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Bioturbation structures of the Kropivnik Fucoid Marls (Campanian–lower Maastrichtian) of the Huwniki — Rybotycze area (Polish Carpathians)

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The Kropivnik Fucoid Marls of the Polish Outer Carpathians contain numerous bioturbation structures, and comprise thin-bedded sandstones, hard and soft marlstones and muddy to clayey, mainly turbiditic shales. Comparison of three sections elucidated the stratigraphic and sedimentological controls on the distribution of the bioturbation structures, which are most common on the soles of sandstone beds, and within and on the tops of beds of hard marlstone overlain by shale. Most of the bioturbation structures are taxonomically undeterminable. Nevertheless, twenty seven ichnospecies, including one new ichnospecies (*Taenidium recurvum*), and seven forms of trace fossils of unknown taxonomic affinity were recognised. Most ichnotaxa were observed as individual specimens. Irregular structures apparently formed by the squashing of burrows filled with fluidised fill, called here turbidichnia, are quite common in some marlstone beds in the lower part of the succession. *Planolites beverleyensis* and *Halopoa imbricata* are the most frequent trace fossils on the lower surfaces of sandstone beds. *Chondrites intricatus, Planolites beverleyensis* and *Thalassinoides suevicus* represent the most common taxa in hard marlstones. Endoreliefs of *Scolicia* isp. are quite frequent in the top parts of marlstone beds in some parts of the succession. Other ichnotaxa were found either rarely or as single specimens only. The burrowing depth, reaching 15 cm below the tops of normally-graded rhythmic units, together with the relatively rich trace fossil assemblage and common occurrence of *Planolite*s and *Thalassinoides*, is interpreted as indicating fully oxic conditions at the bottom of the sedimentary basin.

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INTRODUCTION

The Kropivnik Fucoid Marls (Campanian–lower Maastrichtian; Kotlarczyk, 1978), and the slightly older (Turonian–lower Santonian) Holovnia Siliceous Marls are conspicuous lithostratigraphic units of the Skole Nappe of the Polish Carpathians and contain abundant trace fossils. Structures of the fucoid ichnogroup (Fu, 1991) are particularly characteristic of these rocks which, therefore, were originally termed fucoid marls (e.g. Wiśniowski, 1905).

Książkiewicz (1977) provided the first description on the trace fossils of the Kropivnik Fucoid Marls. He followed the practice then of combining the fucoid-bearing succession with the underlying unit containing siliceous marlstones, as the Siliceous Marls. Later Kotlarczyk (1978) proposed separating the succession containing the siliceous marlstones from the overlying unit calling these units the Holovnia Siliceous Marls and the Kropivnik Fucoid Marls, respectively. Twenty one ichnospecies were mentioned by Książkiewicz (1977) as occurring in the Siliceous Marls, *Chondrites arbuscula* and *Sabularia rudis* being indicated as the most common.

Current opinion on the distribution of the Kropivnik Fucoid Marls and the Holovnia Siliceous Marls in the Skole Nappe suggests that either both units or only one of them occur at the sites where Książkiewicz recorded the trace fossils. Sixteen ichnospecies of the 21 reported by Książkiewicz (1977) from the Siliceous Marls were reported from the sites where the Kropivnik Fucoid Marls crop out. Five ichnospecies were mentioned by Książkiewicz as recorded in the Siliceous Marls without indication of locality. Eleven ichnospecies, i.e. *Sabularia simplex*, *S. rudis*, *S. tenuis*, *Buthotrepis* isp., *Chondrites aequalis*, *C. arbuscula*, *C. flexilis*, *C. intricatus*, *Muensteria geniculata*, *Gordia molassica*, *Helminthoida labirynthica* were reported from the area investigated in the present study.

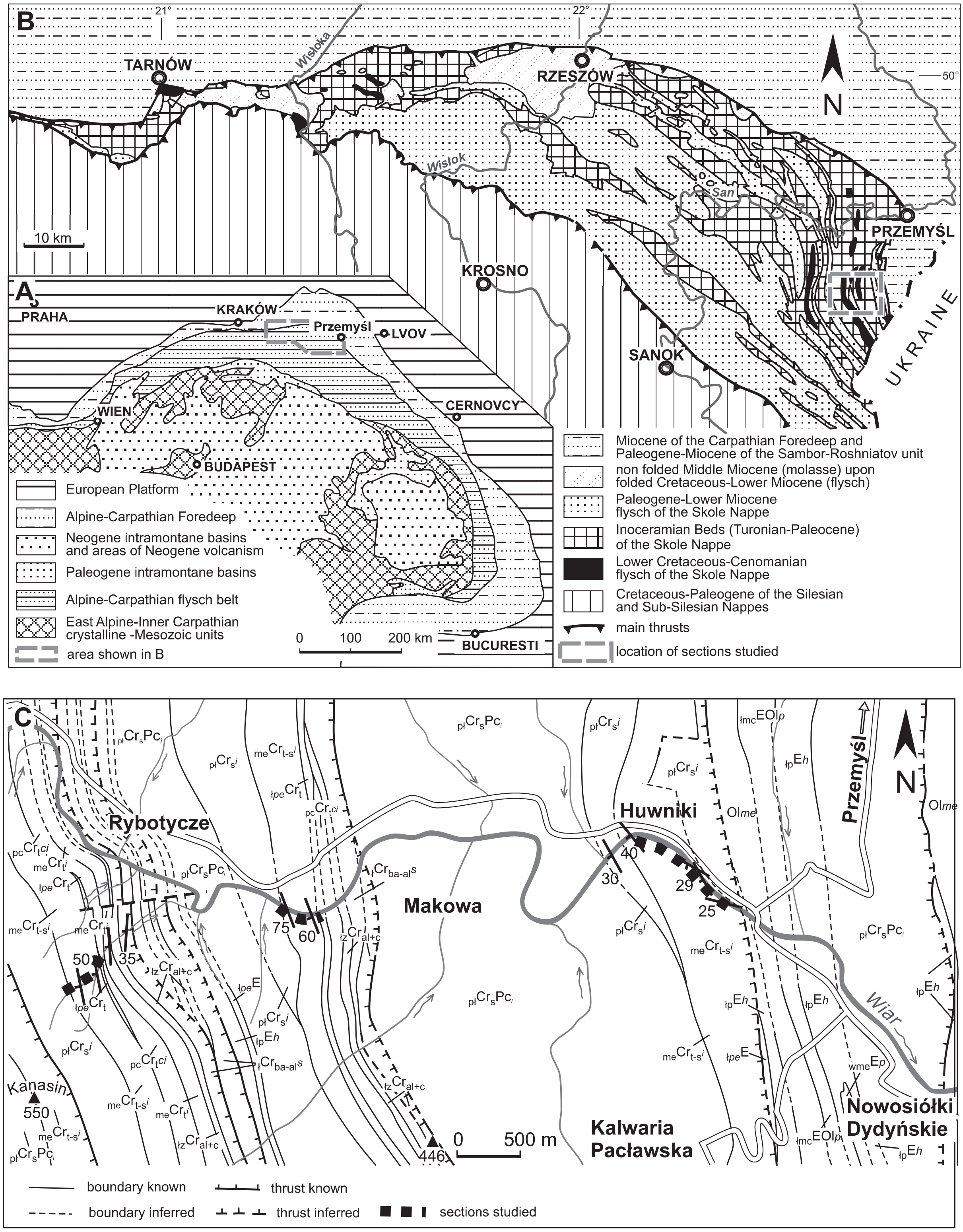

Fig. 1. Location of the exposures investigated

A — location of the Polish sector of the Skole Nappe within the Carpathian-Pannonian region, modified from to the map by Sandulescu (1988); **B** — location of the exposures investigated in the Polish sector of the Skole Nappe modified from the map by Żytko *et al.* (1989); **C** — location of the exposures investigated modified from the map by Gucik *et al.* (1989); $_{ł}Cr_{ba\text{-}al}{}^{s}$ — Spass Shales, Barremian-Albian; $_{łz}Cr_{al+c}$ — green, radiolarian shales, Albian+Cenomanian; $_{me}Cr_{t}{}^{i}$ — marlstones with intercalations of shales and sandstones, Siliceous Marls, Turonian; $_{pc}Cr_{t}{}^{ci}$ — sandstones, marlstones and shales, Cisowa Beds, Turonian; $_{łpe}Cr_{t}$ — variegated shales, Turonian; $_{me}Cr_{t\text{-}s}{}^{i}$ — marlstones with intercalations of shales and thin-bedded sandstones, Fucoid Marls, Turonian–Senonian; $_{pł}Cr_{s}{}^{i}$ — sandstones and shales with intercalations of marlstones, Ropianka Formation, Senonian; $_{pł}Cr_{s}Pc_{i}$ — thin- to thick-bedded sandstones and shales (locally olistholiths of Węgierka Marls) Inoceramian Beds (Ropianka Formation) undivided, Senonian; $_{łpe}E$ — variegated shales, Eocene; $_{łp}Eh$ — green shales and thin-bedded sandstones, Hieroglyphic Beds, Eocene; $_{wme}E_{p}$ — cream-yellow limestones and marlstones, Pasieczna Beds, Eocene; $_{łmc}EOl_{p}$ — shales and mudstones with outsized marlstone clasts, Popiele Beds, Eocene-Oligocene; Ol_{me} — menilitic shales, sandstones, cherts and marlstones, Menilitic Beds undivided

Some of the trace fossils reported from the Siliceous Marls in fact came from the Kropivnik Fucoid Marls, as reported by Uchman (1998) while revising Książkiewicz's trace-fossil data. Uchman considered that the twenty one ichnospecies reported by Książkiewcz (1977) from the Siliceous Marls represent only 17 ichnospecies. Only three ichnospecies (*Chondrites intricatus*, *Zoophycos insignis* and *Helminthopsis abeli*) retain the names given by Książkiewicz. The eleven ichnospecies noted by Książkiewicz from the area investigated here represent eight ichnospecies in the Uchman's classification. Uchman considered that, of the ichnotaxa reported by Książkiewicz from this area, *Sabularia simplex* represents *Ophiomorpha annulata*, *Sabularia rudis* represents *Ophiomorpha* isp., *Sabularia tenuis* represents *Arthrophycus tenius*, *Chondrites aequalis* and *C. flexilis* represent *C. intricatus*, *C. arbuscula* represent *C. targionii*, *Muensteria geniculata* represents ?*Taenidium* isp., *Gordia molassica* represents *Gordia marina*, and *Helminthoida labirynthica* represents *Nereites irregularis*. *Buthotrepis* isp. was not considered by Uchman as Książkiewicz neither described nor illustrated it.

New data regarding the bioturbation patterns and trace fossil assemblages in the Kropivnik Fucoid Marls emerged in the present study from exposures at Huwniki and between Makowa and Rybotycze (Fig. 1). The sedimentary structures resulting from the activity of organisms are collectively referred to as bioturbation structures in the rest of this paper (*cf.* Frey and Wheatcroft, 1989). They are divided into biodeformation structures (Schäfer, 1956) and trace fossils. Structures which display indistinct, highly irregular outlines and non-repeating patterns, resembling swirls of sediment, are included within biodeformation structures whereas these showing sharp, regular outlines and morphologically recurrent patterns are regarded as trace fossils.

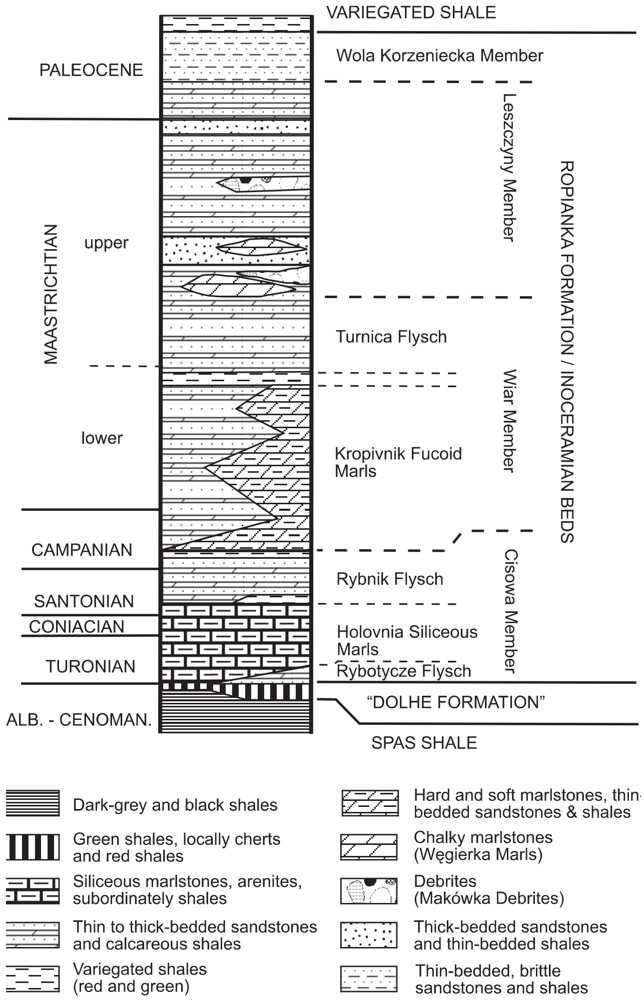

Fig. 2. Generalised stratigraphic log of the Albian–Paleocene of the Skole Nappe of the Polish Carpathians, slightly modified after Kotlarczyk (1988)

LOCALITIES AND METHODS OF STUDY

The study area is located in the eastern part of the Polish Carpathians, some 25–30 km to the south of Przemyśl, and several kilometres to the west of the Poland-Ukraine frontier. The exposures investigated are in the bed of the River Wiar and on the southern slope of the Wiar valley in Huwniki (the Huwniki section) and between Rybotycze and Makowa (the Wiar section), as well as in a creek entering the River Wiar from the south at the eastern end of Rybotycze (the Dolinka section). These exposures show the whole succession of the Kropivnik Fucoid Marls in three separate sections, although only parts of the upper part of the succession at Huwniki are exposed.

Bioturbation structures were analysed on bedding surfaces and in cross-section in the best exposed parts of the succession and in loose fragments. Specimens of all rare structures and well-preserved common structures were collected, and were additionally investigated in the laboratory. The lower part of the Huwniki section provided the best exposures. Cross-sections of individual beds are exposed along many metres, while much material occurs as fragments in scree. This part of succession was also the most thoroughly investigated. The specimens are deposited in the Geological Museum, Institute of Geological Sciences, Jagiellonian University, collection number UJ 177P.

GEOLOGICAL CONTEXT

The Kropivnik Fucoid Marls represent a part of continuous Cretaceous–Lower Miocene succession of deep-water, siliciclastic flysch sediments of the Skole Nappe of the Polish Carpathians. Sedimentation took place in a trough-type deep sea basin (the Skole Trough) bordered to the north by the passive margin of the European Platform and by a submarine ridge (the Sub-Silesian ridge) to the south and south-west. The Sub-Silesian ridge separated the western segment of the Skole Trough from the remaining part of the Carpathian Flysch Basin (Carpathian Flysch Sea). The study area lies in the outer part of the Skole Trough. Its eastern segment was apparently located on the trough slope or at the base of the slope.

