances of about 0.2 cm. The specimen in the section seems to have a post-depositional character, with an infill material lighter in colour than the surrounding sediment.

Association. - *Taphrhelminthopsis* sp.

Remarks. - According to Conkin & Conkin (1968, as referred by Häntzschel 1975) the *Scalarituba* trails were made by deposit-feeding worms or wormlike organisms living in shallow marine, estuarine, or tidal-flat environments, although Seilacher (1964) listed occurrences of this ichnogenus from both *Cruziana*, *Zoophycos* and *Nereites* ichnofacies. The trails are paschicnial according to Ekdale & Mason (1988).

Ichnogenus ?*Taendium* Heer, 1877

?*Taendium carboniferum* Sacco, 1888

Plate I, Fig. F

Material and occurrence. - Four fragmentary specimens were collected from the argillaceous wackestone level between 1.36-2.45 m (Fig. 2).

Description. - Endichnial sub-cylindrical trace fossils divided into several segments, oval or almost rectangular in shape, in which the size decreases from one segment to another. Therefore, the width, within the same trace varies from about 0.9 or 0.6 cm to about 0.3 or 0.2 cm. The length of the collected specimens varies between 3 cm and 6 cm.

Association. - Large forms of *Chondrites* sp.

Remarks. - Regarded as a feeding burrow, fodinichnia, perhaps produced by a polychaete worm, which has made a gallery and backfilled it without turning around (Chamberlain 1971). It is present in the geological record from the Carboniferous to the Eocene (Sacco 1888). There are several similarities between the traces found within the section and *Taendium carboniferum* Sacco, 1888. However, the different segments in *Taendium carboniferum* are of uniform size (Sacco 1888), which is not the case in the traces collected from the Monte Sporno sequence, in which the size of each segment successively decreases. The specimens within the section seems to have a post-depositional character.

Ichnogenus *Taphrhelminthopsis* Sacco, 1888

Taphrhelminthopsis ichnosp.

Plate I, Fig. G; Plate II, Fig. A

Material and occurrence. - Numerous specimens found on the soles of the calcareous sandstone beds between 0-0.08 m (abundant), 0.15-0.23 m (common) and 0.55-0.59 m (rare) (Fig. 2).

Description. - More or less meandering hypichnial bilobate trails, 1 cm to 3 cm wide, very long, about 1 m, in which the amplitudes are up to 32 cm. The height of one lobe in cross section is about 0.5 cm. Mostly the trails exhibit a distinct median furrow, 0.3 cm to 1 cm wide, shallow and nearly flat.

Association. - ?*Scalarituba* sp., in the calcareous sandstone level between 0-0.08 m. No other ichnogenera have been observed in association with *Taphrhelminthopsis* sp. within the levels between 0.15-0.23 m and 0.55-0.59 m.

Remarks. - The ichnogenus is found in flysch deposits from the Cretaceous to the Tertiary in Europe (Häntzschel 1975). Probably, it is a grazing-trail, pasichnia (Häntzschel 1975), produced by a vagile, bottom-living animal (Pienkowski & Westwalewicz-Mogilska 1986). *Taphrhelminthopsis* has a pre-depositional character, confirmed by many authors (e.g. Ksiazkiewicz 1970, 1977; Häntzschel 1975; Roniewicz & Pienkowski 1977; Seilacher 1977; Frey & Seilacher 1980; Kern 1980). The presence of a median furrow between two lateral ridges, indicates that the crawling animal had a longitudinal furrow on its ventral side (Ksiazkiewicz 1977).

Ichnogenus *Zoophycos* Massalongo, 1855

Zoophycos ichnosp.

Plate II, Figs. B, C

Material and occurrence. - Numerous observations in field in the massive mudstone beds between 0.26-0.42 m and 0.82-1.08 m (Fig. 2). In the former bed, three specimens of *Zoophycos* sp. are visible on an area of 1m2, while in the latter bed, six specimens of *Zoophycos* sp. have been counted on an equal area.

Description. - Endichnial complex spreiten systems with a wide range of morphological variations. Some of the *Zoophycos* specimens found in the Monte Sporno sequence are almost circular with a smooth outer margin, while others are more elongated and irregular. The main part of the burrows contains laminae, composed of minor and major lamellae, in which the laminae is connected to a vertical shaft (Häntzschel 1975). Two basic forms can be distinguished in the section; one containing a cylindrical tunnel system in the outer margin, and one without this cylindrical tunnel system. In some of the *Zoophycos* systems visible here, backfill-structures are present in the marginal tunnel system and in some of them, this marginal tunnel system branches off one or two times. Some *Zoophycos* are visible in two or three planes in the sequence, but mostly only one plane occurs. The size of the burrows varies. The largest *Zoophycos* observed in the section is 36 cm long and 12 cm wide, and the smallest one, 8.5 cm long and 6 cm wide. According to Ekdale & Lewis (1991) the diameter of the *Zoophycos* burrows increases downward in a setting.

