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ICHNOLOGICAL ANALYSIS OF AN EOCENE MIXED MARLY-SILICICLASTIC FLYSCH DEPOSITS IN THE NIENADOWA MARL MEMBER, SKOLE UNIT, POLISH FLYSCH CARPATHIANS

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Abstract: The Nienadowa Marl Member, composed mainly of various marly, mixed siliciclastic-marly, or siliciclastic thin-bedded turbidites, is deeply burrowed by opportunistic *Thalassinoides*, *Chondrites*, *Phycosiphon* and *Scolicia*. Ichnofabrics and the trace fossil assemblage indicate well oxygenated environment. Relatively low ichnodiversity is probably related to opportunistic burrowers influenced by possible eutrophy and strong sediment heterogeneity, as well as to preservational potential. Ichnofabrics and trace-fossil tiering patterns are different in the basinal sections of the Nienadowa Marl Member and in the slope/shelf environment represented by marlstone clasts in the coeval debris-flow deposits of the Czudec Clay. *Thalassinoides* penetrates deeper than *Chondrites* in the proximal turbidites and shallower than *Chondrites* in the distal turbidites.

Abstrakt: Ogniwo margli z Nienadowej (og) złożone jest głównie z różnorodnych, marglistych, mieszanych silikoklastyczno-marglistych i silikoklastycznych, cienkoławicowych turbidytów. Utwory te są głęboko zbioturbowane i zawierają oportunistyczne skamieniałości śladowe: *Thalassinoides*, *Chondrites*, *Phycosiphon* i *Scolicia*. Ichnofabric i zespół skamieniałości śladowych wskazują na środowisko dobrze natlenione. Stosunkowo niskie zróżnicowanie ichnotaksonomiczne związane jest z oportunizmem infauny penetrującej w osadzie, przypuszczalnie powodowanym eutrofią, heterogenicznością składu petrograficznego osadu, oraz niskim potencjałem zachowania skamieniałości śladowych. Ichnofabric i skamieniałości śladowe różnią się między basenowymi facjami reprezentowanymi przez ogniwo margli z Nienadowej (og), a facjami skłonu i głębszego szelfu, obecnymi w klastach z równowiekowych osadów spływów kohezyjnych (iły z Czudca). *Thalassinoides* penetruje głębiej niż *Chondrites* w facjach proksymalnych turbidytów, a płycej niż *Chondrites* w turbidytach facji dystalnych.

Key words: ichnofabrics, trace fossils, flysch, Eocene, Carpathians.

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INTRODUCTION

Variability of trace fossil assemblages and ichnofabrics in non-siliciclastic flysch deposits is very poorly known. Probably, each flysch facies has its own trace fossil assemblage and style of ichnofabrics. However, the published data suitable for comparison are very scarce.

The main aim of this paper is a presentation and interpretation of a specific flysch trace fossil assemblage and ichnofabrics from an Eocene mixed marly-siliciclastic thin- and medium-bedded flysch deposits in four sections of the Nienadowa Marl Member in the Skole Unit (Fig. 1). Moreover, marlstone clasts from debris-flow deposits of the partially coeval Czudec Clay from the Wara section are included in the study. Probably, the clasts derive from the basin slope or deeper shelf.

Almost all beds we sampled. The samples were cut and polished. The polished surfaces have been oiled for improving of colour contrast. All the illustrated specimens are housed in the Institute of Geological Sciences of the Jagiellonian University in Kraków.

GEOLOGICAL SETTING

The Skole Unit is composed of overthrusted folds and thrust sheets, and it comprises an up to 7,000 m thick series of various Lower Cretaceous–Miocene deposits (Książkiewicz, 1977a; Kotlarczyk, 1988).

The Nienadowa Marl Member belongs to the Hieroglyphic Formation (Eocene), which embraces various flysch deposits (Fig. 2). The member is widely distributed and it is a marker horizon though it displays strong facies changes. It is 10–20 m thick in most sections. Exceptionally, it reaches 70 m (NE part of the Skole Unit), or disappears entirely from the section (Rajchel, 1990).

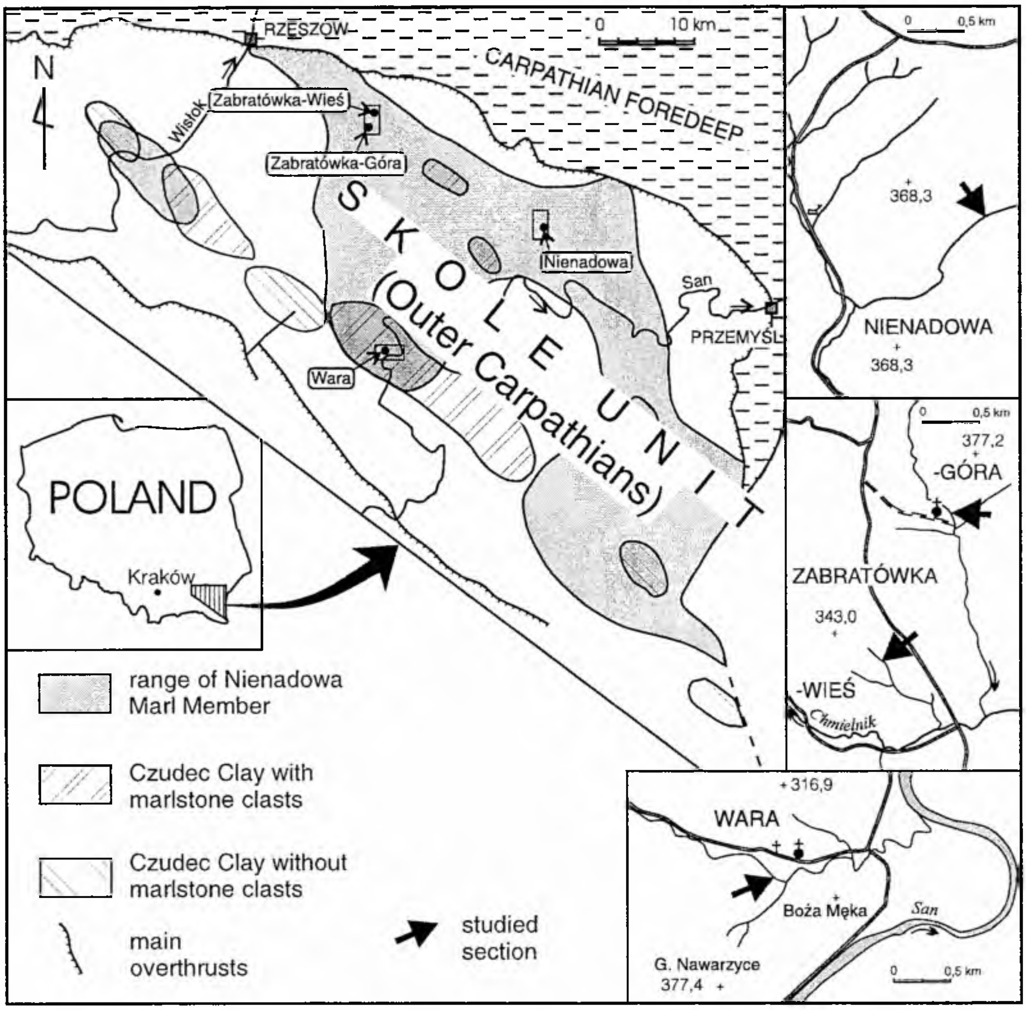

Fig. 1. Location map (partially based on Rajchel, 1990)