The Kropivnik Fucoid Marls was introduced by Kotlarczyk (1978) as an informal lithostratigraphic unit representing the middle part (Wiar Member; Campanian–lower Maastrichtian) of the Ropianka Formation (former Inoceramian Beds;

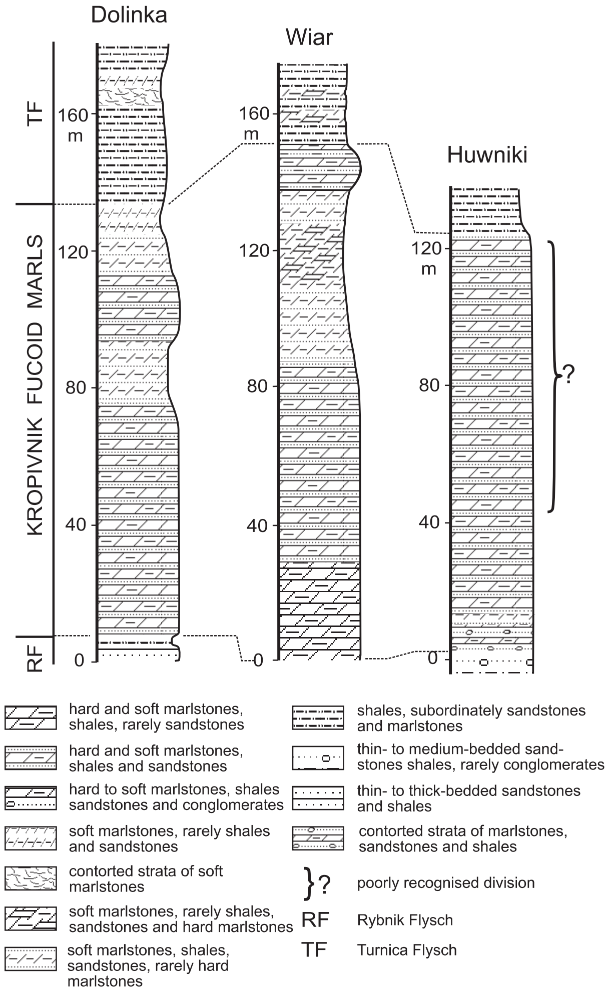

Fig. 3. Generalised lithofacies logs of the sections studied, modified after Leszczyński *et al*. (1995)

Fig. 4. Vertical lithological changes in the lower part of the Huwniki section

Light-coloured beds represent layered hard marlstone consisting of several *ca*. 1 cm thick layers showing normal grading; gray layers represent sandstone, granule conglomerate and soft marlstone and shale beds; ski-stick 1.1 m long for scale

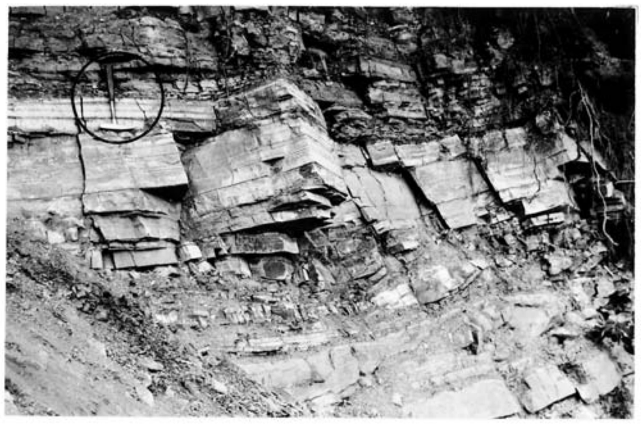

Fig. 5. Large-scale rhythmic package dominated by hard marlstone, underlain and overlain by packages consisting of sandstone, soft marlstone and shale beds; note gradual transitions to both underlying and overlying packages; lower part of Huwniki section; hammer 35 cm long for scale

Turonian–Paleocene; Figs. 1 and 2). Cream-yellow, beige and grey, thin-bedded, hard and soft marlstones interbedded with green to dark green and grey to dark grey muddy to clayey shales and mainly thin-bedded sandstones are characteristic of this 130–170 m thick unit (Kotlarczyk, 1978). Marlstones containing 14–65% carbonates, mainly $CaCO_3$, as suggested by Leszczyński *et al.* (1995) constitute as much as 70% of the succession and the lutites, i.e. marlstones together with shales, as much as 90%. Marlstones, particularly their hard variety, are concentrated in the lower part of the succession and disappear gradually upwards. Sandstones and shales dominate some parts of the succession. Individual, usually thin beds of granule to cobble conglomerates occur locally. The succession wedges gradually out toward the basin centre (Kotlarczyk, 1978, 1985). The rocks occur here in normally graded rhythmic sharp-based units. The basal parts of these comprise sandstone, siltstone or mudstone, rarely granule to pebble conglomerate, grading upwards into marlstone or muddy shale. Except locally in the lower part of the succession, the shale at the top of rhythmic units is always calcareous. Individual units dominated by marlstone are normally less than several centimetres thick, whereas those dominated by sandstone are mainly 5–20 cm thick and normally do not exceed 30 cm. The succession also displays larger-scale rhythmicity.

The sandstones show structures corresponding to the $T_{(a)bc}$ divisions of the Bouma sequence, the siltstons show $T_{(c)d}$ structures, whereas the marlstones correspond to the $T_{(d)e,}$ divisions and the shales to $T_{(d)e}$ (Leszczyński *et al.*, 1995). Facies C2.3 and D2.1 of the classification scheme of Pickering *et al*. (1986) predominate.

These sedimentary structures and patterns indicate sedimentation of the Kropivnik Fucoid Marls mainly by turbidity currents. Turbidite mudstones occur chiefly where marlstones are lacking. The shale at the unit tops corresponds to the Te_p division and seems to represent background sediment (pelagite/hemipelagite). Its significant carbonate content indicates sedimentation mainly above the calcite compensation depth (Leszczyński *et al.*, 1995).

The Kropivnik Fucoid Marls are underlain by the Kanasin Bed, several metres thick layer of red shales caled Kanasin Bed, or grades both downwards and upwards into thin- to thick-

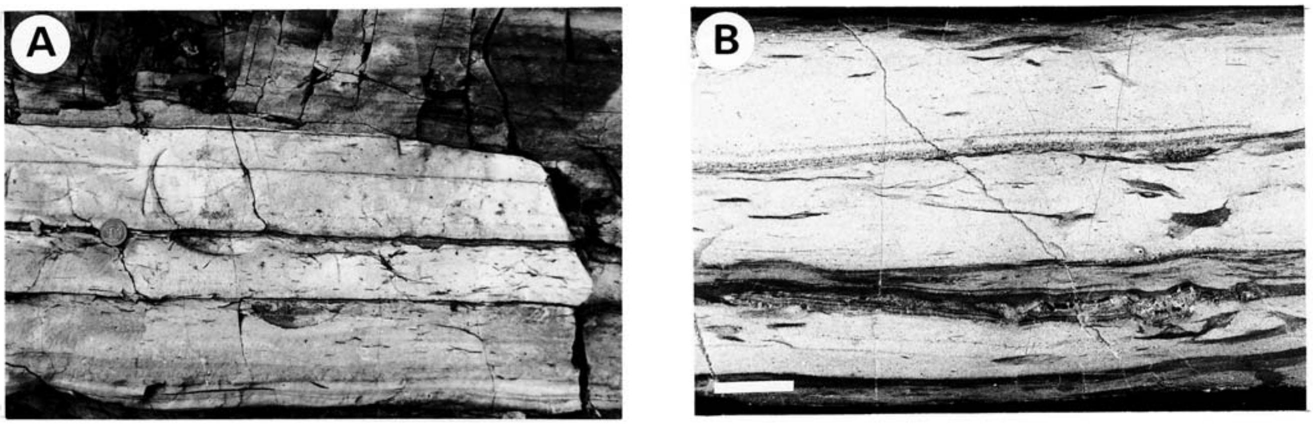

Fig. 6. Hard marlstone beds consisting of packages of normally graded layers

A — four layers of normally graded deposits dominated by hard marlstone; the uppermost layer is overlain by fine-grained sandstone (Bouma division T_b); dark grey streaks visible in whitish background are bioturbation structures; note that bioturbation structures are most numerous in the middle layer which is overlain by a thick dark grey layer of shale; lower part of Huwniki section; coin (14 mm in diameter) for scale; **B** — five layers of marlstone; the three thick layers show distinct normal grading; the number of bioturbation structures increases upwards within the two thickest layers; lower part of Wiar section; white bar represents 1 cm

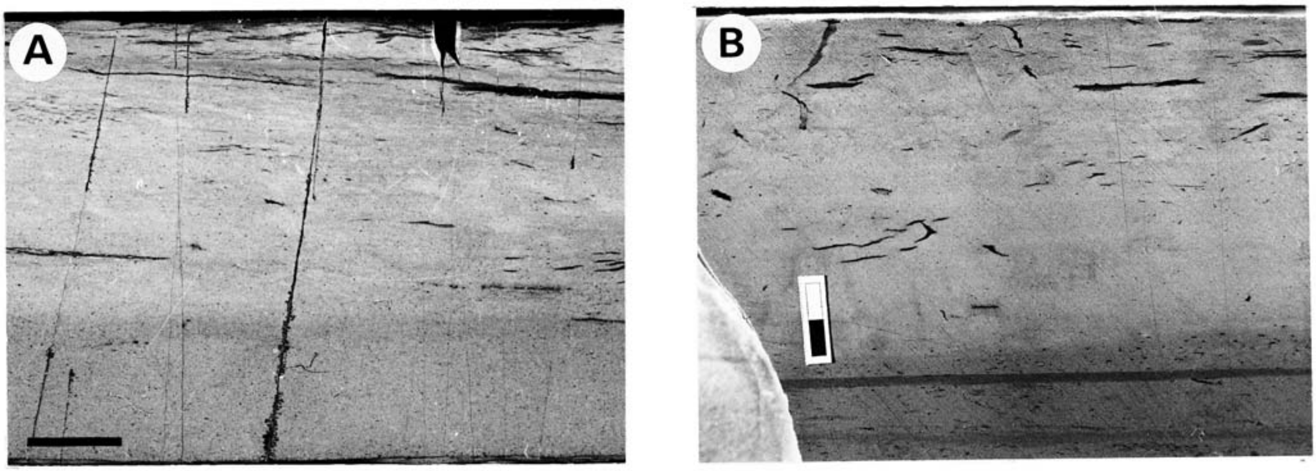

Fig. 7. Typical layers of hard marlstone showing normal grading

A — unit starting with siltstone (grey) which grades upward into hard marlstone (light grey); hard marlstone grades to soft marlstone (1 cm below unit top) and further to dark grey shale (dark in photo) in the top part of the unit; note increasing upwards number of burrows (dark dots and streaks); lower part of Wiar section; black bar represents 1 cm; **B** — unit starting with laminated siltstone (grey) grading upward to marlstone (light grey); number of burrows increases upwards; lower part of Huwniki section; scale bar 1 cm

bedded sandstones interbedded with shales termed the Rybnik Flysch and the Turnica Flysch, respectively (Kotlarczyk, 1978). This unit is known from a large area of the Skole Nappe, including its Ukrainian and Romanian sectors (Golovninskaya and Stryiskaya Svita, Hangu Beds; Kotlarczyk, 1978).

The Kropivnik Fucoid Marls in the sections investigated are 130–150 m thick (Leszczyński *et al.*, 1995; Fig. 3). Their upper boundary in particular, though is questionable. All facies associations and rhythmicity characteristic of this unit in general occur also in the sections in question (Figs. 4–7). However, the sections differ in the proportion and distribution of particular rock types. Hard marlstones occur chiefly in the lowest 80 m of the succession in all three sections. They frequently occur in beds consisting of several more or less distinctive, normally graded layers, usually 1–5 cm thick (Fig. 8). The layers start with a lamina or several laminae of fine sand or silt which grades upwards to a massive marlstone. The latter is frequently overlain by a mm-thick lamina of clayey or muddy shale (Figs. 6B and 7A).

Isolated thin beds of indistinctly layered hard marlstone occur in the lower part of the succession. The marlstone displays irregularly shaped dark-coloured spots and streaks of bioturbation structures and partly preserved 1 mm-thick dark-coloured primary laminae 5 mm to 2 cm apart (Fig. 8B). Similar features are displayed by the soft marlstones and marly shales, which occur in packages up to several metres thick in the upper part of the succession, particularly in the Dolinka section.

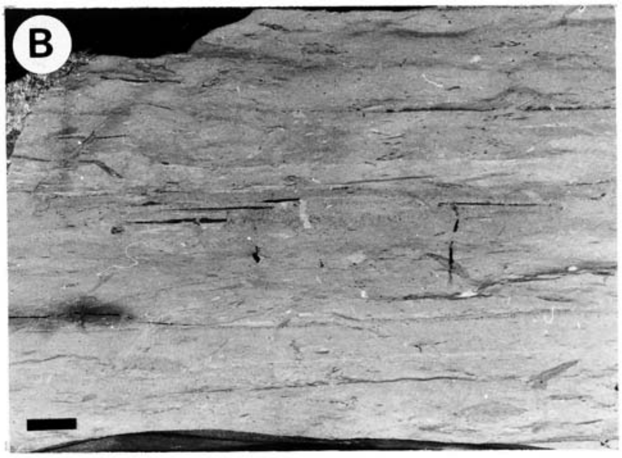

Fig. 8. Variability of structure of marlstone beds

A — distinctively layered marlstone consisting of a set of marlstone layers (light) separated by laminae of shale (dark grey) and sandy or silty (grey) sediment; note variability in distribution of burrows (dark grey dots, spots and streaks); lower part of Wiar section; black bar represents 1 cm; **B** — indistinctly layered marlstone showing chaotic structure emphasized by bioturbation; indistinctive layering is displayed by partly preserved thin, dark grey, parallel-laminae; lower part of Wiar section; black bar represents 1 cm

The sandstones occur here mainly in beds up to 10 cm thick. Thicker beds, reaching 40 cm, are most frequent in the Dolinka section. Sandstones and shales prevail over marlstones in packets metres to several tens of metres thick (Fig. 3). The sandstones, which occur in beds thicker than 5 cm, are composed basically of siliciclastic material (Bromowicz, 1974) and pass upwards into muddy shale or soft marlstone.

Disrupted and distorted units up to 1.3 m thick, occur in the lower part of the succession in the Huwniki section and in the upper part of the Dolinka section, while several beds of granule to cobble conglomerates occur in the lower part of the Huwniki section. Some marlstone beds in the lower part of the succession, particularly in the Huwniki section, show intense disruption (Fig. 9).

BIOTURBATION STRUCTURES

GENERAL ASPECTS

Bioturbation structures are recorded mainly on the soles and tops of sandstone and siltstone beds, on tops of marlstone beds in units where marlstones are overlain by shale, and within the marlstone beds (Figs. 6–9). The structures are generally more common in packages containing distinctive sandstone beds and where the marlstones are overlain by at least several millimetres of shale. In cross-section, bioturbation structures appear mainly in marlstones. The abundance of burrows in individual beds thicker than 5 cm increases upwards whereas in the thinner beds it tends to be constant (Figs. 6 and 7; *cf.* Leszczyński *et al*., 1995). Trace fossils are rare or even absent in the marlstone beds, which occur in the normally graded rhythms where shale is lacking. Burrows disappear at depths greater than 7 cm below unit tops.

Structures in the form of different size, straight to curved stripes, irregular spots, and branching, plant-like patterns, traditionally called fucoids (*cf.* Fu, 1991) are the most common on bedding-parallel surfaces in marlstone, and on surfaces separating marlstone from the overlying shale as well as these separating siltstone from marlstone or shale. All these structures are built of grey material resembling that of the overlying shale. Simple structures in the form of differently sized knobs and flattened, straight to curved, differently branching ridges of different size are recorded on the lower surfaces of sandstone and siltstone beds. These structures (hypichnia) usually represent semirelief casts of pre-depositional burrows (Seilacher, 1953, 1962), whereas these within beds (endichnia) represent flattened full relief structures. The post-depositional burrows preserved in full relief on soles of sandstone and siltstone beds were recorded only in graded units less than 10 cm thick. The most abundant bioturbation structures on sandstone and siltstone soles occur in beds underlain by shale.