Association. - *Chondrites* sp., *Helminthoida labyrinthica* and probably ?*Saerichnites* sp. and Incerta No. 1.

Remarks. - *Zoophycos* Massalongo, 1855 was originally described as a marine algae (see Plicka 1968). Later, it has also been regarded as a body fossil of a sabellid (a polychaete annelid) worm (Bischoff 1968; Plicka 1968). But the general opinion is that *Zoophycos* is a complicated fodinichnial trace fossil, produced by a deep burrowing, deposit-feeding animal (e.g. Häntzschel 1962, 1975; Seilacher 1967). The *Zoophycos* system probably represent a work of a lifetime, under which the sediment has been reworked by lateral backfill, resulting in spreite structures (Seilacher 1962). *Zoophycos* is a cosmopolitian trace fossil with an occurrence in the geological record from the Ordovician to the Tertiary (Häntzschel 1975). It seems to be tied to the host sediment and not to the surface sediment (Kotake 1991). The *Zoophycos* burrows within the examined section are of post-depositional origin.

Note. - In the massive mudstone bed between 0.82-1.08, backfill structures with a dark sediment infill are frequent (Plate II, Fig. D). These vary in size and direction. The smallest one reaches a length of 7 cm, and the largest one, 33 cm. The width of the structures is about 0.7-1 cm. Some of them are simple tubes, while others are branched. When seeing *Zoophycos* in cross section, it may be visible as tubes with backfill structures (e.g. Ekdale & Bromley 1983; Ekdale & Bromley 1991). Perhaps these backfilled tubes, frequent in this mudstone level are parts of the *Zoophycos* system seen in cross-section, or perhaps they should be classified as an ichnogenus of their own.

Unidentified trace fossils

Ichnogenus Incerta No. 1

Plate II, Fig. E

Material and occurrence. - Several specimens present in the same debris material as ?*Saerichnites* sp., probably belonging to the massive mudstone bed between 0.26-0.42 m (Fig. 2).

Description. - Endichnial? trails consisting of a furrow, sometimes with sediment infill, sometimes not. The width varies between 0.2 and 0.5 cm. Both straight and strongly curved traces are represented and they loop without preferred direction.

Association. - ?*Saerichnites*, and if belonging to the mudstone level between 0.26-0.42 m, also *Zoophycos* sp., *Helminthoida labyrinthica* and *Chondrites* sp.

Remarks. - The trails could not be identified using existing nomenclature. Some doubts exists whether Incerta No.1, within the section, are of pre-depositional or post-depositional origin.

Ichnogenus Incerta No. 2

Plate II, Fig. F

Material and occurrence. - Fragments of two trails found in the calcareous sandstone level between 1.13-1.19 m (Fig. 2).

Description. - Hypichnial trace fossils. One of them, consisting of a furrow, 0.1-0.2 cm deep, 0.4-0.5 cm wide and 12 cm long. The other trail is visible as two oval openings at the sediment surface, probably connected with a furrow within the sediment. The openings reach a length of about 1.2-1.5 cm and are about 0.7 cm wide.

Association. - No other trace fossils have been observed in association with Incerta No. 2.

Remarks. - The trails could not be identified using existing nomenclature. The specimens show a pre-depositional character.

Ichnogenus Incerta No. 3

Plate II, Fig. G

Material and occurrence. - Several specimens noticed in the calcareous sandstone level between 1.26-1.28 m (Fig. 2).

Description. - Hypichnial flat ridges, 0.5-1.0 cm wide and 3.0-5.0 cm long, almost straight. Thin, about 0.1 cm in cross section.

Association. - No other trace fossils have been observed in association with Incerta No. 3.

Remarks. - The trails could not be identified using existing nomenclature. The specimens show a pre-depositional character.