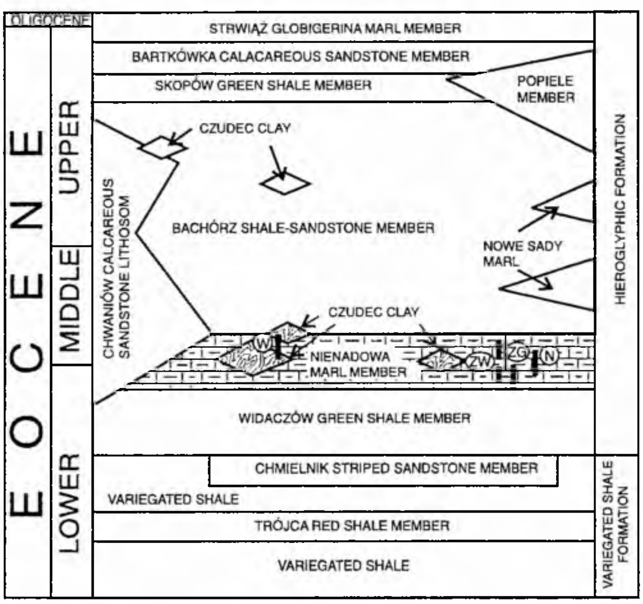

Fig. 2. Stratigraphic column of the Paleogene flysch deposits of the Skole Unit (after Rajchel, 1990). Studied sections: W – Wara; ZW – Zabratówka Wieś; ZG – Zabratówka Góra; N – Nienadowa

The Nienadowa Marl Member is composed mainly of various marly, mixed marly-siliciclastic, or siliciclastic turbidites, which are commonly 5 to 30 cm thick. The lower and middle parts of the beds are hard. The upper parts of beds, composed mainly of turbiditic-pelagic green calcareous or muddy mudstones, are soft (Figs. 3–6).

The siliciclastic beds are composed of calcareous or calcareous-siliceous, fine- to medium-grained, quartz-glauconite sandstones. Some sandstone beds, especially in the Wara section (Fig. 3), contain large amount of marly matrix and biogenic silica, and subordinate glauconite. Such rocks can be ascribed to gaizes. Weathered gaize beds are commonly strongly porous, because of leaching out of calcium carbonate. Some sandstone beds contain horizons enriched in coalified plant detritus.

In mixed siliciclastic-marly beds, hard, usually siliceous, marlstone overlies the basal, sandstone, part of turbidites, with a gradual passage. In some beds, the sandstone part is absent, and the marlstone forms the hard parts of beds. The marlstones are usually green and, less commonly, brownish in colour. They contain various amounts of silica, sometimes more than 60% of the rock mass. The silica-rich marls pass locally to marly cherts. The silica seems to derive, at least partially, from tests of radiolaria and sponge spicules, which are common in the marlstones and shales.

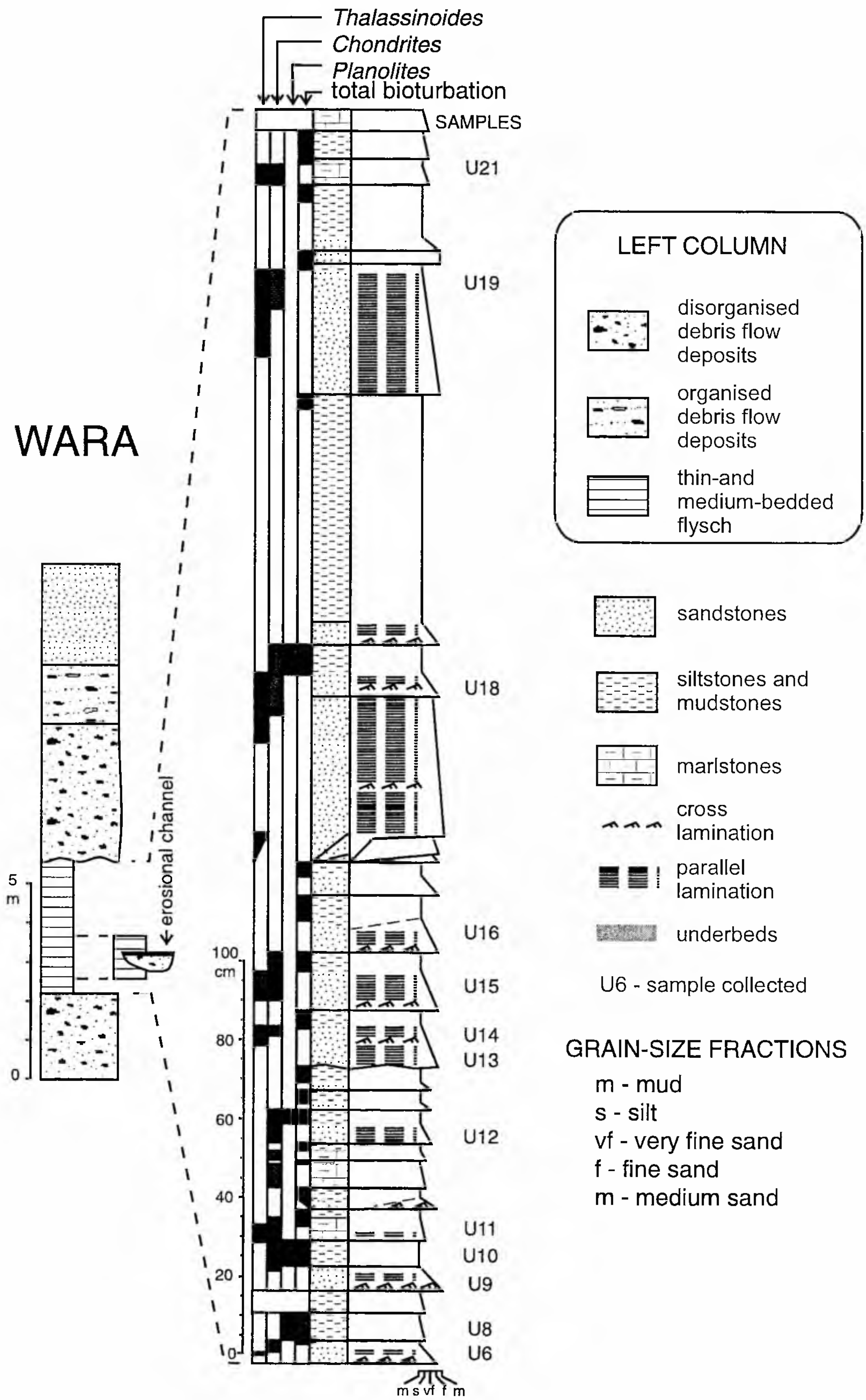

Fig. 3. Lithological column of the Nienadowa Marl Member at Wara with the range chart of trace fossils and bioturbation