Dark-coloured, strongly flattened spots, dash-like marks, thin, bedding-oblique regular to irregular, sometimes branch-

Fig. 9. Layered bed consisting of plastically deformed, normally graded, burrowed hard marlstone (light) grading into shale (thin, dark grey bedding-parallel laminae); lower part of Wiar section

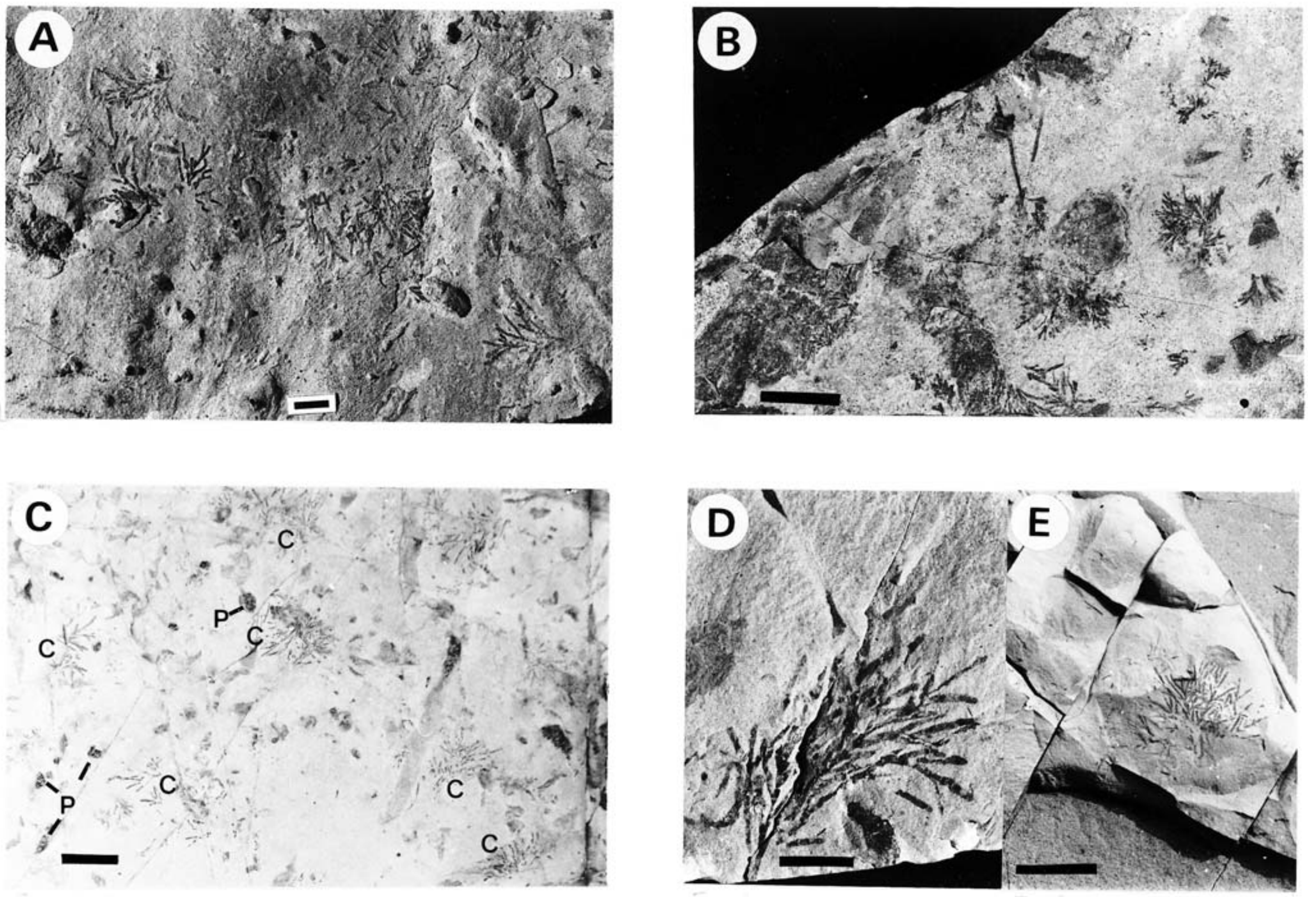

Fig. 10. *Chondrites intricatus*

A — full relief adherent to lower surface of sandstone bed; lower part of Huwniki section (UJ 177P2); scale bar represents 5 mm; **B** — full reliefs at upper surface of marlstone bed; lower part of Huwniki section (UJ 177P3); black bar represents 1 cm; **C** — full reliefs (c) at upper surface of marlstone bed; small, bedding-oblique burrows visible in cross-sections (p) represent *Planolites beverleyensis*; lower part of Dolinka section; black bar represents 1 cm; **D** — full relief at parting surface of marlstone bed, lower part Huwniki section (UJ 177P5); black bar represents 2 cm; **E** — full relief at parting surface of marlstone bed; lower part of Huwniki section; black bar represents 5 mm

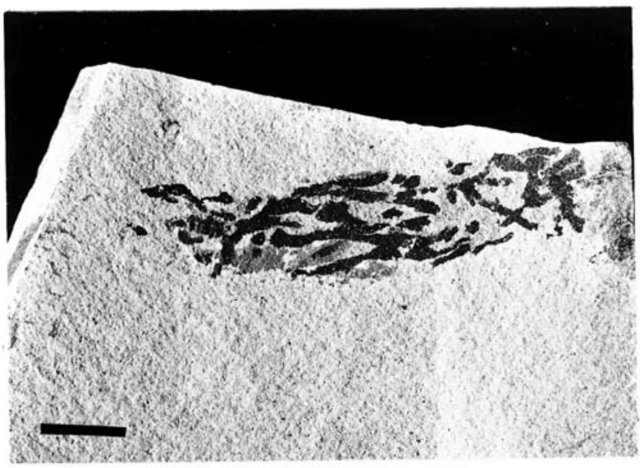

Fig. 11. *Chondrites intricatus* var. *Bandchondrites*

Endichnial full reliefs in a *Planolites*-type burrow within marlstone (UJ 177P6); lower part of Huwniki section; black bar represents 5 mm

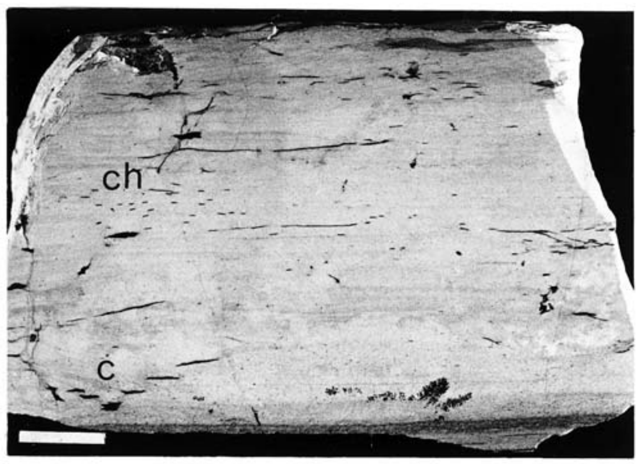

Fig. 12. *Chondrites intricatus* (ch) and *Cladichnus fischeri* (c)

Endichnial full reliefs in marlstone visible in section perpendicular to bedding (UJ 177P13); lower part of Huwniki section; black bar represents 1 cm

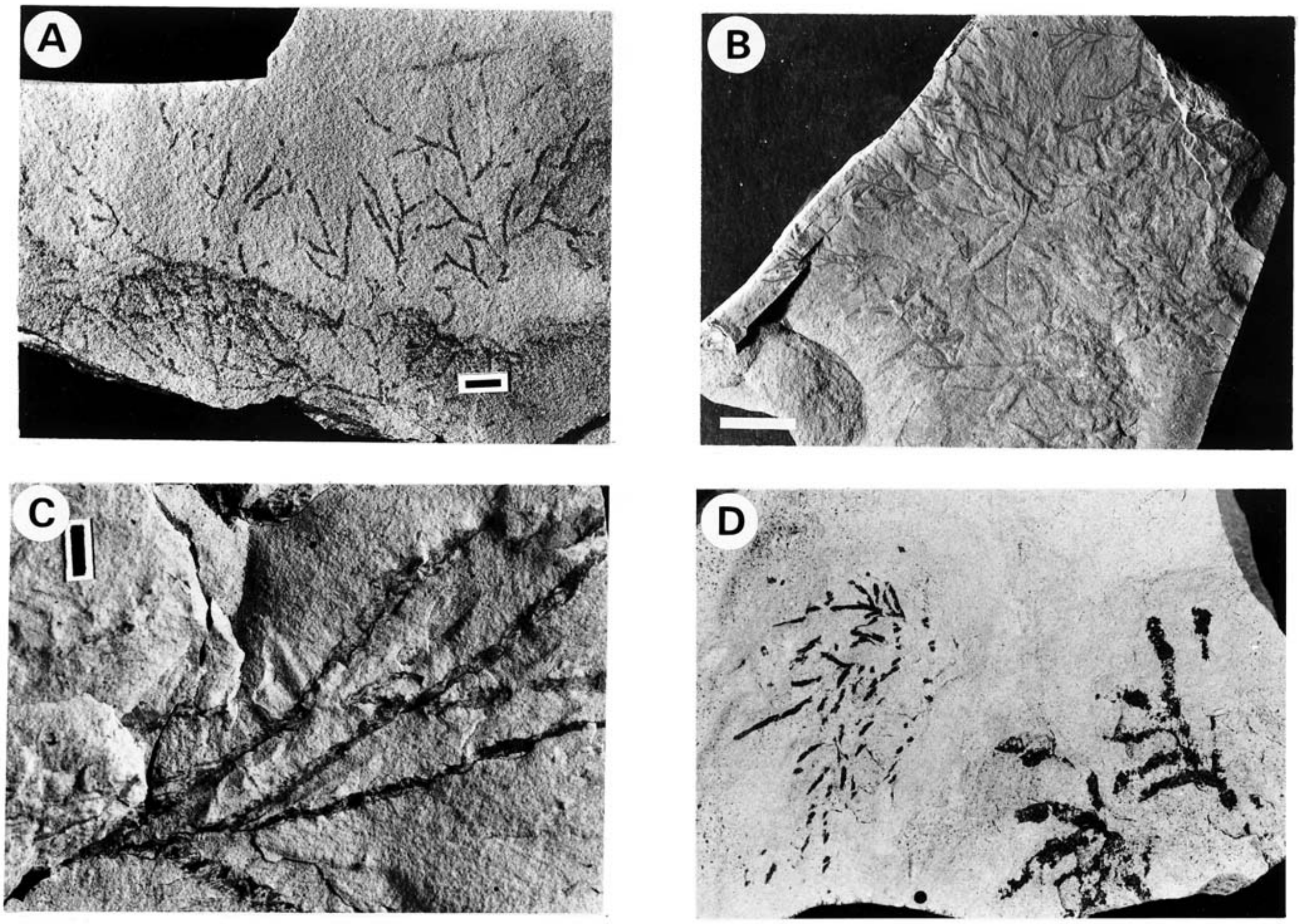

Fig. 13. *Chondrites targionii*; endichnial full reliefs; note differences in burrow sizes and patterns

A — specimen at parting surface in siltstone (T_b); middle part of Huwniki section (UJ 177P8); black bar represents 5 mm; **B** — specimen at parting surface in marlstone; white bar represents 2 cm; **C** — specimen at parting surface in marlstone showing intense, small-scale soft-rock deformation (UJ 177P10); lowermost part of Huwniki section; black bar represents 5 mm; **D** — two systems differing in burrow size (UJ 177P11); lower part of Huwniki section; black dot represents 1.5 mm

ing streaks, which occur separated or in clusters, are characteristic bioturbation structures seen in cross-sections of marlstone and siltstone beds. Such structures are concentrated in the top parts of marlstone beds. They are most frequent in beds overlain by shale (Fig. 7). Characteristically, the most distinct bioturbation structures in marlstones are filled with material mesoscopically similar to that forming the overlying shale. In contrast, in shales, burrows filled with marl are missing and distinct bioturbation structures are rare.

The bioturbation structures in marlstones appear to be represented also by irregular, poorly contrasting, spot-like structures resembling marble cake (Fig. 7). These correspond to the biodeformation structures of (Schäfer, 1956) and some mantle and swirl structures of Lobza and Schieber (1997). Structures of this type are particularly characteristic of the uppermost part of marlstone beds. They are visible mainly on breakage surfaces of wet rock and on polished surfaces.

Taxonomically determinable bioturbation structures are reasonably common in these rocks, mainly being chondritids (*cf.* Książkiewicz, 1977). Other taxa are recorded rarely or as individual specimens only. Most of the distinct bioturbation

Fig. 14. *Nereites irregularis* on top surface of sandstone bed; upper part of Wiar section (UJ 177P9); white bar represents 1 cm

structures comprise taxonomically indeterminat knobs, ridges, spots, dots and stripes of different size. The assemblage of bioturbation structures on the lower surfaces of sandstone beds becomes generally richer up the succession.

A total of 27 different ichnotaxa, including one new ichnospecies and seven forms of undetermined trace fossils were recognised in this study. Only nine ichnospecies of the 21 recorded from these rocks by Książkiewicz (1977) were found: *Chondrites aequalis*, *C. flexilis* and *C. intricatus* which all, according to the interpretations by Uchman (1998), may be assigned to *Chondrites intricatus* (Figs. 10–12, 18); *C. arbuscula* and *C. furcatus*, assigned here following Uchman (1998) to *C. targionii* (Fig. 13); *Helminthoida serrata* and *H. labyrinthica*, assigned here following Uchman (1998) to *Nereites irregularis* (Fig. 14); and *Muensteria geniculata*, assigned here, together with *Taphrhelminthopsis auricularis*, to *Scolicia ?plana* (see remarks in description of *Scolicia*).

These ichnotaxa in general resemble those described by Książkiewicz (1977). Except for chondritids, which occur throughout the succession, the other taxa are frequent only at certain levels. The chondritids occur in marlstones, at different depths relative to the bed top and up to 10 cm below it, and in transition zones from marlstone to underlying siltstone or sandstone. *Chondrites intricatus* tends to occupy deeper parts of beds than *Chondrites targionii*. The latter was most frequently recorded in transition zones from marlstone or shale to underlying siltstone or sandstone, however, the maximum depth of its occurrence relative to bed tops is *ca.* 7 cm. The burrows are usually only 1–2 mm thick whereas those recorded elsewhere are thicker (3–7 mm see Uchman, 1999). *Chondrites targionii* usually occurs in the transitions from arenite to siltite, in intervals corresponding to the division T_d of turbidites. *Nereites irregularis* has been recorded in the upper part of the succession, mainly in packages impoverished in marlstones, at tops of sandstone beds overlain by a several centimetres thick mudstone. In one sandstone sample containing this trace fossil, an irregular ridge covered irregularly with pustules similar to the burrows included by Uchman (2001) within *Nereites missourriensis* Weller (cf. *Scalarituba missourriensis* Weller; D'Alessandro, 1980, pl. 38, fig. 4) occurs besides semirelief specimens of *Palaeodictyon strozzii* Menghini at the bed sole.

NEWLY RECORDED ICHNOTAXA

Bergaueria Parntl, 1945
Bergaueria ?hemispherica Crimes, Legg, Marcos and Arboleya, 1977
(Fig. 15)

1995 *Bergaueria hemispherica* Crimes, Legg, Marcos and Arboleya; Uchman, p. 10–11, pl. 2, figs. 4, 5.

Material. — 1 specimen collected (UJ 177P1); several observations in the field.

Diagnosis. — *Bergaueria* lacking a shallow, central depression (Pemberton *et al.*, 1988).

Description. — Hypichnial mound on lower surface of sandstone beds, with hemisperical termination, oval in outline,

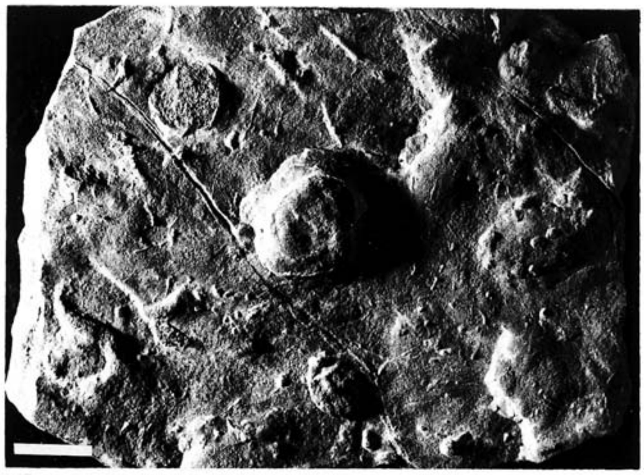

Fig. 15. *Bergaueria ?hemispherica*

Hypichnial cast of a vertical domichnial or cubichnial burrow; lower surface of sandstone bed; upper part of Wiar section; white bar represents 2 cm

24 mm long, 18 mm wide, and 10 mm high, filled passively with sand.

Remarks. — The trace fossil is pre-depositional and represents the cast of a vertical hollow. It can represent domichnia or cubichnia of shallow burrowers or casts of washed upper part of deeper vertical burrows.

Chondrites von Sternberg, 1833
Chondrites ?recurvus (Brongniart, 1823)
(Fig. 16)

1991 *Chondrites recurvus* (Brongniart); Fu, p. 19–21, pl. 2, fig. E.
1999 *Chondrites recurvus* (Brongniart); Uchman, p. 93, pl. 5, fig. 6.

Material. — One specimen with a fragment of one burrow system recorded and collected (UJ 177P7).

Diagnosis. — A system of tunnels in which branches arise only on one side of the masterbranch and which are all

Fig. 16. *Chondrites ?recurvus*

Endichnial full relief in marlstone bed (UJ 177P7); lower part of Huwniki section; black bar represents 5 mm

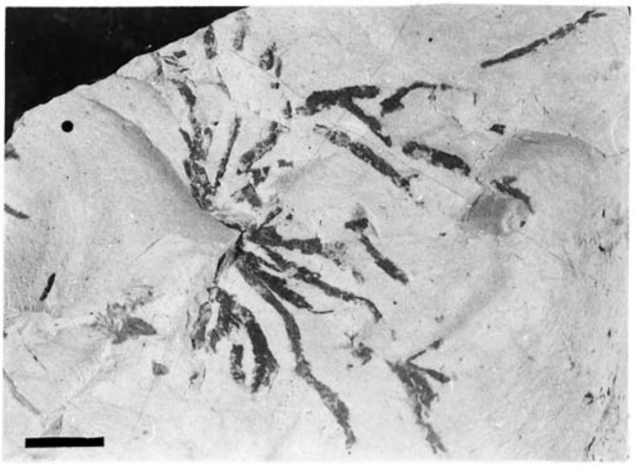

Fig. 17. *Chondrites* isp.