Discussion

Characteristics of the ichnofauna

The ichnofauna represented in the Monte Sporno sequence is dominated by horizontal trails exhibiting a wide variety of morphological features, like meandering trails (*Taphrhelminthopsis* sp. and *Helminthoida labyrinthica*), spreiten burrows (*Zoophycos* sp.), irregular meshes (?*Megagrapton* sp.), and branched plant like burrows (*Chondrites* sp.). Segmented trace fossils (?*Taendium carboniferum*) and other forms like sinous trails (?*Scalarituba* sp.), flat ridges (Incerta No. 3) and traces marked as furrows (Incerta No. 1 and Incerta No. 2), also occur, but these morphological forms are only represented one or two times respectively within the section and are therefore not seen as a dominant part of the ichnofauna. The traces are classified as either fodinichnial or pascichnial according to Seilachers (1964) ethological classification. Such trace fossils have been made by deposit-feeding animals, with either a position within the sediment or as mobile epibenthos grazing at the sediment surface. Deposit-feeding is referred to Seilacher (1967) the dominant life-style in bathyal to abyssal marine benthic environments. Therefore, assemblages dominated by trace fossils produced by deposit-feeding animals often indicate very deep marine settings. According to the Seilacherian (1964) ichnofacies model, and because of the following features; a rather diverse trace fossil assemblage morphologically, dominated by fodinichnial and pascichnial forms with an occurence within a turbiditic sequence, the ichnofauna in the studied section should be placed in the *Nereites* ichnofacies (Fig. 4).

Preservation of the traces

Flysch trace fossils can be of either pre-depositional or post-depositional origin in relation to the deposition of the enclosing turbidite bed (Seilacher 1962). Pre-depositional trace fossils are the result of successional colonization whereas post-depositional trace fossils are the result of synchronous colonization (Leszcynski 1993*a*). In the Monte Sporno sequence, both pre-depositional and post-depositional traces occur, which is a typical feature for the *Nereites* ichnofacies (Seilacher 1964). The trace fossils of pre-depositional origin were produced in the hemipelagic facies underlying the turbidite bed (e.g. Seilacher 1977). Quiet, stable conditions prevailed during this period free of the influences of turbidites and with only small variations in the environmental factors (Frey & Pemberton 1984). The animals living in this environment had plenty of time to rework the sediment (Wetzel 1991). The pre-depositional traces within the section, are preserved as hypichnial (according to the toponomic classification of Martinsson 1970) impressions on

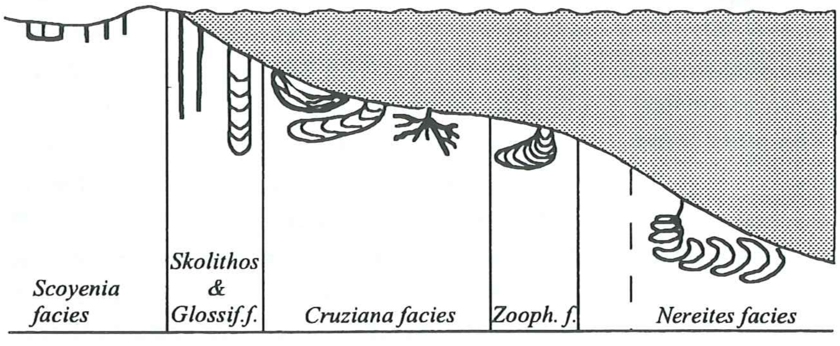

Fig. 4. Bathymetric zonation of trace fossil assemblages (=ichnofacies). Simplified after Seilacher (1967).

the sole of the overlying turbidite. Such trails are represented by *Taphrhelminthopsis* sp., ?*Megagrapton* sp., *Helminthoida labyrinthica* and probably also Incerta No. 3 and Incerta No. 2. The quiet intervals were interrupted abruptly by turbidity currents and the newely deposited sediment established an environment suitable for a more opportunistic, less stable fauna (Seilacher 1977; Frey & Seilacher 1980). The trails produced by these opportunistic organisms that flourished in a relatively short period after the turbidite deposition, are classified as post-depositional trace fossils and they occur as endichnial structures according to the toponomic classification of Martinsson (1970). To such traces in the sequence, *Chondrites* sp. belongs, with a position within the sedimentary unit and with infilled material which sharply separates it from the enclosing sediment. Also *Zoophycos* sp. and ?*Scalarituba* sp. shows a post-depositional character together with ?*Taendium carboniferum*. Some doubts exists whether ?*Saerichnites* sp. and Incerta No. 1 are to be regarded as pre-depositional or post-depositional trace fossils. These trails were found in the debris material and have not been observed *in situ* within the section.