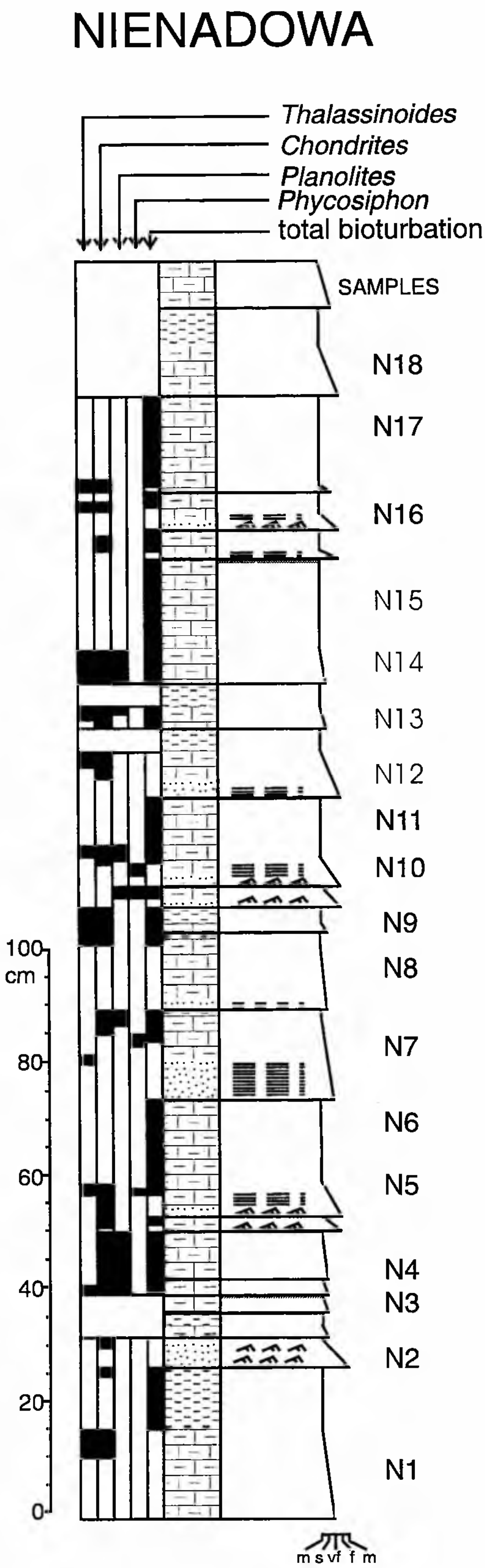

Fig. 4. Lithological column of the Nienadowa Marl Member at Nienadowa with the range chart of trace fossils and bioturbation. For explanations see Fig. 3

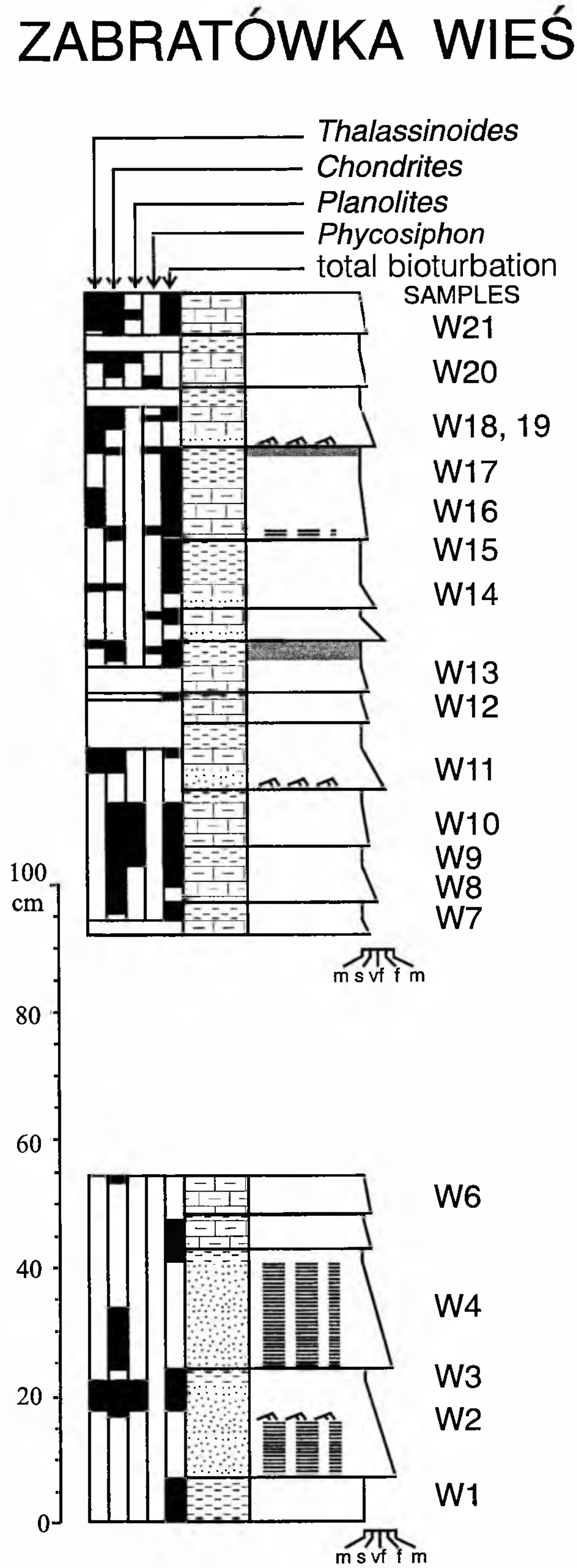

Fig. 5. Lithological column of the Nienadowa Marl Member at Zabratówka Wieś with the range chart of trace fossils and bioturbation. For explanations see Fig. 3