Endichnial full relief in marlstone; lower part of Huwniki section (UJ 177P12); view of lower surface of specimen; black bar represents 1 cm

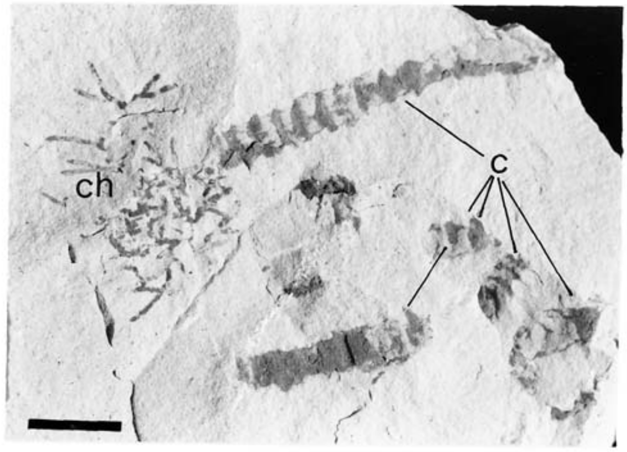

Fig. 18. *Chondrites intricatus* (ch) and *Cladichnus fischeri* (c)

Bedding-parallel to slightly oblique, endichnial full reliefs in marlstone (UJ 177P46); lower part of Huwniki section; black bar represents 1 cm

curved in one direction or in a lyre-shape into two, bilaterally opposed directions. There are commonly one or two orders of branching, rarely a third (Fu, 1991).

D e s c r i p t i o n . — A burrow system consisting of a masterbranch from which second-order branches and third-order branches arise in one direction and all appear to be curved towards the termination of the masterbranch. The termination of the masterbranch curves toward the second order branches. Burrows 2.2 mm wide with crudely regular outline, filled with dark grey mud. The burrow system occurs in a marlstone bed.

R e m a r k s . — The described specimen corresponds with *Chondrites recurvus*, although it represents only a fragment of a larger system whose features remain unknown.

Chondrites isp.
(Fig. 17)

M a t e r i a l . — One specimen recorded and collected (UJ 177P12).

D e s c r i p t i o n . — Horizontal to slightly oblique, endichnial burrow system consisting of a bunch of slightly winding, strongly flattened burrows 1–1.5 mm wide radiating from one point. Some burrows show Y-shaped second-order branching. The second-order branches are oriented downwards relative to those of the first order.

R e m a r k s . — The system is moderately preserved. The second-order branching is visible in full only in one case. The system appears to display a branching pattern similar to the burrow system called *Chondrites* isp. by Fu (1991), although the Polish burrows do not show neither distinctive notches nor serrate margins. Uchman (1998, fig. 21) included a similar system of burrows found in the Huwniki section within *Chondrites targionii*.

Cladichnus D'Alessandro and Bromley, 1987
Cladichnus fischeri (Heer, 1877)
(Figs. 12 and 18)

1958 *Taenidium fischeri* Heer; Seilacher, p. 1072, tab. III, fig. 48.
1999 *Cladichnus fischeri* (Heer); Uchman, p. 111–112, pl. 12, fig. 2.

M a t e r i a l . — 3 specimens collected (UJ 177P13, 177P32, 177P46).

D i a g n o s i s . — Radiating and primary successively branched *Cladichnus* (D'Alessandro and Bromley, 1987).

D e s c r i p t i o n . — Endichnial trace fossil composed of a system of moniliform horizontal to subhorizontal straight to arcuately elongated, strongly flattened burrows, lacking linings. The burrows are 6–8 mm wide, 0.5 mm thick in vertical section, filled with dark grey mud. Burrows of one system are distributed at different levels in the sediment.

R e m a r k s . — The structure was noted in partly preserved burrow systems only. A fragment of one branch only was found in one specimen (UJ 177P13, Fig. 21B). In the same specimen, the structure was recorded perpendicular to bedding (Fig. 12). It is marked here with dark grey dash-like marks distributed at several levels within the sedimentary unit.

Halopoa Torell, 1870
Halopoa imbricata Torell, 1870
(Fig. 19)

1998 *Halopoa imbricata* Torell; Uchman, p. 115, fig. 9.

M a t e r i a l . — 3 specimens collected (UJ 177P14, 177P15, 177P16); several observations in the field.

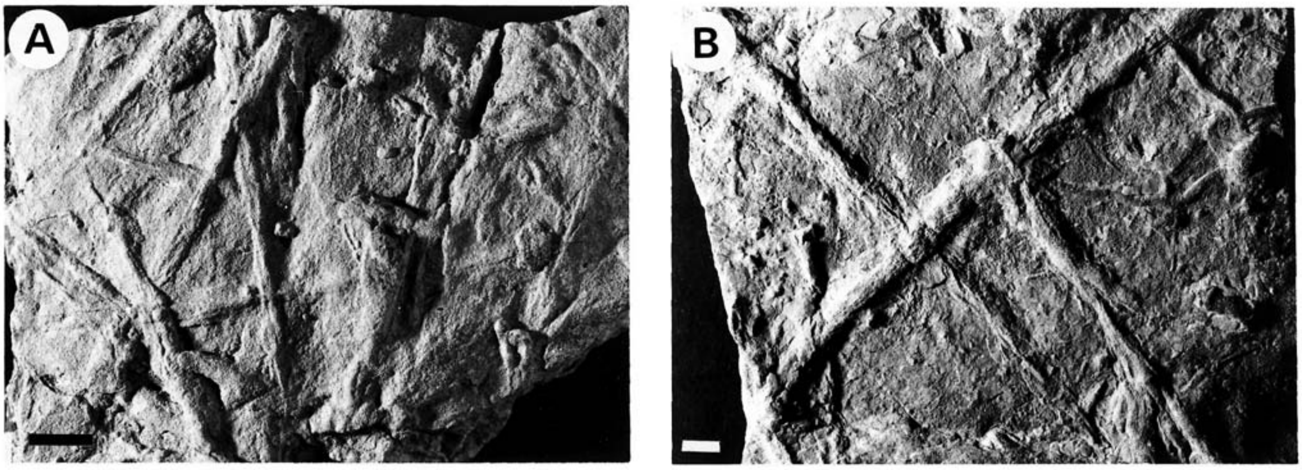

Fig. 19. *Halopoa imbricata*

Hypichnial semireliefs on lower surface of sandstone beds; upper part of Wiar section; **A** — specimen UJ 177P16; black bar represents 2 cm; **B** — specimen UJ 177P14; white bar represents 1cm

D i a g n o s i s . — Unbranched *Halopoa* with horizontal, relatively long and continuous furrows and wrinkles (Uchman, 1998).

D e s c r i p t i o n . — Hypichnial, straight, pre-depositional, long ridges, 8 mm in cross-section, showing more or less distinctive longitudinal, irregular, imperfectly overlapping wrinkles and furrows of different sizes. The ridges are inter crossing and interpenetrating.

R e m a r k s . — The burrows are recorded on soles of sandstone beds only, resting on grey shale, mainly in the upper part of the succession.

Ophiomorpha Lundgren, 1891
Ophiomorpha rectus (Fischer-Ooster, 1858)
(Fig. 20)

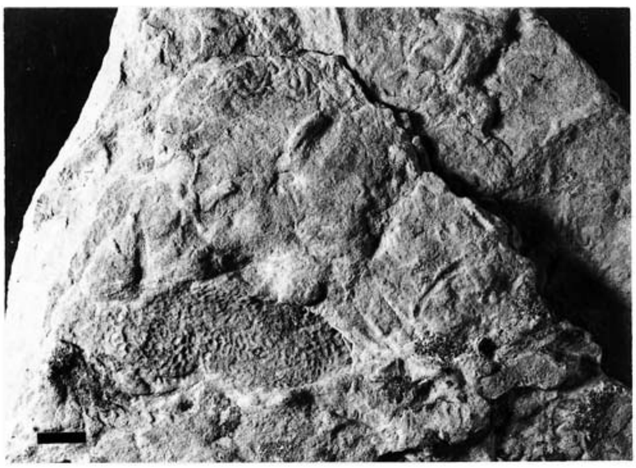

Fig. 20. *Ophiomorpha rectus*

Endichial form at parting plane in top part of sandstone bed; middle part of Wiar section (UJ 177P4); black bar represents 1 cm

1977 *Tubulichnium incertum* n. isp.; Książkiewicz, p. 143, pl. 11, fig. 14, text-fig. 29.
1998 *Ophiomorpha rectus* (Fischer-Ooster); Uchman, p. 126–128, fig. 26.

M a t e r i a l . — One specimen collected (UJ 177P4).

D i a g n o s i s . — Mostly horizontal, rarely branched, winding *Ophiomorpha* lined with very small muddy pellets (Uchman, 1998).

D e s c r i p t i o n . — Small fragment of a horizontal, curved, strongly flattened endichnial burrow, 20 mm wide, with one surface covered with tiny oval dents arranged in an irregular network, representing casts of pellets lining the burrow wall.

?*Ophiomorpha* isp.
(Fig. 21)

M a t e r i a l . — 1 specimen collected (UJ 177P13); several observations in the field.

D e s c r i p t i o n . — Straight to slightly curved, horizontal to vertical, endichnial, cylindrical, full-reliefs, 5–10 mm in cross-section, locally showing rare Y-shaped branching and thin muddy linings. The burrow outline is rough to smooth. The former is due to armouring of the burrow wall with grains 1–2 mm in size. Swellings occur in some burrow segments (Fig. 21A). The burrows are filled with coarse sand with grains up to 2 mm across. The fill in the largest burrows shows a faint meniscate structure. According to size and texture of fill they are similar to burrows distinguished here as *Palaeophycus* isp.

Paleodictyon Menghini in Savi and Menghini, 1850
Paleodictyon (*Glenodictyum*) *strozzii* Menghini, 1850
(Fig. 22)

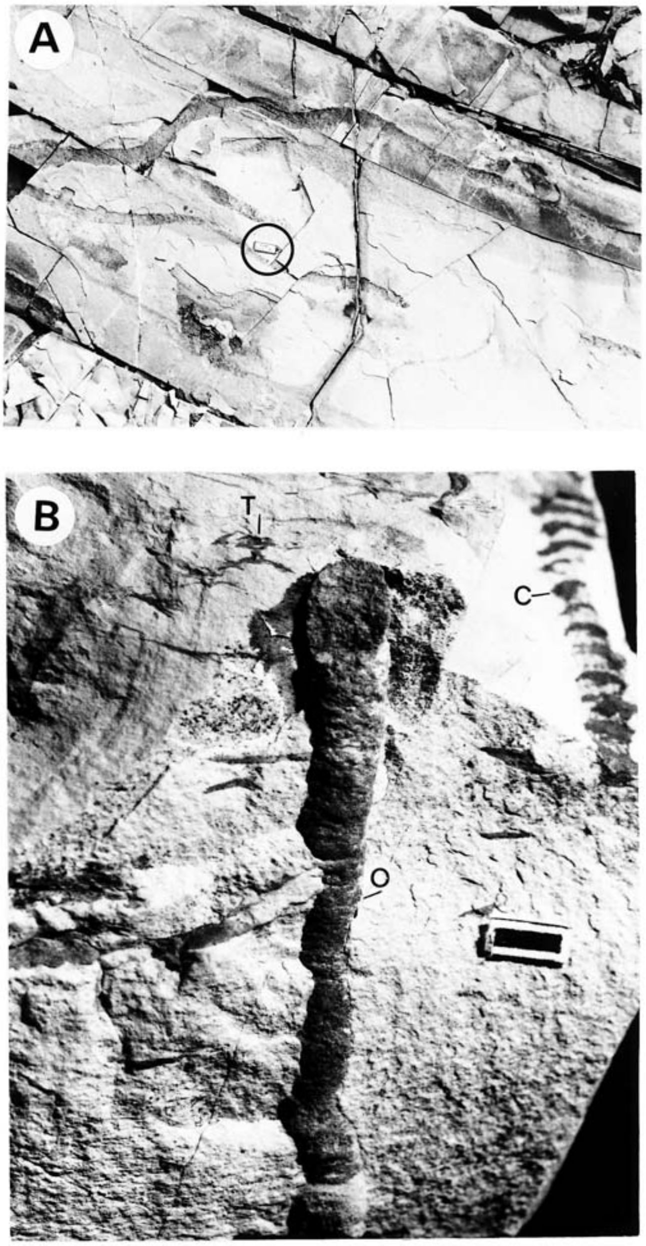

Fig. 21. ?*Ophiomorpha* isp.

Full reliefs from lower part of Huwniki section; **A** — specimens at parting surface in horizontally laminated siltstone (T_d); note differences in burrow size and two swellings in left sector of the lower burrow; scale encircled; **B** — full relief of vertical burrow (o) full relief of *Cladichnus fischeri* (c) and turbidichnus (T) in marlstone (UJ 177P13); scale bar represents 5 mm

1977 *Paleodityon carpathicum* Matyaszovsky; Książkiewicz, pl. 28, figs. 4, 5.
1995 *Paleodictyon strozzii* Menghini; Uchman, p. 53, pl. 14, fig. 7.

M a t e r i a l . — 2 specimens collected (UJ 177P7, UJ 177P18); several observations in the field.
D i a g n o s i s . — Small *Glenodictyum*, net 2–6 mm in size and 0.2–1.0 mm in string diameter (Uchman, 1995).
D e s c r i p t i o n . — Networks as in diagnosis, locally with slightly larger mesh size. All specimens except for one represent semireliefs of partly preserved systems on lower surfaces of sandstone beds. A net-like structure appearing to consist of four meshes surrounded by strings preserved as full

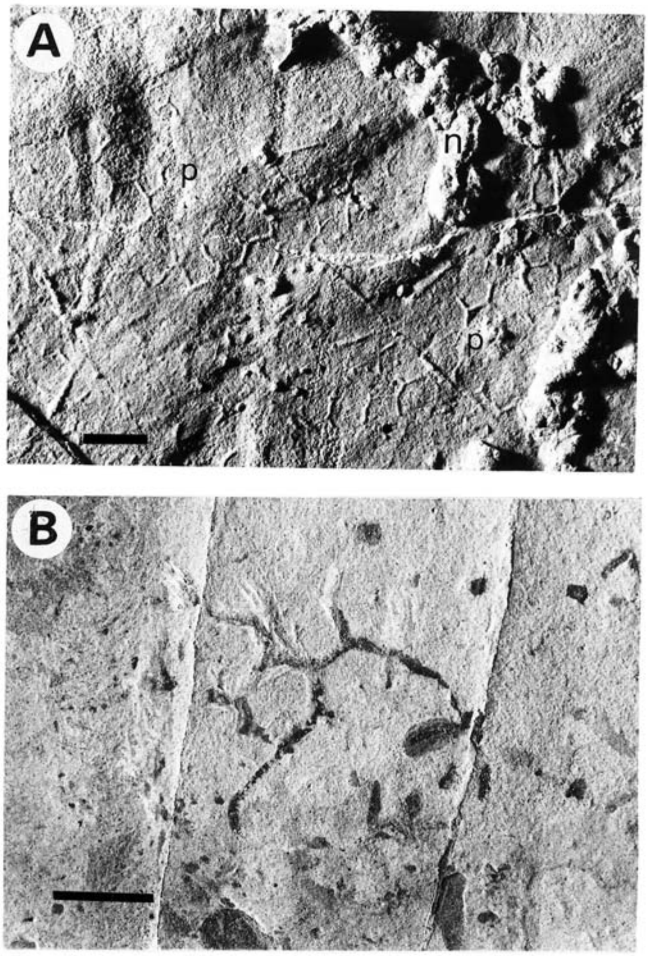

Fig. 22. *Paleodictyon strozzii*

A — semirelief (p) and full relief of ?*Nereites* isp. (n) on lower surface of sandstone bed; upper part of Wiar section (UJ 177P18); black bar represents 1 cm; **B** — full relief in transition zone from marlstone to shale; lower part of Huwniki section (UJ 177P7); black bar represents 5 mm

reliefs was found in one specimen in a marlstone-shale transition (Fig. 22B).
R e m a r k s . — All specimens except for the supposed full relief were found in the upper part of the succession.