Vertical distribution of the trace fossils

As shown in Fig. 2, there is a remarkable vertical change in the trace fossil content through the section, from bed to bed and from one turbidite facies to another. Factors that affect the vertical distribution of the trace fossils, discussed amongst others by Leszczynski (1991, 1993*a*), Ekdale *et al.* (1984) and Ekdale & Mason (1988), are for instances grain size and sediment composition, the thickness of the bed, oxygenation at the sea-floor, benthic food supply of the sediment, and the sedimentation rate. Within the examined section, it is obvious that these factors have influenced the vertical distribution of the ichnofauna in one way or another.

Grain size and sediment composition. - As mentioned in a previous chapter, there is an obvious connection between trace fossils and lithology in the sequence. The coarser-grained beds within the section (Fig. 2), composed of calcareous sandstones and classified as siliciclastic turbidite facies, exhibit mainly meandering forms or meshes horizontal to bedding on their soles. It must, however, be emphasized that the trails in these parts of the section, originally were produced in the upper parts of the underlying hemipelagic facies (except from ?*Scalarituba* sp. which presumably was produced within the sandstone bed), and when buried, causing an impression on the sole of the overlying turbidite. The ichnofauna herein is represented by *Taphrhelminthopsis* sp., ?*Megagrapton* sp., ?*Scalarituba* sp., and also by Incerta No. 2 and Incerta No. 3.

The fine-grained beds within the section (Fig. 2), composed of massive mudstone or argillaceous wackestone, are classified as carbonate turbidite facies. The massive mudstone beds show a more diverse ichnofauna than the coarser grained beds, with a mainly vertical distribution within the sediment. *Chondrites* sp., *Zoophycos* sp. and *Helminthoida labyrinthica* occur numerously and the sediment is in some parts almost entirely bioturbated. It must, however, be observed that the specimens of *Helminthoida labyrinthica* originally were produced in the coarser underlying hemipelagic facies. The argillaceous wackestone bed, between 1.36 and 2.45 m, is also dominated by vertical burrows but exhibits a more sparse ichnofauna than the mudstone beds. *Chondrites* sp. occurs herein together with some specimens of ?*Taendium carboniferum*.

Accordingly, there is a clear trend within the section that horizontal surface trails are restricted to the coarser grained beds, whereas the vertical burrows dominate in the finer grained beds. An explanation can be given in the fact that coarse-grained sediments are less stable than fine-grained deposits. Burrowing would in the former lead to a collapse of the sediment. Instead, within the coarser grained deposits, body appendages used for excavation is necessary for allowing the animal to displace the material (e.g. Bromley 1990). Systematic grazing trails, horizontal to bedding-plane, are therefore the preferred form of these trace fossils. On the contrary, fine-grained compressible material, such as the mudstones and argillaceous wackestones in the section, can be pressed sidewards and compacted, and are therefore suited for deeper penetrating organisms (e.g. Bromley 1990), like those producing *Chondrites* sp. and *Zoophycos* sp.

Thickness of the beds. - Besides the composition of the sediment, the thickness of the beds also seems to affect the composition of the ichnofauna. The most bioturbated sequences (the mudstone beds) reach a thickness of about 16-26 cm. This seems to be the most favourable thickness for digging. The 110 cm thick argillaceous wackestone bed at the top of the studied section with a sparse ichnofauna, perhaps did not gave rise to a penetrabel environment for the organisms. The trace fossil bearing calcareous sandstones with a thickness between 2.5 and 13 cm exhibit a more monotonous ichnofauna than the thicker mudstone beds, which is, except from ?*Scalarituba* sp., not produced within these sandstone beds but within the underlying hemipelagic layers. Probably these thin layers did not create conditions favourable for food supply.

Oxygenation. - As mentioned earlier in this paper, the section is dominated by pascichnial and fodinichnial trace fossils reflecting a mainly deposit-feeding fauna. These ethological forms are typical for substrates with a lack of abundant oxygen (Ekdale & Bromley 1984*b*; Savrda & Bottjer 1986; Ekdale & Mason 1988). The occurrence of specific burrows, especially *Chondrites* and *Zoophycos*, are valuable for the interpretation of the depositional environment. Both *Chondrites* and *Zoophycos* were produced below the water-interface. Animals producing such trails were forced to take their respiration water from the sediment surface through a permanently open tube (Ekdale & Mason 1988; Wetzel 1991).