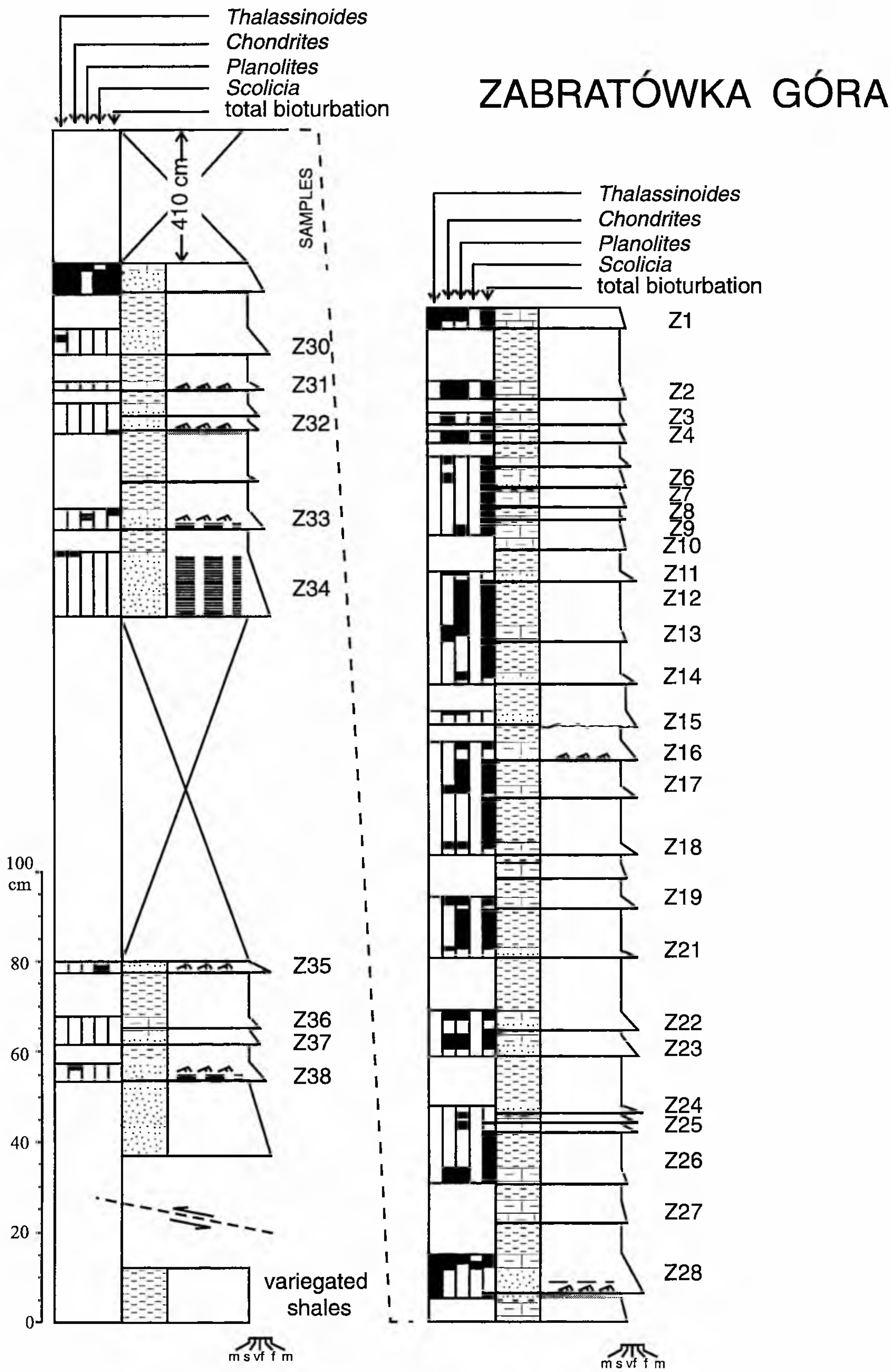

Fig. 6. Lithological column of the Nienadowa Marl Member at Zabratówka Góra with the range chart of trace fossils and bioturbation. For explanations see Fig. 3

The upper parts of beds are composed of green, homogeneous, soft, calcareous mudstones, or even locally muddy marlstones, except for the Zabratówka Wieś section, where non-calcareous mudstones occur at the tops of some beds. Locally, the upper parts of the turbidites are hard and cemented with calcium carbonate and/or silica, and welded with the overlying bed (Fig. 5). Such layer forms a kind of the so-called underbed *sensu* Ricken & Elder (1991). In several cases, even a few turbiditic beds are welded together and form one coherent layer.

The sandstone and marlstone parts of several beds displays Tb, Tc, Td, and rarely Ta Bouma divisions. The thicker sandstone beds (10–30 cm) contain characteristic thick set of parallel Tb lamination and very thin Tc division. In some outcrops, 1.5 m-thick, parallel-laminated sandstone beds have been noted, which, however, are beyond the studied sections analysed in this paper. Beds are continuous within the outcrops, and their soles are usually very even, usually with poorly developed erosional structures. Only in the Wara section, some beds display uneven soles or even wedging out. In one case, a thick turbidite truncates erosionally two thin underlying beds. Moreover, in the Wara section, a small erosional channel crops out. It is filled with a debris-flow deposit (Fig. 3).

The beds are commonly cracked, and the cracks and bed surfaces are impregnated with mangane oxides. Generally, the beds become lighter in colour towards the top.

In several sections, the Nienadowa Marl Member comprises intercalations or is replaced by debris-flow deposits of the Czudec Clay, which are also present in other parts of the Hieroglyphic Formation, but concentrate close to the Nienadowa Marl Member (Rajchel, 1990). The Czudec Clay, apart of different exotic pebbles supported by muddy matrix, contains also fragments of marlstone beds or marlstone clasts, which are very similar to the marlstones from the Nienadowa Marl Member, but usually less silicified, and without the Bouma sequence and bedding planes. Probably, they were deposited particle by particle on basin slope or deeper shelf. The marlstone clasts were analysed in the Wara section.

The Nienadowa Marl Member is dated at the Early/Middle Eocene on the base of benthic foraminifers (Rajchel, 1990), and related to the uppermost part of the *Saccaminoides carpathicus* Zone and to the lowermost part of the *Reticulophragmium amplectens* Zone, according to Morgiel & Szymakowska (1978), and Geroch & Nowak (1984). The interval is correlated to the transition between the P9 and P10 zones (Toumarkine & Luterbacher, 1985), and to *Buriella clinata* through *Theocotyle cryptocephala* radiolarians zones (Bąk *et al.*, 1997).