Palaeophycus Hall, 1847
?*Palaeophycus* isp.
(Fig. 23)

M a t e r i a l . — 2 specimens collected (UJ 177P17, UJ 177P48).
D e s c r i p t i o n . — Straight to slightly curved, horizontal, endichnial, cylindrical, full-reliefs, 10–25 mm wide, showing distinctive muddy linings which are thicker in the lower parts of burrows and tend to disappear in the upper parts of burrows (Fig. 23B). The burrows are filled with coarse sand with grains up to 2 mm across. According to fill, they resemble burrows grouped

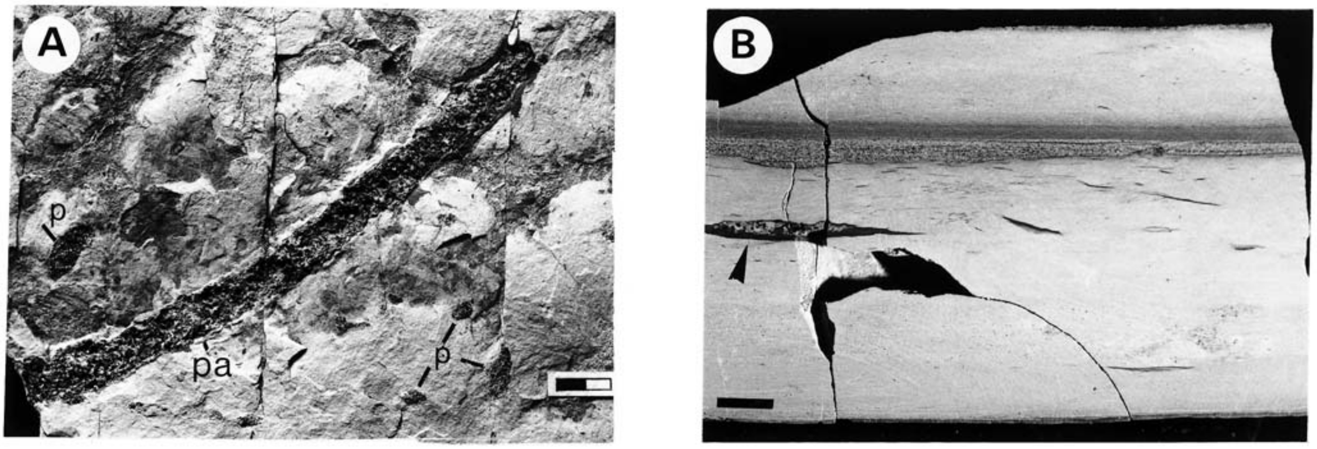

Fig. 23. *Palaeophycus* isp.

A — horizontal full relief of burrow (pa) in marlstone (UJ 177P17); lower part of Huwniki section; note large amount of coarse grains in burrow fill; muddy lining of burrow wall is visible in some places; small, bedding-oblique burrows visible in cross-sections (p) represent *Planolites beverleyensis*; scale bar (black-white couple) represents 1 cm; **B** — vertical section of burrow (arrowed); note disappearance of lining in upper part of burrow (UJ 177P48); lower part of Huwniki section; black bar represents 1 cm

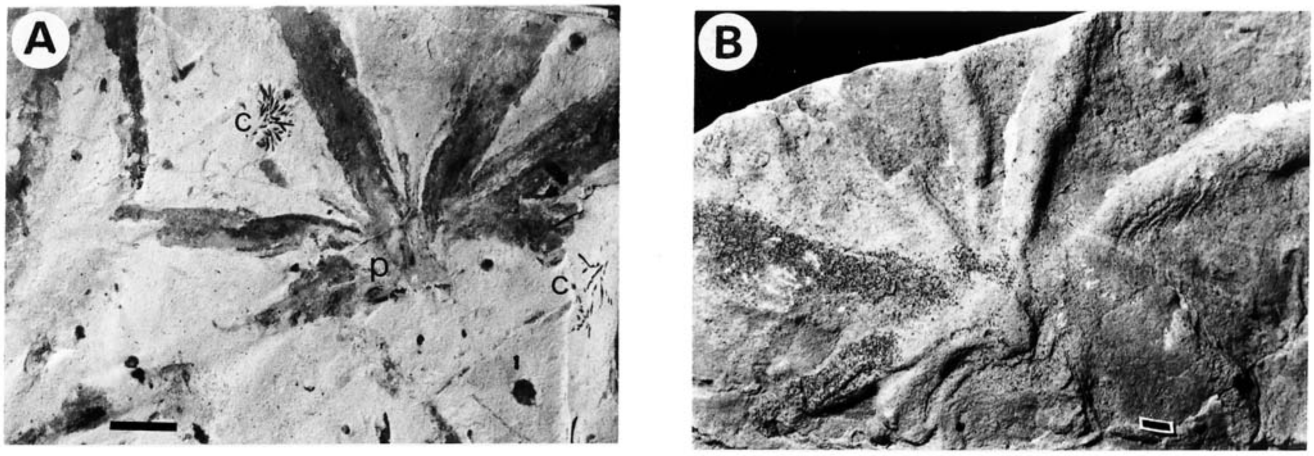

Fig. 24. *Phycodes* isp. A (p);

A — endichnial relief in upper part of marlstone layer; note two clusters of tiny *Chondrites intricatus* (c); lower part of Huwniki section (UJ 177P20); black bar represents 1 cm; **B** — semirelief on lower surface of sandstone bed; middle part of Wiar section (UJ 177P19); black bar represents 5 mm

here into ?*Ophiomorpha* isp. In fact both burrow types look alike when only their upper part is visible in plan view.

Phycodes Richter, 1850
Phycodes isp.
(Fig. 24)

M a t e r i a l. — 2 specimens collected (UJ 177P19, 177P20).
D e s c r i p t i o n. — A branched structure consisting of several burrows branching outwards from one point in a palm-like pattern. The burrows are *ca*. 5 cm long, up to 0.8 cm wide, somewhat superimposed, and diverge at different angles. Well-preserved burrow terminations are elliptically rounded.
R e m a r k s. — The structure is recorded in one specimen in strongly flattened full relief in the top part of a marlstone bed (Fig. 24A) and in one specimen in semirelief on the undersurface of a sandstone bed (Fig. 24B). The former has burrows filled with dark grey mud. Burrows are only 1 mm thick in vertical section. The small thickness of burrows relative to their width suggests that they were very loosely filled with sediment. The morphology of branches in the specimen preserved in semirelief indicate that their terminations result from curving upwards as is characteristic for *Phycodes* igen.

Phymatoderma Brongniart, 1849
Phymatoderma penicillum Uchman, 1999
(Fig. 25)

1999 *Phymatoderma penicillum* n. isp.; Uchman, p. 114, pl. 13, fig. 3.

M a t e r i a l. — 2 specimens collected (UJ 177P21, UJ 177P49).

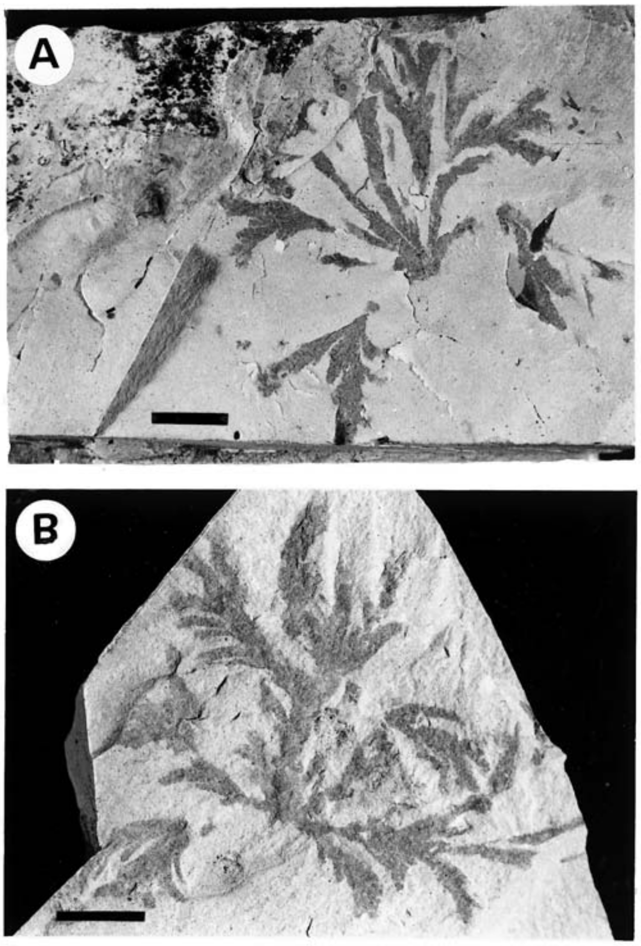

Fig. 25. *Phymatoderma penicillum*

Endichnial reliefs in upper part of marlstone bed; lower part of Huwniki section; **A** — specimen UJ 177P21; **B** — specimen UJ 177P49; black bar in both photographs represents 1 cm

D i a g n o s i s . — *Phymatoderma* with relatively sparsely packed, thin lobes in which most branches (probes) occur at distal parts. The distal parts of branches form paint brush-like structures (Uchman, 1999).

D e s c r i p t i o n . — Endichnial structure composed of 8 fan-like branched lobes in one specimen (Fig. 25A) and 4 in the second one (Fig. 25B). The lobes in one specimen are *ca*. 2 mm wide in their proximal part and as much as 5–10 mm across in their distal part. The second specimen is slightly different. The lobes display branching over their whole length and are more ragged than in the former specimen. The burrow fill shows faint granulation, which is most distinctive along the burrow outline. The diameter of the whole burrow system is 5 cm in both specimens.

R e m a r k s . — Both specimens occur in upper parts of marlstone beds. The burrow fill is darker than the surrounding sediment. The specimen illustrated in Figure 25B might represent a different ichnospecies.

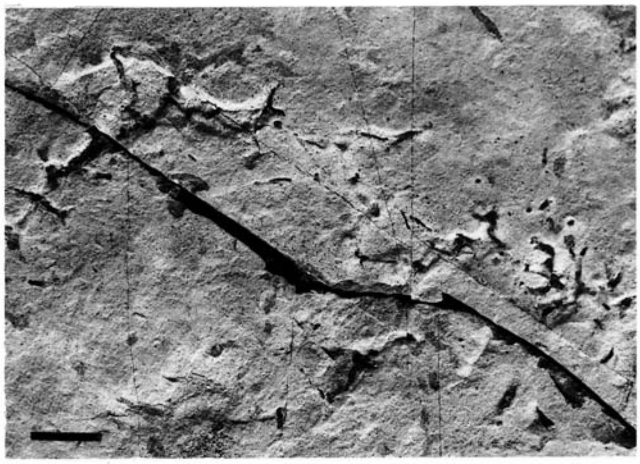

Fig. 26. ?*Pilichnus* isp.

Bedding-parallel full relief at passage from siltstone to overlying marlstone (UJ 177P22); lower part of Huwniki section; black bar represents 5 mm

Pilichnus Uchman, 1999
?*Pilichnus* isp.
(Fig. 26)

M a t e r i a l . — 3 specimens collected (UJ 177P22, 177P23, 177P44); several observations in the field.

D e s c r i p t i o n . — System of horizontal, curved, thread-like, unwalled full reliefs, densely dichotomously branched. Branches are only 1–2 mm long. The entire system shows some similarity to a system of plant roots, to *Protopaleodicton spianata* (Geinitz) burrows (e.g. Uchman, 1998, fig. 102) and in some cases to *Chondrites intricatus*. The threads consist of dark grey pyritized mud or limonite.

R e m a r k s . — This was recorded, densely distributed in the lower part of a marlstone layer grading to the underlying silty lamina. The system differs from the specimens of *Pilichnus* described in the literature in the greater thickness of burrows and in the shorter branches.

Planolites Nicholson, 1873
Planolites beverleyensis Billings, 1862
(Figs. 10C and 23A)

1998 *Planolites beverleyensis* Billings; Uchman, p. 121, fig. 16.

M a t e r i a l . — 1 specimen collected (UJ 177P17); many observations in the field.

D i a g n o s i s . — Relatively large, smooth, straight to gently curved or undulose cylindrical burrows (Pemberton and Frey, 1982).

D e s c r i p t i o n . — Horizontal to oblique, simple, straight to gently curved, unlined burrows strongly flattened to circular and elliptical in cross-section, 1.5–5 mm in diameter, filled with homogeneous material similar to that forming the

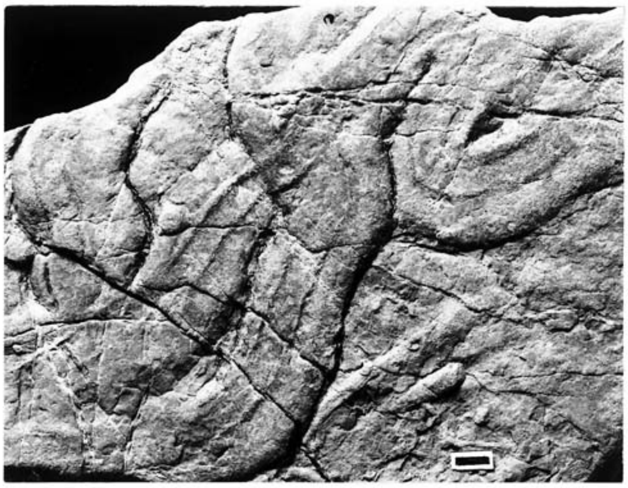

Fig. 27. *Scolicia ?plana*;

Hyporelief on lower surface of thin sandstone bed; upper part of Wiar section (UJ 177P24); scale bar 5 mm

Fig. 29. Indistinctly meniscate endichnial structure (arrowed) resembling *Scolicia ?plana* in winding style and width;

Horizontal section of burrow in marlstone; lower part of Huwniki section (UJ 177P26); black bar represents 5 mm

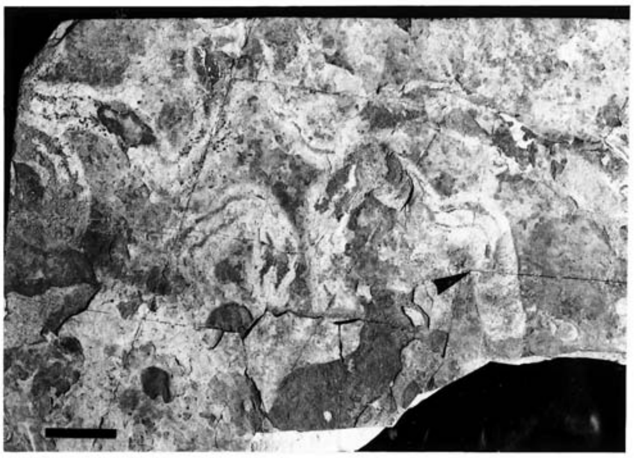

Fig. 28. *Scolicia ?plana*

Highly flattened form with segments showing uniserially meniscate fill (arrowed); burrow at contact of shale with overlying silty marlstone (UJ 177P50); lower part of Huwniki section; black bar represents 2 cm

overlying shale or sandstone. Horizontal burrows filled with muddy material are strongly flattened. In some specimens these burrows are reworked by *Chondrites intricatus* var. *bandchondrites*. They occur together with different ichnospecies, at different depth levels within the turbidite beds. Simple, flattened ridges of similar size as the endichnial forms which occur in semireliefs on soles of sandstone beds appear to represent the same ichnospecies.

Scolicia De Quatrefages, 1849
Scolicia ?plana (Książkiewicz, 1970)
(Figs. 27–29)

1977 *Subphyllochorda striata* Książkiewicz; Książkiewicz, p. 132–133, pl. 15, fig. 1.
1998 *Scolicia plana* (Książkiewicz); Uchman, p. 153–156, figs. 59–60.

Material. — 2 specimens collected (UJ 177P24, UJ 177P50); several observations in the field.

Diagnosis. *Scolicia* in which the flat medial ridge is longitudinally divided by a shallow furrow or crest (Uchman, 1998).

Description. — Trilobate, horizontally winding to meandering, hypichnial full relief, 17 mm wide, in the shape of a flat cylinder. The median lobe is 5 mm wide, flat to slightly concave, bordered by 1 mm wide lateral rims. The cylinders are inter crossing and interpenetrating.

Remarks. — The recorded specimens differ from *Scolicia plana* as defined by Uchman (1998) in the lack of transversal striation on the median lobe, in the absence of a distinctive longitudinal furrow or crest dividing the median lobe and in a slightly smaller width of the burrow. However, the difference in the features of the median lobe may result from incomplete cleaning of the burrow surface from the surrounding mudstone. Also the specimen drawn by Książkiewicz (1977, fig. 24) shows transversal striation over only part of the median lobe. This distinctive ichnofossil was recorded in thin-bedded sandstones of the upper part of succession in individual beds in all investigated sections.

One specimen was found where this species occurs highly flattened at the contact of shale with overlying silty marlstone (UJ 177P50, Fig. 28). The internal structure of burrow fill is visible in some its segments. The fill is meniscate, with 5–8 menisci per 1 cm. Meniscate burrows of this kind (Fig. 29) are fairly frequent locally in marlstones (*cf.* Książkiewicz, 1977). Książkiewicz (1977) assigned such burrows to *Muensteria geniculata* Sternberg, whereas Uchman (1998) redefined them as *Taenidium* isp. These seem to differ from burrows assigned here to *Scolicia* in their uniserial meniscation (see Uchman, 1998). It seems also that burrows of the same size and course but lacking distinctive meniscation (Fig. 29) were produced by the same species and in this sense represent the same ichnospecies.