The presence of *Chondrites* sp. indicates, according to Ekdale & Bromley (1984*a*), very low oxygene levels in the interstital water of the sediment. *Chondrites* reflects an environmental tolerance of oxygene levels lower than any other ichnogenus (Ekdale & Bromley 1984*a*), and because of this, *Chondrites* sp. typically represents the last ichnotaxa in the examined bioturbated sequence. The morphology of the *Zoophycos* burrows differs with changing oxygen-level (Wetzel & Werner 1981). In well oxygenated environments, the *Zoohycos* burrow system has a single J-shaped tube, with only one open connection to the sea-floor, while *Zoophycos* in oxygen-depleted deposits has developted a double, U-shaped tube with two openings at the sea-floor that allows it to be continuously ventilated (Wetzel & Werner 1981). The *Zoophycos* systems within the Armorano road section, are more like the latter ones.

According to these statements, the *Chondrites* and *Zoophycos* bearing beds of mudstone or argillaceous wackestones in the section should be interpreted as oxygen-depleted ancient environments. Also the size of the trace fossils (e.g. *Chondrites* and *Zoophycos*) can be of help when reconstructing the oxygenation at the sea-floor. A decrease in the oxygen availability results, according to Savrda & Bottjer (1986), and Marintsch & Finks (1978), in a decrease of the size of the burrows. But within the studied section, the reverse conditions seem to exist. Large forms of *Chondrites* sp. are herein the last represented ichnogenus.

Food supply. - The population density mainly depends on the supply of food available at the sea-floor (Jumars & Wheatcroft 1989). If the sediment is intensively bioturbated, it can be assumed that the rate of food supply was high within the substrate, and vice versa. The horizontal surface traces produced in the background sediment (hemipelagic facies), nowadays visible as impressions on the soles of the calcareous sandstones, reflect quiet water conditions, in which organic matter was settled from suspension (Frey 1978). These systematically meandering pre-depositional traces were produced by organisms adapted to a muddy substrate with meagre food supply (Miller III 1991), which gave rise to a low denisty and low diversity ichnofauna. The infauna of the mudstone beds and the argillaceous wackestone probably reflects a more turbulent environment, in which the animals were forced to seek for food deeper within the sediment. Horizontal surface trails are missing, exept from *Helminthoida labyrinthica* which occurs as impressions on the soles of the mudstones. This quite diverse, post-depositional high density infauna, indicates that the rate of food supply was proportionally high in comparison with the environment of the pre-depositional trace fossil assemblages.

Sedimentation rate. - The activity of the infauna within the section was probably also affected by the rate of sedimentation. Low sedimentation rates correspond to a low number of tiers (Wetzel 1991). This is obviously reflected in the ichnofauna originally produced in the background sediments (hemipelagic facies), in which horizontal near-surface trails are present on the soles of the overlying calcareous sandstone beds. No vertical burrows are represented here.

Turbidites affect the infauna by a dramatical increase of sediment deposition in a short time (Wetzel 1991). An increased sedimentation rate is indicated by a larger number of tiers and an extension of the bioturbated zone (Wetzel 1991), as reflected in the strongly bioturbated mudstone levels within the section, dominated by deeper, mainly vertical burrows and an absence of surface trails. The lack of trace fossils in some levels of the section, probably means that the rate of deposition was so high that the organisms living in the environment met an untimely death and were buried under the new load long before bioturbation was completed (e.g. Howard 1978).

Conclusions

Flysch sequences display alternating environments with variations in substrata, food supply, oxygenation and sediment accumulation, as reflected in the ichnofauna. The ichnofauna in the Monte Sporno sequence is rather representative for trace fossil assemblages in flysch deposits. It consists solely of fodinichnial and pascichnial forms of either pre-depositional or post-depositional origin in relation to the enclosing turbidite bed. The occurrences of trace fossils, such as *Chondrites* sp., *Zoophycos* sp., *Helminthoida labyrinthica* and *Taphrhelminthopsis* sp., within a turbiditic sequence, are indicative of an ancient deep-water environment in the bathyal-abyssal realm and are typical for the Seilacherian (1964) *Nereites* ichnofacies. The prevailing conditions in this deep-sea environment are more or less reflected in the ichnofauna. The presence of ichnotaxa such as *Chondrites* and *Zoophycos* point to oxygen-depleted conditions at the time when organisms occupied the finer grained substrates in the section. The organisms living in these deposits probably flourished in a relatively short time and were adapted to a rather turbulent, unstable environment in which they were forced to seek for food deeper within the substrat, resulting in vertical burrows. The trails of the coarser grained levels were produced by organisms adapted to an environment in which quiet, stable conditions, free of the influences of turbidites prevailed and with a meager food supply within the substrate. Horizontal surface trails therefore dominate these levels. The lack of trace fossils in some parts of the section probably means that the rate of deposition was so high that the organisms living in the environment were buried under the new load long before bioturbation was completed.

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