SEDIMENTARY ENVIRONMENT

Probably, sedimentation of the Nienadowa Marl Member deposits was strongly influenced by sediments in the source area. Quartz-glauconitic sands and marly muds were redeposited together in turbidity currents. Possibly, these sediments, derived probably from different energy/bathymetric zones, have been mixed together on their way downslope. The non-calcareous pelagic shales in some beds in the Zabratówka Wieś section (Fig. 5), suggest temporary deposition close or below the CCD (cf. Hesse, 1975). Intercalations or associations of debris-flow deposits indicate periods of slope instability due to tectonic activity and/or eustatic changes. It is not clear if the deposits accumulated in a deep-sea fan, or tongue-shaped cover, or in some other depositional form. Nevertheless, some proximal/distal trend can be recognized. It can't be excluded that individual turbidites contain more sand in the proximal part and more marl in the distal part, similary to detrital carbonate turbidites (Meischner, 1964; Einsele, 1991). Thus, it can be concluded that the more sandy facies of the Wara section, with common scouring, discontinuous beds, erosional channel, and association of debris-flow deposits, are more proximal than the remaining deposits from the other studied sections.

TRACE FOSSILS

The following trace fossils were recognized: *Chondrites targionii*, *Palaeophycus* isp., *Phycosiphon incertum*, *Planolites* isp., *Scolicia* isp., ?*Taenidium* isp., ?*Teichnichnus* isp., and *Thalassinoides suevicus*. They have been observed on parting surfaces and in polished slabs.

Chondrites targionii (Brongniart 1828) (Fig. 7A) occurs as regularly branching tunnel systems consisting of flattened, commonly slightly curved, cylinders, which ramify at depth to form a dendritic network. Primary successive branchings are well visible. The angle of branching is usually sharp. The cylinders are 1.5–2.0 mm wide. Their filling is commonly darker or lighter and more fine-grained than the host rock. In cross-sections, groups of small spots occur (Figs. 7F, 8A–D, 9A–B, 10A, C). They are interpreted as *Chondrites* isp.

Palaeophycus isp. (Fig. 10C) is a horizontal to oblique, thin-walled cylindrical trace fossil, about 2 mm wide, preserved in endichnial full relief.

Phycosiphon incertum Fischer-Ooster 1858 (Figs. 7C–E, 8D, 9B) occurs in horizontal sections as small, planar, light spreite lobes, bordered by a thin, dark-filled marginal tunnel. The tunnel is 0.7–1.0 mm wide, and the lobes are 2–3 mm wide and up to 15 mm long. In cross-section, they are visible as thin horizons of darker, elongate spots surrounded by a lighter mantle, which were previously described as *Anconichnus horizontalis* Kern (1978) that, in turn, has been placed in synonymy with *Phycosiphon incertum* (Wetzel & Bromley, 1994).

Planolites isp. (Fig. 10A, C) is a horizontal or subhorizontal, simple, cylindrical, unwalled burrow, preserved in full relief, with structurless filling differing in lithology from the host rock. The burrow is 3–6 mm wide. Rarely, this form is preserved in semi-relief on soles of beds.

Scolicia isp. (Figs. 7F, 8A, 10C) is a horizontal cylindrical trace fossil, which is elliptical, slightly bilobated in cross section. Its meniscate filling is well visible along the middle part of the trace fossil in the longitudinal vertical section. The trace fossil is about 25 mm wide and about 20 mm high in cross section. *Scolicia* is produced by echinoids (Smith & Crimes, 1983).