Fig. 30. *Scolicia* isp. A (arrowed)

Bedding-parallel endichnial relief at contact of marlstone with overlying sandstone (UJ 177P27); lower part of Huwniki section; scale bar represents 1 cm

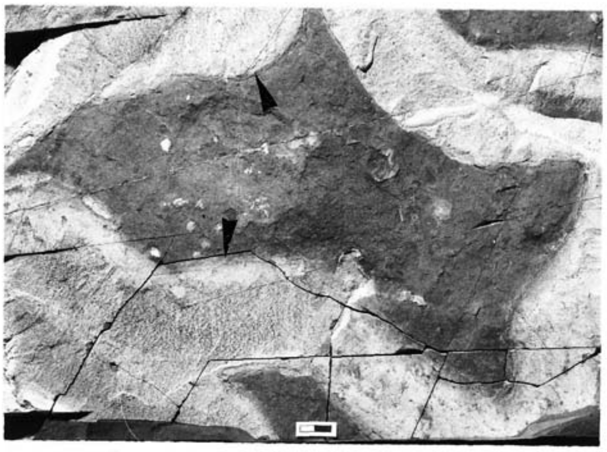

Fig. 31. *Scolicia* isp. A (arrowed)

Bedding-parallel endichnial relief in siltstone; note indistinct to invisible meniscate structure; lower part of Huwniki section (UJ 177P29); scale bar (black-white couple) represents 1 cm

Scolicia isp. A
(Figs. 30 and 31)

M a t e r i a l . — 4 specimens collected (UJ 177P27, 177P28, 177P29, 177P55); several observations in the field.
D e s c r i p t i o n . — Endichnial, winding, biserialy meniscate, strongly flattened cylinder, 30 mm wide and up to 3 mm thick. The biseriality of the menisci is expressed by slight concavity of the median zone of the burrow.
R e m a r k s . — Burrows of this type were recorded only in marlstones, in the lower part of normally-graded units. The meniscate structutre is displayed by packets of arcuate vari-coloured laminae. Similar burrows were recorded by Uchman (2001, pl. 9, fig. 8) in the Eocene of the Pyrenees and these were also distinguished as *Scolicia* isp. There are also specimens in which this structure is poorly visible (Fig. 31), although generally it is visible only in some burrow sections. The indistinctive meniscate structure occurs in burrows located in a mesoscopically homogeneous mud.

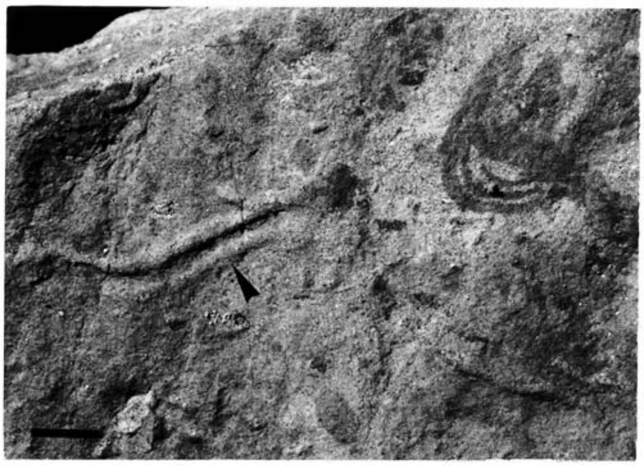

Fig. 32. ?*Scolicia* isp. (arrowed)

Semirelief on lower surface of sandstone bed; middle part of Huwniki section (UJ 177P30); black bar represents 5 mm

?*Scolicia* isp.
(Fig. 32)

M a t e r i a l . — 1 specimen collected (UJ 177P30).
D e s c r i p t i o n . — Hypichnial, irregularly winding, bilobate semirelief, 2.7 mm wide, in the form of two parallel ridges 1.0 mm wide, separated by a median trough 0.7 mm wide. It occurs on a sandstone sole. Some its segments were entirely erased by an eroding current prior to casting. It resembles in shape the washed-out forms of *Scolicia* (Uchman, 1995) distinguished by Sacco (1888) as *Taphrhelminthopsis* but is significantly smaller than burrows earlier included in this ichnogenus. Its shape suggests that the original burrow represented fodinichnia, produced by active sediment reworking.

Taenidium Herr, 1877
Taenidium recurvum isp. nov.
(Fig. 33)

1958 *Muensteria hoessii* Heer; Seilacher, p. 1070, tab. 2, fig. 40 (partim).
1987 *Taenidium cameronensis* (Brady); D'Alessandro and Bromley, p. 743, fig. 6 (partim).

H o l o t y p e . — UJ 177P51, Fig. 33A.
D e r i v a t i o n o f n a m e . — Latin: *recurvus* — curved backwards. The ichnospecies name was inspired by the burrow course, which is winding, and is frequently curved backwards.
M a t e r i a l . — 3 specimens collected (UJ 177P51, UJ 177P52, UJ 177P53); several observations in the field.

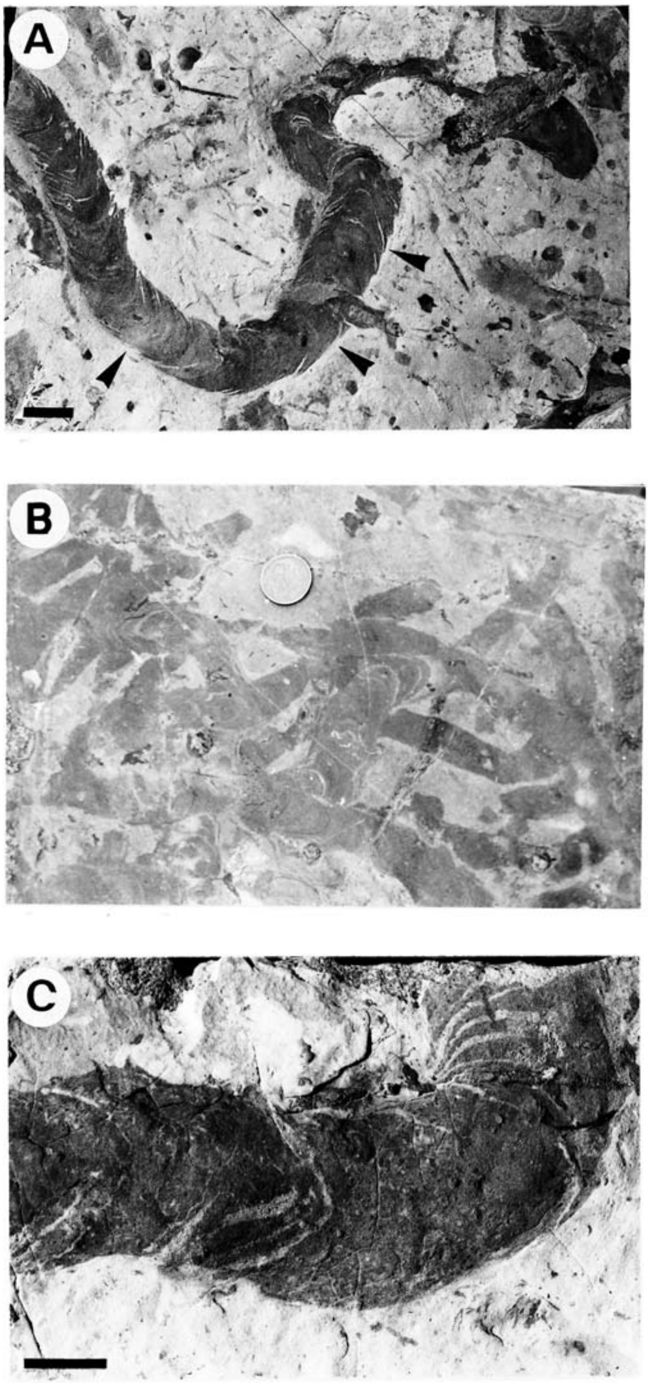

Fig. 33. *Taenidium recurvum* isp. nov.

Planar views of bedding-parallel to sub-parallel, endichnial relief in upper part of marlstone bed; lower part of Huwniki section; **A** — holotype (UJ 177P51), small form, arrowed; black bar represents 1 cm; **B** — system of burrows of small form; coin (15 in diameter) for scale; **C** — fragment of large form (UJ 177P52); black bar represents 2 cm

D i a g n o s i s . — Winding to meandering, locally intersecting, bedding parallel to subparallel, unbranched, unwalled, meniscate, backfilled burrow, 10–25 mm wide. The fill is homogeneous, usually segmented, with deeply concave to hemispherical meniscate interfaces, rarely non-compartmentalized.

D e s c r i p t i o n . — Bedding parallel to subparallel, winding, locally intersecting, distinctively meniscate backfilled, unwalled, unbranched, endichnial burrow. Except for one specimen, the burrow is 12–14 mm wide in plan view. In one specimen a small burrow fragment 21–25 mm wide was recorded (Fig. 33C). The respective forms are accordingly termed large and small, respectively. The fill consists of homogeneous, dark, fine-grained material displaying densely stacked distinct to indistinct meniscate structure. The distinct meniscate structure of burrow fills is in planar section marked by alternations of deeply arcuate to hemispherical, crescent-shaped segments of dark-coloured material separated by much thinner laminae of light-coloured sediment resembling and passing into that surrounding the burrows. The segments are 1–2 mm thick in the small form and 2–8 mm in the large one. The light-coloured intersegment laminae are 0.1–0.5 mm thick in the burrows of the small form and as much as 1 mm thick in the large form. The structure of the fill appears thickly packeted to non-compartmentalized in burrow divisions where either the menisci are too densely or diffusely stacked. The burrow occurs in the top parts of marlstone layers.

R e m a r k s . — The burrow shows similarity to *Muensteria hoessii* of Seilacher (1958) in width and the deeply arcuate shape of menisci, but differs from it in possessing narrower light-coloured intersegment laminae (?segments) relative to the thickness of the dark-coloured segments. The burrow construction, particularly the meniscate fill, indicates that it represents a feeding trace (fodinichnion).

Taenidium isp. A.
(Fig. 34)

M a t e r i a l . — 1 specimen collected (UJ 177P54); several observations in the field.

D e s c r i p t i o n . — Winding to meandering, locally intersecting, bedding parallel to sub-parallel, unbranched, unwalled,

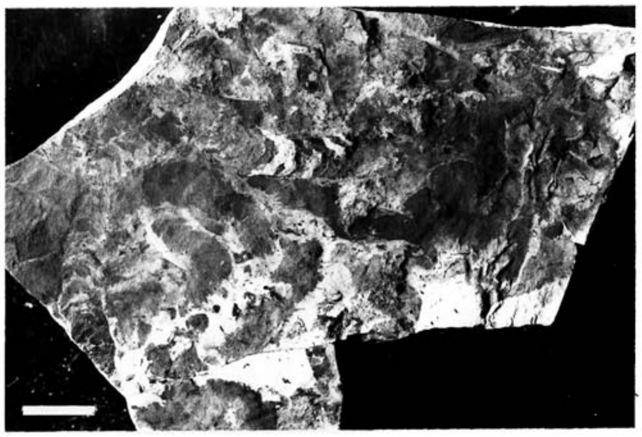

Fig. 34. *Taenidium* isp. A

Planar view of bedding-parallel to sub-parallel, endichnial full relief at upper surface of rock parting in passage zone from marlstone to overlying shale (UJ 177P54); lower part of Huwniki section; white bar represents 2 cm meniscate, backfilled burrow, 10–12 mm wide. The fill is heterogeneous, usually segmented (thinly packeted), with segments hemispherical in plan section. Segments alternately of dark grey and grey material, the former being slightly thicker than the latter, attaining 2 mm. These segments also protrude slightly out of the burrow. The boundary between segments is indistinct. Fragments of light-coloured material surrounding the burrow which are wedged between the protruding segments of dark-coloured material accentuate the segmented structure of the burrow fill in some burrow divisions.

R e m a r k s . — In its width and course, this burrow resembles *T. recurvum*. However, it differs from this species in its different structure of fill (shape and size of segments). Moreover, in contrast to *T. recurvum*, the menisci are diffuse. It seems therefore that this burrow represents a separate species of *Taenidium*. A burrow of this type was also mentioned by Uchman (1998, fig. 66B) from Książkiewcz's trace-fossil collection from the exposures at Huwniki. Uchman classified it with *Taenidium* isp. As with *T. recurvum*, it represents a feeding trace.

Taenidium isp. B.
(Fig. 35)

M a t e r i a l . — 1 specimen collected (UJ 177P25); several observations in the field.

D e s c r i p t i o n . — Winding to meandering, locally intersecting, bedding parallel to sub-parallel, unbranched, unwalled, meniscate, backfilled burrow, 15 mm wide. The fill is heterogeneous, segmented, with segments hemispherical. Segments built of light grey material alternate with dark grey ones. The segments of the former are thicker (2 mm) than the latter (0.4 mm). The segments are indistinctly separated and grade into each other.

R e m a r k s . — In its width and course, this burrow resembles *T. recurvum*. *T.* isp. A and *Scolicia plana* (Książkiewicz). However, it differs from the first of these in its different fill structure (shape and size of meniscate segments). Moreover, in contrast to *T. recurvum*, but similarly to *T.* isp. A, the menisci are diffuse. From *T.* isp. A it differs in its slightly larger size and in the smaller thickness of menisci. Burrows of both types may, though, be produced by the same animal but under different circumstances and may therefore represent the same species of *Taenidium*.

Thalassinoides Ehrenberg, 1944
Thalassinoides suevicus (Rieth, 1932)
(Fig. 36)

1999 *Thalassinoides suevicus* (Rieth); Uchman, p. 106, pl. 10, figs. 5–9.

M a t e r i a l . — 1 specimen collected (UJ 177P31); several observations in the field.

Fig. 35. *Taenidium* isp. B

Planar view of bedding-parallel endichnial full relief at upper surface of rock parting in passage zone from marlstone to overlying shale; lower part of Huwniki section (UJ 177P25); black dot represents 1.5 mm

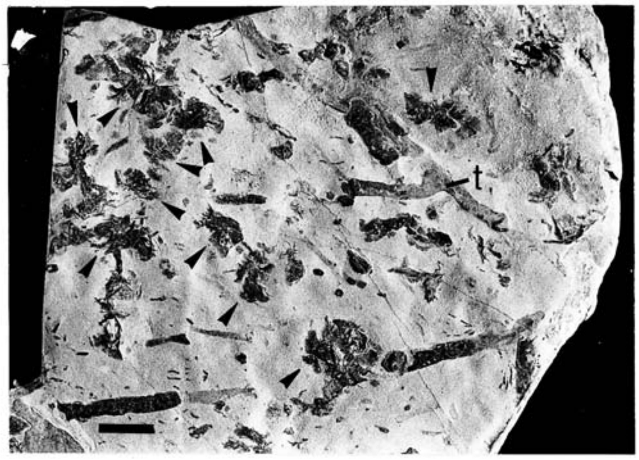

Fig. 36. *Thalassinoides suevicus* (T) and turbidichnia (arrowed)

Endichnial full reliefs at upper bedding surface in marlstone (UJ 177P31); note ragged outlines and variable pattern of turbidichnia which in general shape appear similarly to *Hydrancylus* igen.; lower part of Dolinka section; black bar represents 1 cm

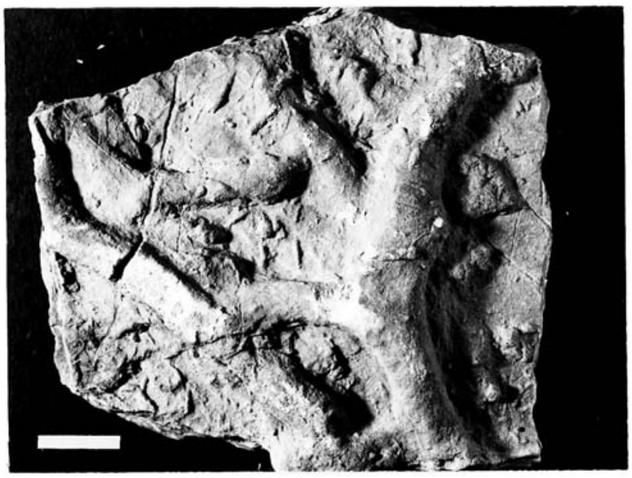

Fig. 37. *Thalassionoides* isp.