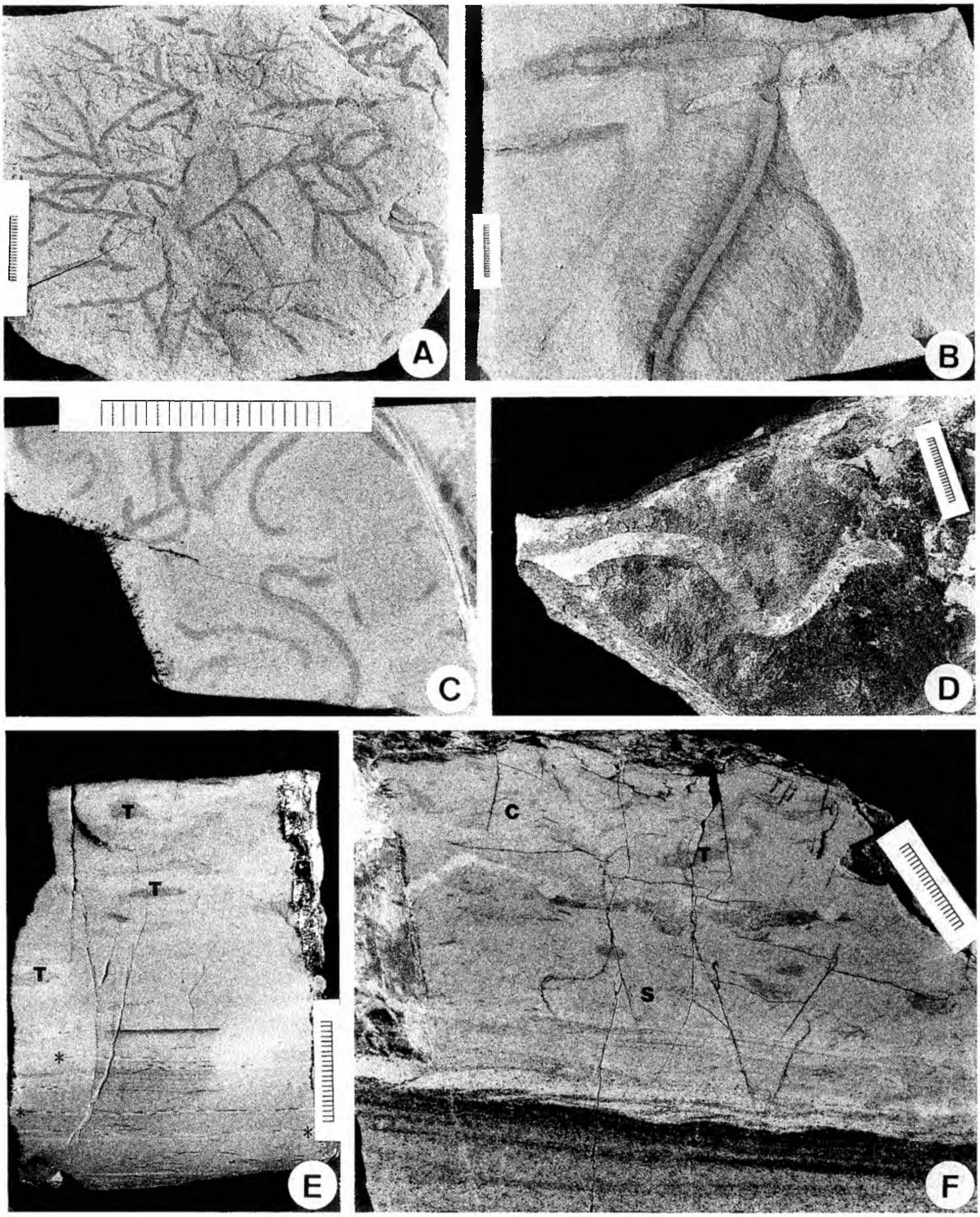

Fig. 7. Trace fossils and examples of ichnofabrics from the Nienadowa Marl Member. Millimetric scale. **A.** *Chondrites targionii*; gaize sandstones, horizontal parting surface, Wara, U25. **B.** *Thalassinoides suevicus*; gaize sandstones, horizontal parting surface, Wara, U19. **C.** *Phycosiphon incertum*; siliceous marlstone, horizontal surface, Zabratówka Wieś, W16. **D.** ?*Thalassinoides* isp.; Wara, marlstone, U18. **E.** *Thalassinoides* (T) in totally bioturbated background, and *Phycosiphon* in thin horizons (*); siliceous marlstone, vertical cross-section, Zabratówka Wieś, W16. **F.** *Thalassinoides* (T), *Chondrites* (C) and ?*Scolicia* (S) in totally bioturbated background; glauconitic sandstone in the lower part, and siliceous marlstone in the middle and in the upper part; vertical cross-section, Zabratówka Góra, Z28

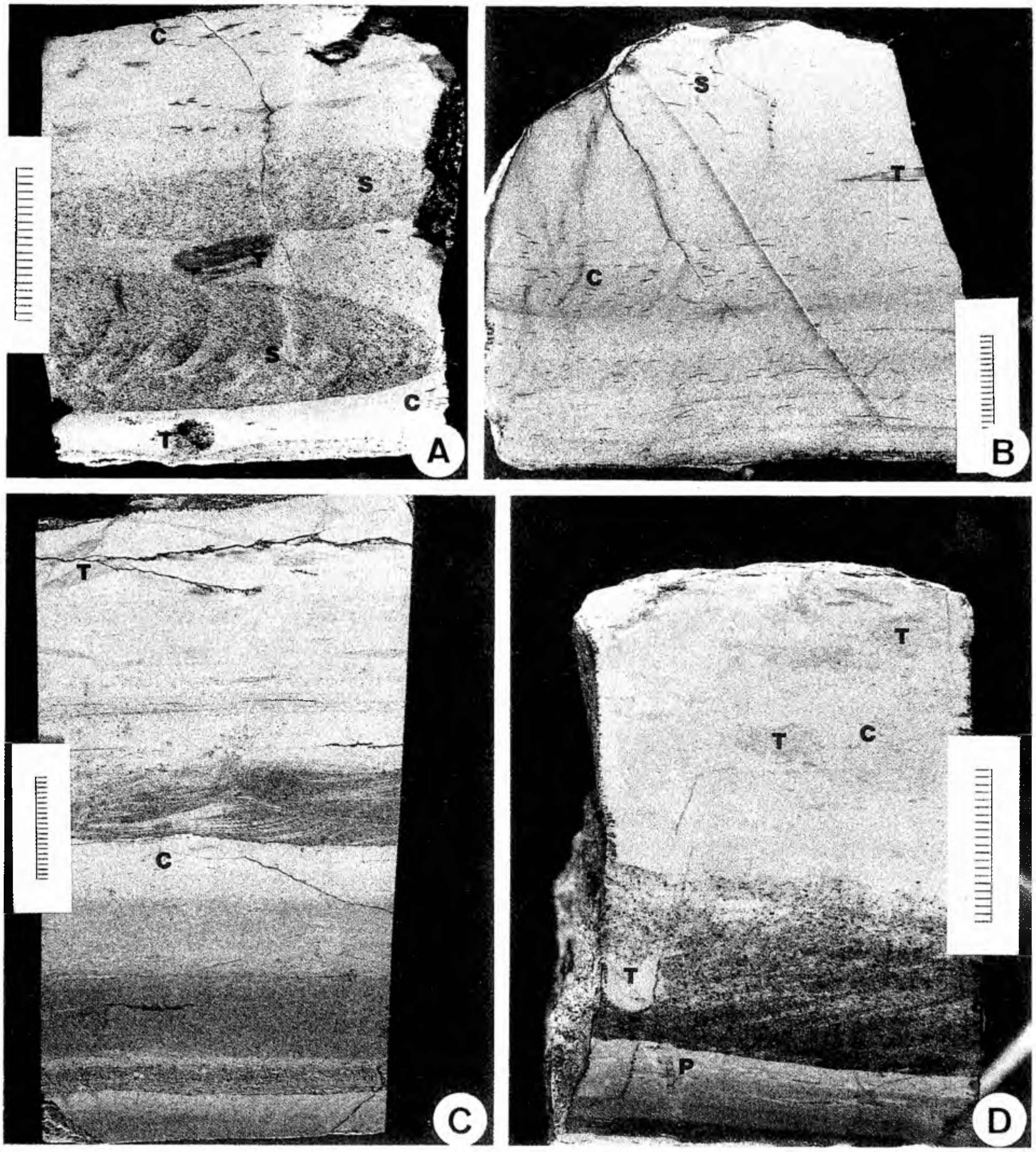

Fig. 8. Examples of ichnofabrics from the Nienadowa Marl Member in vertical cross-sections. Millimetric scale. **A.** *Scolicia* (S), *Thalassinoides* (T) and *Chondrites* (C) in totally bioturbated background. The cemented underbed in the lower part is composed of sandstone overlaid by marlstone. *Thalassinoides* is filled with glauconitic sandstone piped from the overlying bed. *Scolicia* is filled with glauconitic sandstone. The upper part of the bed is composed of totally bioturbated marlstone; Zabratówka Góra, Z29. **B.** *Chondrites* (C) and *Thalassinoides* (T) in siliceous marlstone. Background of the upper part is totally bioturbated; horizontal lamination is present in the lower part; Nienadowa, N12. **C.** An underbed and two turbidites cemented together in a single layer. The turbidites are composed of thin basal sandstone layer overlain by marlstone. The upper part of the marlstone is totally bioturbated. The larger spots in the upper turbidite are cross-sections of *Thalassinoides* (T). The smaller spots and specks are *Chondrites* (C) traces; Nienadowa, N16. **D.** A turbidite with underbed. *Phycosiphon* (P) in the upper part of the underbed. *Thalassinoides* (T) and *Chondrites* (C) are common in the upper, marlstone part of the bed and rare in the lower, sandstone part of the bed; Zabratówka Wieś, W19

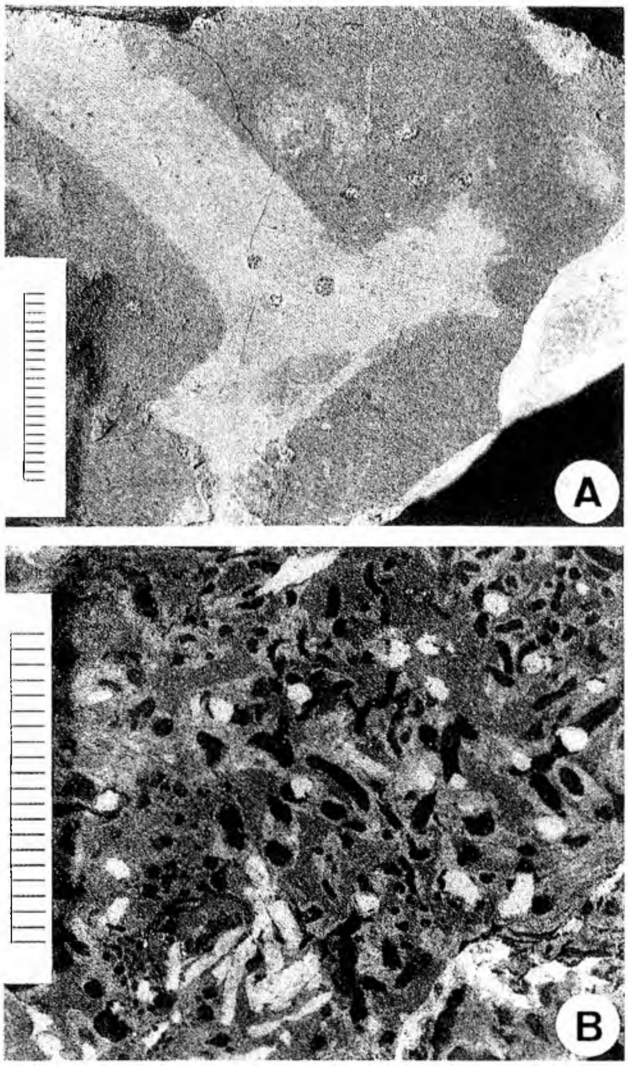

Fig. 9. Examples of ichnofabrics from the Nienadowa Marl Member in horizontal cross-sections. Millimetric scale. **A.** *Thalassinoides suevicus* crosscut by small sandy pipes, which are probably shafts of *Chondrites*. Lower surface of the underbed illustrated in Fig. 8D; marlstone, Zabratówka Wieś, W19. **B.** *Phycosiphon incertum* (darker spots in light mantle) crosscut by *Chondrites* (light spots). The upper part of the same underbed illustrated in Figs. 8D and 9A; marlstone, Zabratówka Wieś, W19

?*Taenidium* isp. (Fig. 10C) is a horizontal winding, unwalled trace fossil, 7 mm in diameter. It is filled with darker, meniscate sediment.

?*Teichnichnus* isp. (Fig. 10C) is an endichnial vertically-stacked, unwalled spreiten structure, 6–8 mm wide, and at least 20 mm long.

Thalassinoides suevicus (Rieth 1932) (Figs. 7B, 9A) is a predominantly horizontal, more or less regularly branched, essentially cylindrical, smooth, walled to unwalled, filled burrow system. Individual tunnels are 6–13 mm wide. Dichotomous Y-shape bifurcations, without enlargement at points of bifurcation, are common. The fill is the same as the host rock or is coarser- or finer-grained. Locally, in the Wara section, the burrows are filled with a soft, green argillaceous substance, which locally impregnates also the burrow wall. Occasionally, the filling displays meniscate structure. Rarely, this ichnotaxon is preserved in semi-relief on beds sole. In cross-sections, *Thalassinoides* occurs as oval spots (Figs. 7E–F, 8A–D, 9A, 10A, C). A single, meandering, cylindrical trace fossil from the Wara section (Fig. 7D)

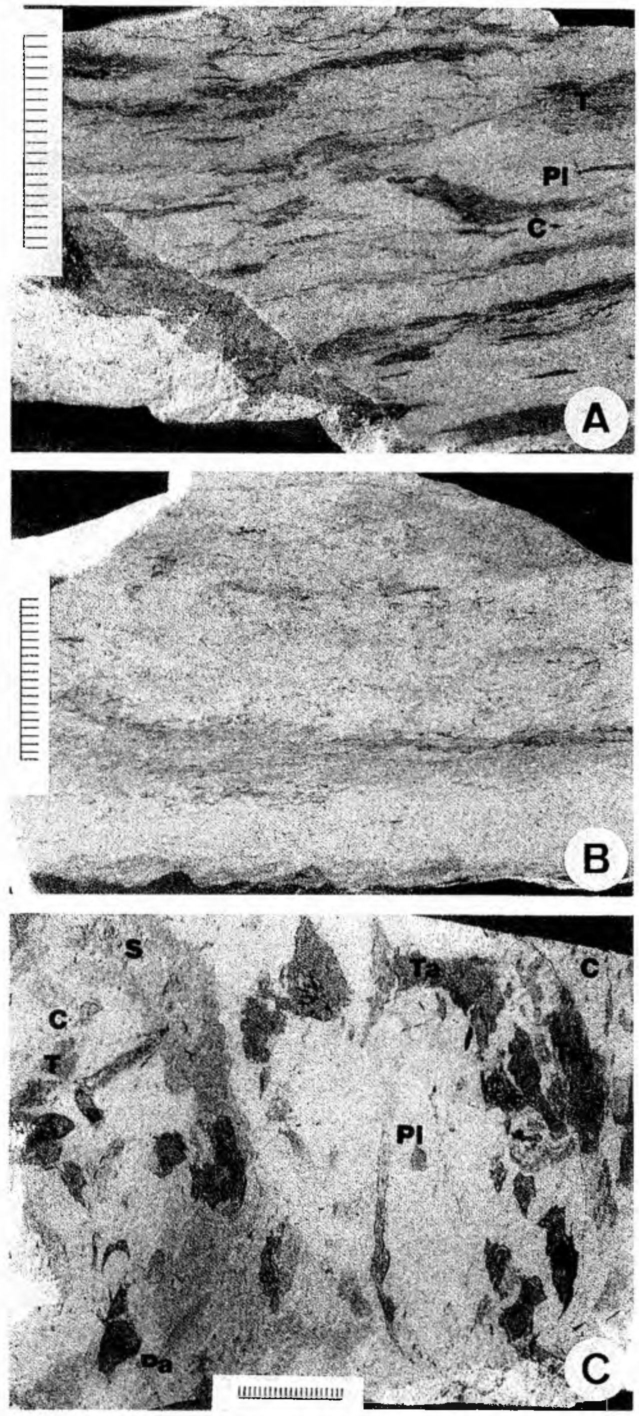

Fig. 10. Examples of ichnofabrics in marlstone clasts from the debris-flow deposits of the Czudec Clay at Wara. Millimetric scale. **A.** Smeared *Thalassinoides* (T), *Planolites* (Pl) and *Chondrites* (C) in totally bioturbated background. **B.** Vague mottling in totally bioturbated background. **C.** *Thalassinoides* (T), *Planolites* (Pl), *Chondrites* (C), *Scolicia* (S), *Palaeophycus* (Pa), ?*Teichichnus* (Te) and ?*Taenidium* (Ta) in totally bioturbated background

is probably a fragment of *Thalassinoides*. This taxon is produced mainly by crustaceans (Bromley, 1996).