Semirelief on lower surface of fine-grained sandstone (UJ 177P4); middle part of Wiar section; white bar represents 2 cm

D i a g n o s i s . — Predominantly horizontal, more or less regularly branched, essentially cylindrical burrow system, dichotomous bifurcations are more common than T-shaped branches (Howard and Frey, 1984).
D e s c r i p t i o n . — Burrows preserved as horizontal endichnial fillets (flattened tunnels) with sharp margins, without visible walls and with hypichnial ridges preserved both in full relief and in semirelief. The burrows are 5–10 mm wide and display dichotomous branching. It seems that this taxon is represented also by semireliefs in the form of several centimetres long ridges, which appear to branch.

Thalassinoides isp.
(Fig. 37)

M a t e r i a l . — 1 specimen collected (UJ 177P4); several observations in the field.
D e s c r i p t i o n . — Hypichnial, curved, branched semireliefs 1–2 cm wide. Branching mainly Y-shaped, usually enlarged at points of bifurcation. Burrow margins are smooth, locally slightly irregular. The size of burrows varies within one system.

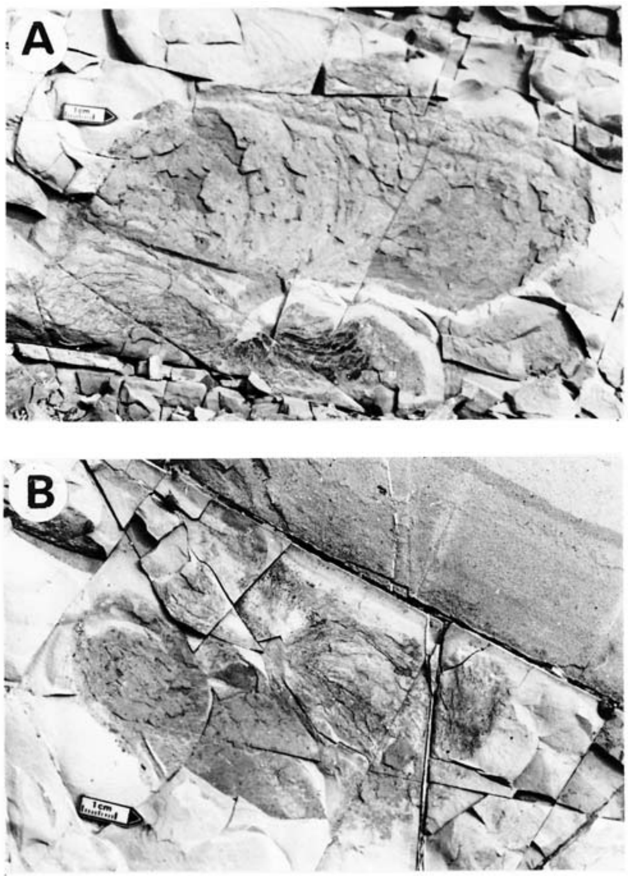

Fig. 38. *Zoophycos brianteus*

Bedding-parallel full reliefs, 45 cm apart, at the same surface at passage from siltstone to marlstone; lower part of Huwniki section

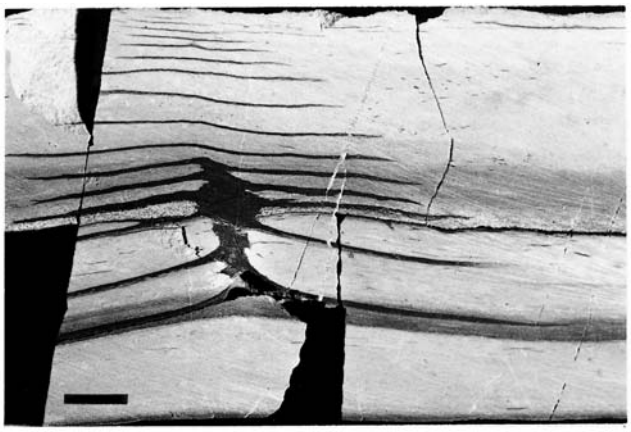

Fig. 39. *Zoophycos* isp.

Vertical section of spiral form cutting two fining-upward units of marlstone (UJ 177P57); lower part of Huwniki section; black bar represents 1 cm

Zoophycos Massalongo, 1855
Zoophycos brianteus Massalongo, 1855
(Fig. 38)

1977 *Zoophycos brianteus* Massalongo; Książkiewicz, p. 109, pl. 10, figs. 2, 3.
1999 *Zoophycos brianteus* Massalongo; Uchman, p. 116, pl. 13, fig. 6.

M a t e r i a l . — 3 specimens observed in the field in one bed.
D i a g n o s i s . — *Zoophycos* having a more or less circular to elliptical outline in planar view, without lobes (Uchman, 1999).
D e s c r i p t i o n . — Endichnial, helicoidal structure, 10–20 cm in diameter, showing a rounded outline in plan view and with distinctive spreiten extending arcuately from the centre to the burrow margin, and consisting of several vertically stacked coils. The central part of the burrow is elevated by about 1 cm. Burrow diameter increases toward the lower coils. The specimens are recorded in a 3 cm thick marlstone layer passing downwards into siltstone and upwards to calcareous shale, and are situated 40 to 45 cm apart.

Zoophycos isp.
(Fig. 39)

M a t e r i a l . — 1 specimen (UJ 177P57).
D e s c r i p t i o n . — Spirally coiled structure extended vertically, marked by laminae of dark-coloured, homogeneous sediment. Single volutions in axial section conelike, sloping gently outwards. Successive whorl diameters and thicknesses generally increase downwards: diameters change from 1 cm in the uppermost whorl to 9 cm in the lowermost, whereas thicknesses increase respectively from 0.1 to 1 mm. The whole

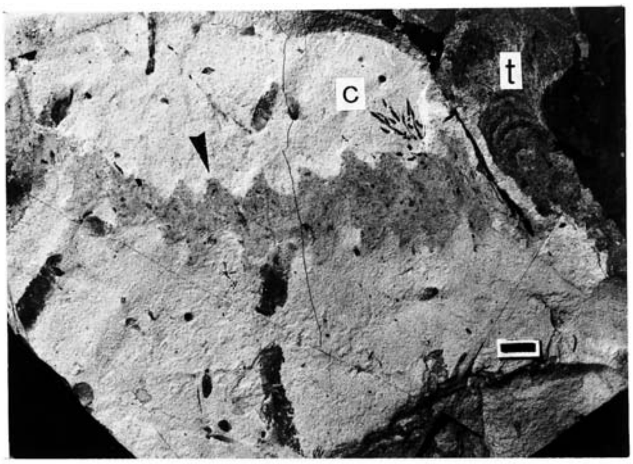

Fig. 40. Form A (arrowed)

Bedding-parallel relief in upper part of marlstone layer; ?*Taenidium* isp. (t) and *Chondrites intricatus* (c) in the upper right corner; lower surface of specimen (UJ 177P35); lower part of Huwniki section; black bar represents 5 mm

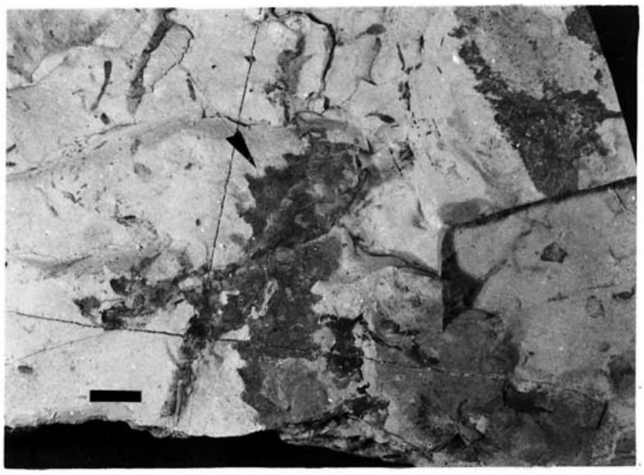

Fig. 41. Form B (arrowed)

Bedding-parallel full relief in upper part of marlstone layer; upper surface of specimen (UJ 177P36); lower part of Huwniki section; black bar represents 5 mm

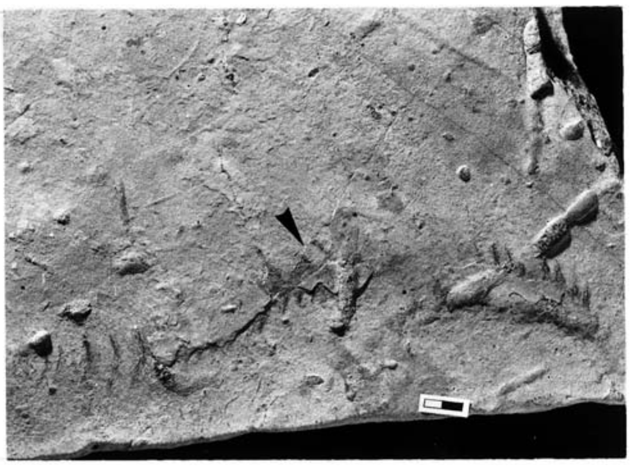

Fig. 42. Form C (arrowed)

Semirelief on undersurface of sandstone bed; lower part of Huwniki section (UJ 177P37); scale bar (white-black couple) represents 1 cm

structure is 4.5 cm high. The axis of the spiral is irregular and extends nearly vertically to bedding.

R e m a r k s . — The specimen extends over two fining-upward units of marlstone

UNDETERMINED TRACE FOSSILS

Form A
(Fig. 40)

M a t e r i a l . — 1 specimen (UJ 177P35).

D e s c r i p t i o n . — Curved, unlined, horizontal, endichnial, ribbon-like, full relief, showing regularly cuspate outline resembling a saw, as much as 15 mm wide. The burrow is filled with dark grey mud with some admixture of irregularly scattered coarser grains. The burrow fill looks homogenous lacking meniscation. It was found in top part of a marlstone layer.

R e m a r k s . — The cuspate outline of the burrow suggests similarity to the ichnofossil Form C and to some extent to Form B. As in these ichnotaxa it lacks distinct separation of segments marked with the cusps.

Form B
(Fig. 41)

M a t e r i a l . — 1 specimen (UJ 177P36).

D e s c r i p t i o n . — Curved, unlined, horizontal, endichnial, flat, full relief, showing regularly cuspate outline, resembling a saw, as much as 20 mm wide between the cusps. The burrow is filled with dark grey mud, without meniscation. It was found in the top part of a marlstone layer.

R e m a r k s . — The cuspate outline of the burrow suggests a similar origin to the ichnofossil Form A. As in this ichnotaxon it lacks distinct separation of segments marked with the cusps. It is very similar to Form A although, the cusps are slightly smaller and more densely distributed.

Form C
(Fig. 42)

M a t e r i a l . — 1 specimen (UJ 177P37).

D e s c r i p t i o n . — Sub-horizontal, hypichnial semirelief in the form of a winding row of arcuate rib-like ridges 15 mm wide. The ridges are *ca.* 1mm thick, 2–6 mm apart, and appear to be slightly asymmetric in cross-section, with the concave side more steeply inclined.

R e m a r k s . — The burrow pattern suggests that the structure presents a cast of a locomotion trace.

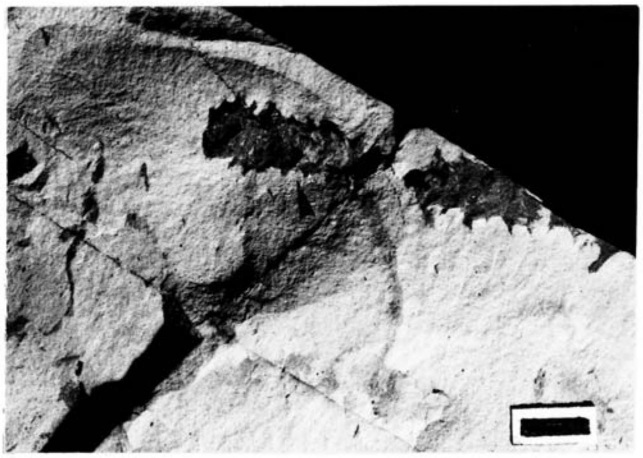

Fig. 43. Form D (arrowed)

Bedding-parallel full relief in upper part of marlstone layer; lower part of Huwniki section (UJ 177P38); scale bar represents 5 mm

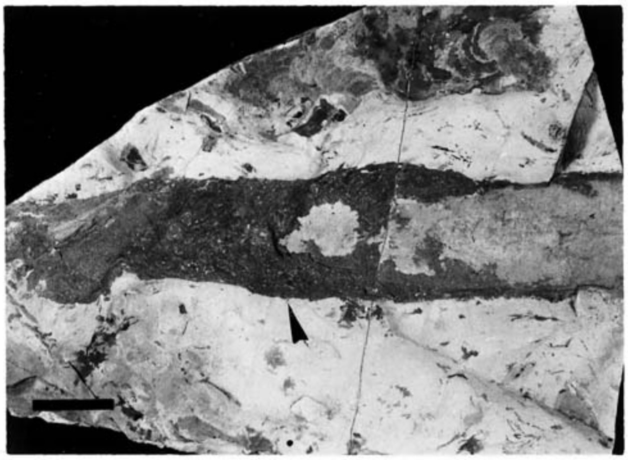

Fig. 44. Form E (arrowed)

Bedding-parallel full relief in association with *Chondrites intricatus*, ?*Taenidium* isp. and turbidichnia; upper part of marlstone layer (UJ 177P39); lower part of Huwniki section; black bar represents 2 cm

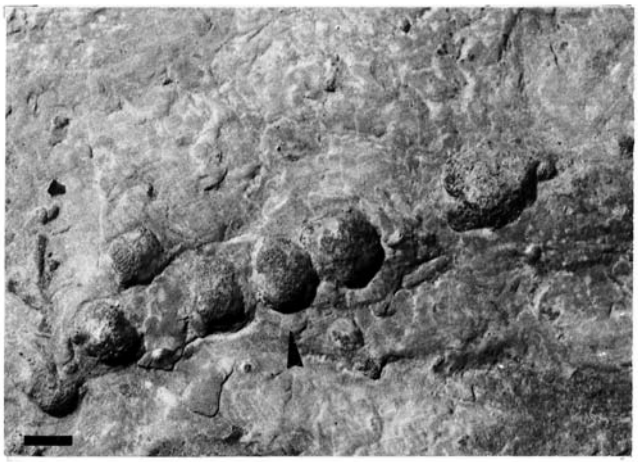

Fig. 45. Form F (arrowed)

Semirelief on lower surface of sandstone bed; lower part of Huwniki section (UJ 177P40); black bar represents 5 mm

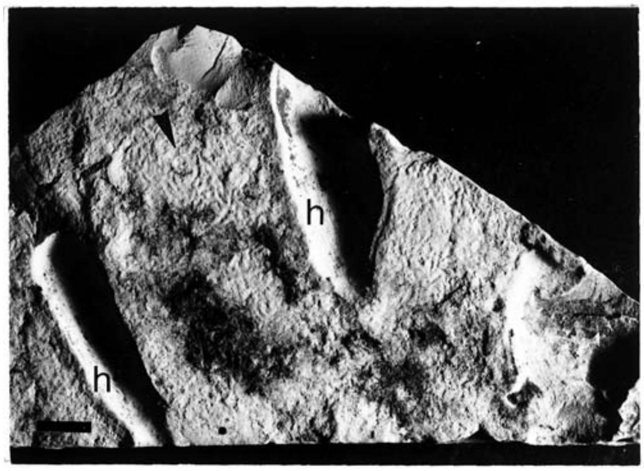

Fig. 46. Form G (h)

Upper surface of marlstone layer; note also crowded tiny furrows (arrowed) of undetermined ichnotaxon between large structures; lower part of Huwniki section (UJ 177P41); black bar represents 1 cm

Form D
(Fig. 43)

M a t e r i a l . — 1 specimen (UJ 177P38).
D e s c r i p t i o n . — Straight, unlined, horizontal, endichnial, strongly flattened, string-like, full relief showing cuspate outline, resembling a plant stem, 3 mm wide. The cusps seem to surround the stem. The fossil is filled with dark grey mud similar to that filling most of the burrows in the sections investigated. The fill indicates its affiliation with burrows.

Form E
(Fig. 44)

M a t e r i a l . — 2 specimens (UJ 177P39; UJ 177P60); several specimens observed in the field.
D e s c r i p t i o n . — Horizontal, slightly curved, flattened, unwalled full relief of irregular width 27–32 mm, showing faint meniscate structure of the filling material. The burrow is as much as 3 mm thick in vertical section. The fill consists of dark grey mud with irregularly scattered coarser grains. The meniscate structure is expressed in a tendency for the fill to split and in the cuspate outline of the burrow in some divisions.
R e m a r k s . — The structure occurs in marlstone layers, as much as 1cm below their tops. It represents a feeding trace (fodinichnia) of a relatively large wormlike animal. All specimens recorded represented only relatively small fragments of the burrow. None of the specimens displayed branching.

Form F
(Fig. 45)

M a t e r i a l . — 1 specimen (UJ 177P40).
D e s c r i p t i o n . — A row of 7 rounded, disconnected knobs cast on a sandstone sole. The knobs are 4–6 mm in diameter, 1–2 mm apart and as much as 2 mm high.
R e m a r k s . — The knob located outside the row in Figure 48 was displaced during preparation of the specimen. The lack of connection between the knobs makes this trace similar to the uniserial *Saerichnites*. However, the lack of connection between the knobs may result simply from erosion of the higher burrow part. Thus, one cannot exclude that the trace fossil represents a preservational aspect of *Hormosiroidea*. The distance between the knobs, though, is much smaller than in the known species of *Hormosiroidea*.

Form G
(Fig. 46)

M a t e r i a l . — 1 specimen (UJ 177P41).
D e s c r i p t i o n . — Epichnial depression in the shape of an elongate ellipse, 1–1.7 cm wide, up to 5 cm long and up to 1.5 cm deep.
R e m a r k s . — The structures are similar in form to *Naviculichnium marginatum* Książkiewicz (Uchman, 1998, fig. 65) but are wider.

DEFORMED BURROWS

Endichnial structures in the form of bedding-parallel to oblique, irregularly lobate to elongate, frequently multistorey lamellae of different size, variable morphology and thickness, of dark-coloured mud, locally interwoven with the host rock; also, short, irregular, bedding-oblique shafts and nests occur in some marlstone beds (Figs. 9, 47 and 48). In sections parallel to bedding, these structures look like irregular blots or spots, frequently lobate, sometimes distinctly branched, one to several centimetres in diameter, showing irregular and frequently fractal-like outlines, whereas in sections perpendicular to bedding they are marked as bedding-parallel to oblique, irregular streaks or clusters of streaks showing irregularly distributed hair-like projections (Fig. 48).

The shape of these structures changes irregularly from place to place. Some structures appear as small, irregularly ramified intrusions (Fig. 47F), hardly comparable to typical burrows. Such structures occur either in beds in which structures showing straight courses and/or regular outlines are absent (Fig. 9) or in beds where they occur besides burrows showing more regular features (Figs. 36, 44 and 47E). These structures show in cross-sectional view some similarity to structures called swirl traces (Lobza and Schieber, 1999), although, the latter appear to display less distinct outlines. Seen parallel to bedding, some specimens show some similarity to *Rorschachichnus amoeba* Gregory (Gregory, 1991). However, in contrast to this species, they never have a globose shape, noted by Gregory (1991) as one of the characteristic features of *Rorschachichnus*.

The material composing these structures, being similar to that of undoubted burrow-fills, and their general pattern suggest that they were formed either due to squashing of burrows filled with liquid fill, locally with squeezing of the fill out into surrounding soft-soupy sediment, or that the traces underwent deformation due to sediment fluidisation. The latter mode of origin seems plausible where the structures occur in beds marked by irregular lamination (Fig. 9).

The shape of some structures indicates an origination due to injection of some burrow-fill material into the adjacent sediment. Such modifications are marked by delicate haloes around burrows (Fig. 47E). Some structures show modification by tearing of the original burrow and squeezing of its fill into fissures within the surrounding sediment (Fig. 47F).

Irrespective of their precise mode of origin, features of all these structures indicate that they represent deformed burrows. Because of their highly irregular outline, it is proposed here to call such structures turbidichnia (sing. turbidichnus) after the Latin word *turbidus* meaning disordered. They differ from biodeformation structures in being easily visible, like the undeformed burrows.

DISCUSSION

The strata investigated show vertical bioturbation patterns typical of turbidite–interturbidite couplets (see Książkiewicz, 1977; Leszczyński, 1993; Uchman, 1999). This is reflected in the upwards increasing bioturbation intensity in individual fining-upward units and in occurrences of burrow casts on bed soles. Moreover, the coarse-grained rocks contain structures produced in soft sediment exclusively whereas marlstones and shales contain structures produced in a soupy to soft sediment. There is also some difference in trace fossil assemblages in different rock types. All these features result from control of bioturbation mainly by the thickness and textural profile of individual turbidite beds, sediment consistency, benthic oxygenation regime and recurrence time of turbidite sedimentation (see Wetzel, 1984, 1991; Leszczyński, 1993; Uchman, 1999).

The co-occurrence of structures produced in sediments of different consistency is a common feature of fine-grained sediments, irrespective of their origin. The relative consistency of such sediments may change as compaction to rock takes place. Therefore, biodeformation structures usually occur in the background of such rocks while distinct trace fossils occur in the foreground. In some beds, the bioturbation structures show that stiffened, bioturbated sediment experienced fluidisation and consequent physical deformation. The bioturbation structures contained in such beds underwent various modifications which, in many cases, greatly changed their original features and hindered their taxonomic classification.

The rarity of distinct bioturbation structures in shales suggests low levels of bioturbation in these rocks. However, abundant casts of burrows on the lower surfaces of sandstone beds underlain by shale conversely indicate a intensive bioturbation of shales. Intense bioturbation of the shales is also suggested by their irregular, rough splitting, a feature typical of totally bioturbated deposits. Most probably, the rare occurrence of distinct bioturbation structures in shales was caused by the negligible contrast between burrow-fills and the host sediment (*cf.*

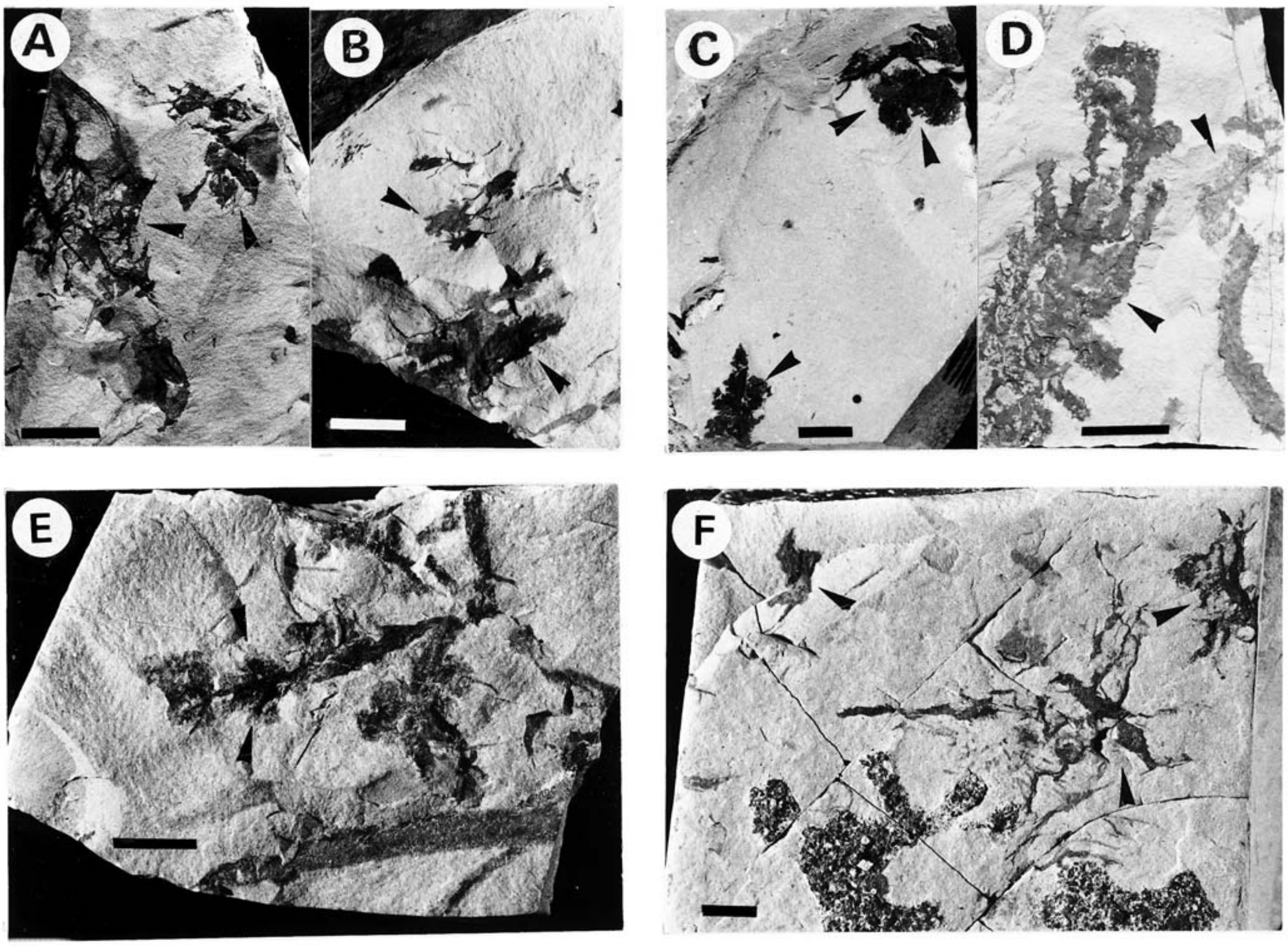

Fig. 47. Turbidichnia (arrowed) and associated ichnofossils

Endichnial full reliefs in marlstone; note highly irregular outlines of turbidichnia; all specimens from lower part of Huwniki section; **A** — view closely parallel to bedding at lower splitting surface (UJ 177P32); black bar represents 1 cm; **B** — view oblique to bedding (UJ 177P58); bottom part of bed from middle right to middle lower part of photo; white bar represents 1 cm; **C** — view slightly oblique to bedding at upper splitting surface of rock (UJ 177P33); black bar represents 1 cm; **D** — view parallel to bedding at splitting surface in marlstone (UJ 177P56); black bar represents 2 cm; **E** — view parallel to bedding at splitting surface in upper part of marlstone (UJ 177P4); black bar represents 5 mm; **F** — view parallel and oblique (in upper left) to bedding (UJ 177P34); shape of structure indicates influence of deformation of fluidised sediment and sediment shearing during its origin; black or white bar represents

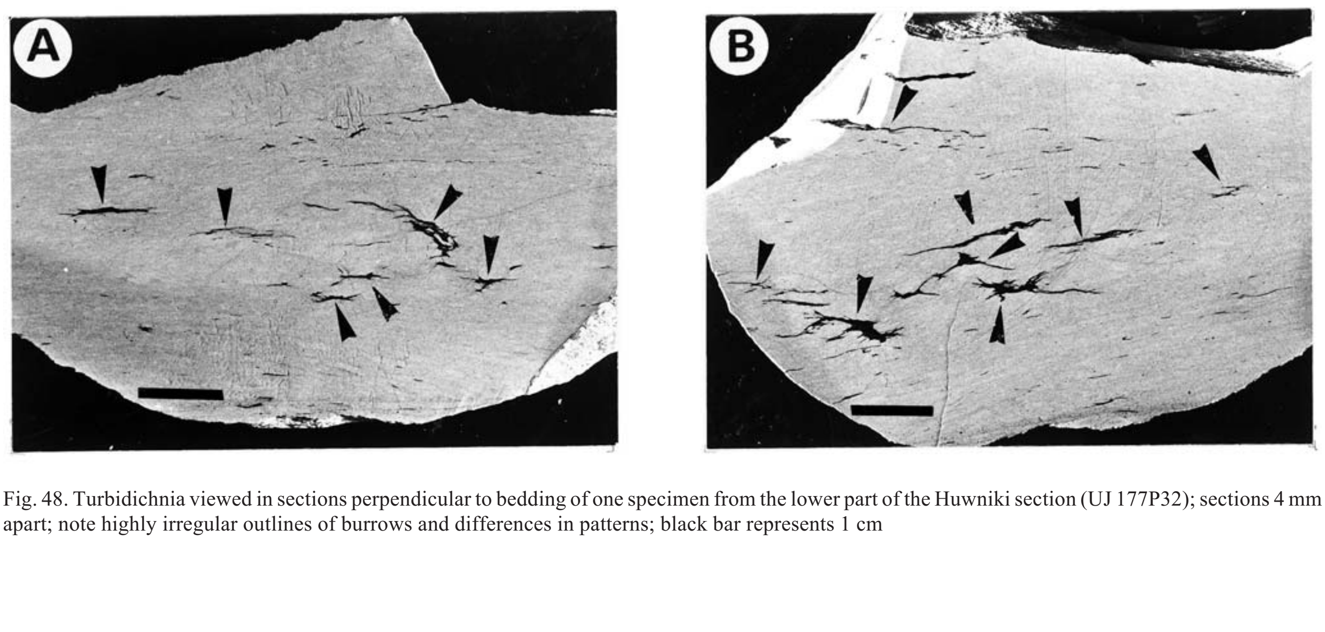

Fig. 48. Turbidichnia viewed in sections perpendicular to bedding of one specimen from the lower part of the Huwniki section (UJ 177P32); sections 4 mm apart; note highly irregular outlines of burrows and differences in patterns; black bar represents 1 cm

Bromley, 1996; Uchman, 1999; Schieber, 2003). The mainly "pelagic" origin of shales (background deposits) suggests slow vertical accretion, a fluid consistency of their uppermost part throughout accretion, and gradual stiffening, mainly due to compaction, with progressive burial. The earliest burrows were produced when the sediment had a soupy consistency. Only those excavations having strengthened walls and/or being filled with sediment differing in texture or mineralogical composition, or actively filled burrows, had a chance of being preserved and visible (Bromley, 1996). Unfortunately, burrows of this type are rare in the shales in question.

In shales, the occurrence of sand-filled burrows is restricted to beds where the shale is overlain by sandstone, in normally graded units less than 15 cm thick. This specific circumstance, together with the occurrence of post-depositional burrows only on the lower surfaces of such units, reflects the maximum burrowing depth in these sediments. Considering that the present thickness of the depositional units represent *ca.* 40–70% of their original thickness, the maximum burrowing depth seems to have ranged 20–35 cm in these sediments. The depth was greater than in the underlying Holovnia Siliceous Marls, where it was presumably less than 25 cm (Leszczyński, 2003). This suggests that oxygenation of the basin floor was greater during sedimentation of the Kropivnik Fucoid Marls than during sedimentation of the Holovnia Siliceous Marls.

The rarity of bioturbation structures on the lower surfaces of sandstone and siltstone, which rest on marlstones, as well as in such marlstone, seems to result from restricted accessibility of these sediments to burrowers. The absence of shale between marlstone and the overlying arenite suggests a short time interval of the background sedimentation, when the sea floor was available for burrowing. Frequent sedimentation of turbidites thicker than an average burrowing depth could restrict or preclude sediment burrowing. This was apparently the factor responsible for the lack or scarcity of burrows in marlstones immediately overlain by sandstone or shale.

CONCLUSIONS

The sediments enclosed in the succession of the Kropivnik Fucoid Marls display a complex assemblage of bioturbation structures consisting of biodeformation structures, trace fossils and deformed burrows called here turbidichnia.

The vertical pattern of bioturbation is typical of turbidite-interturbidite couplets (Książkiewicz, 1977; Leszczyński, 1993; Uchman, 1999). Distinct bioturbation structures are most abundant in marlstones and scarcest in shales. Deposits of normally graded units lacking shale at the top are usually free of distinct bioturbation structures due to short recurrence time of turbidite sedimentation.

Distinct trace fossils occur in all rock types whereas biodeformation structures occur nearly exclusively in marlstones. The lack of distinct biodeformation structures in shales results from an insufficient contrast of burrows produced in these sediments while they possessed a soupy consistency.

Most of the bioturbation structures recorded in the sections investigated are taxonomically indeterminate. Nevertheless, taxonomically determinable structures are still relatively common in these rocks, chondritids being most common (*cf.* Książkiewicz, 1977). *Planolites*, *Halopoa, Thalassinoides* and *Scolicia* were recorded rarely whereas other taxa were recorded as individual specimens only.

Twenty seven ichnotaxa, including *Taenidium recurvum* isp. nov. and seven forms of trace fossils of unknown taxonomic affinity, were recognised in the sections investigated in this study. Only nine ichnospecies of the twenty one recorded in these rocks by Książkiewicz (1977) were found in this study. The difference between the trace fossil assemblage recorded by Książkiewicz and by the present author results from the rare occurrence of most of the ichnotaxa present and from the scarcity of determinable specimens of some taxa.

Planolites beverleyensis and *Halopoa imbricata* were the most frequent trace fossils observed on sandstone soles in this study. *Chondrites intricatus*, *Planolites beverleyensis* and *Thalassinoides suevicus* represent the most common taxa in hard marlstones. Endoreliefs of *Scolicia* isp. are locally frequent in the top parts of marlstone beds.

The burrowing depth, reaching 15 cm below the top of normally-graded units, together with the relatively rich trace fossil assemblage and common occurrence of *Planolites* and *Thalassinoides*, indicates fully oxic conditions at the bottom of the sedimentary basin.

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