DISTRIBUTION OF TRACE FOSSILS AND ICHNOFABRICS

Chondrites, *Planolites* and *Thalassinoides* occur in all examined sections (Figs. 3–6). *Phycosiphon* is present only in the Nienadowa and Zabratówka Wieś sections, and *Scolicia* occurs only in the Zabratówka Góra section. Majority of the trace fossils occur within beds as endichnia and exichnia forms.

The soft mudstones or marlstones at the top of turbiditic beds are totally bioturbated. In most cases, trace fossils are not visible there in polished slabs, or only better visible *Chondrites* and poorly contrasted *Planolites* locally occur against bioturbated background. The bioturbated background is characterized by more or less distinct mottling expressed by colour changes. Only some underbeds display more distinct trace fossils, including *Chondrites*, *Planolites*, *Thalassinoides* and *Phycosiphon* (Fig. 9A–B).

The upper parts of the hard marlstone and sandstone beds, below the mudstones, and the entire thin beds, display totally bioturbated background (Fig. 8A–B). Common *Planolites* and *Chondrites* and less common *Thalassinoides* and *Phycosiphon* occur in these parts of beds. Contours of trace fossils are commonly smeared and their appearance is modified by diagenetic processes, mainly dissolution.

In the middle and lower parts of beds, commonly thicker than 7–10 cm, except of some thin beds, primary sedimentary structures are preserved. Trace fossils are there absent or rare. *Thalassinoides*, *Scolicia*, *Phycosiphon* and *Chondrites* represent there the locally encountered ichnotaxa (Figs. 7E–F, 8A–D).

The soles of beds are only rarely covered with semireliefs of *Planolites* and undeterminable knobs, and more rarely with semireliefs of *Thalassinoides*.

Locally, the fills of *Thalassinoides* and *Planolites* are preferentially reworked by *Chondrites*. *Planolites* and *Chondrites* occur more commonly in fine-grained deposits. *Scolicia* is associated with sandstones. *Phycosiphon* occurs exclusively in marlstones. *Thalassinoides* does not show any lithological preferences.

TIERING PATTERN

Burrows are formed at different levels (tiers) within the sediment. Tiering patterns of some fossils in turbidite beds and the overlying pelagic and hemipelagic deposits is usually recognized on the grounds of the toponomic position of traces and their cross-cutting relationships (Wetzel & Aigner, 1986; Uchman, 1991). However, in the case of deep bioturbation in thin-bedded flysch this can be very complicated, because some deeper trace fossils extend to older turbidites (Uchman, 1995) and overprint older ichnofabric. For this reason, such forms as *Chondrites* can occur both in the lower part of beds, where primary depositional structures are preserved, and in the totally bioturbated uppermost part of beds (Figs. 7F, 8A–D, 11). Thus application of the toponomic position to the recognition of tiering pattern is limited in deeply-burrowed thin-bedded flysch.

We observed several cross-cutting relationships. *Phycosiphon* and *Planolites* are crosscut by *Chondrites* and *Thalassinoides*. *Thalassinoides* is crosscut by *Chondrites*. *Scolicia* is crosscut by *Thalassinoides* and *Chondrites*. Thus *Chondrites* crosscuts all other trace fossils. This suggests that *Chondrites* is the deepest trace fossil, analogically as in the English Chalk (Bromley & Ekdale, 1986; Ekdale & Bromley, 1991). However, in two thick beds of the Wara section *Thalassinoides* occurs up to 18 cm and *Chondrites* only up to 8 cm, down from the eroded tops of the beds. This indicates that *Thalassinoides* is deeper than *Chondrites*.

Probably, the maximum penetration depth in the investigated sections does not exceed 25 cm, including compaction. Shallow tiers are occupied by *Scolicia*, *Phycosiphon* and *Planolites*. Models of tiering pattern in certain sections are shown in Fig. 12.

The marlstone clasts from the Czudec Clay in the Wara section contain three types of ichnofabrics (Fig. 10). The trace fossil tiering pattern in

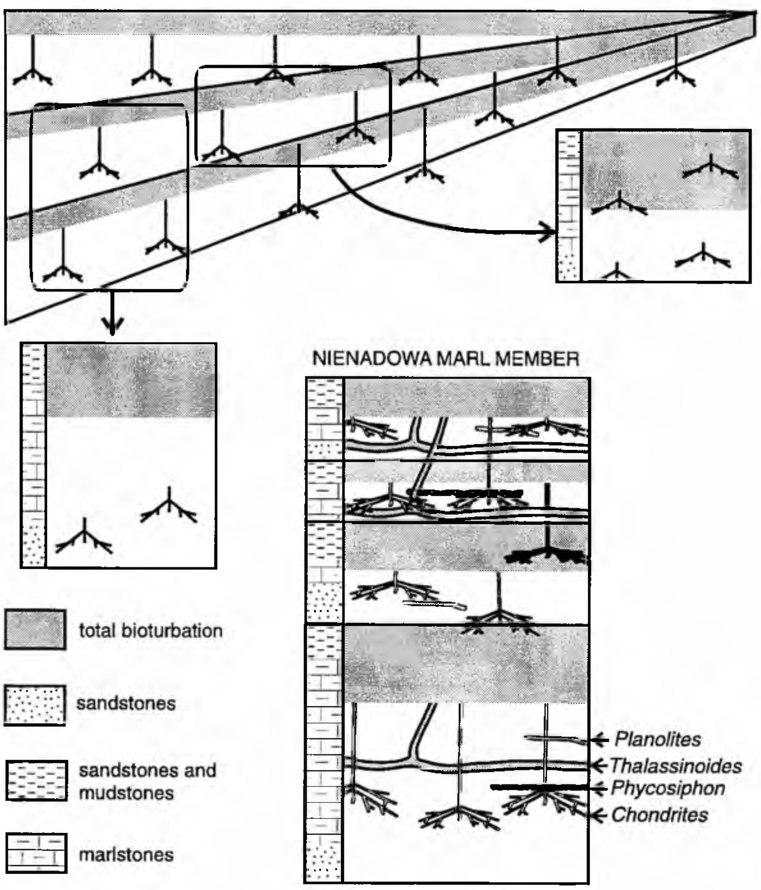

Fig. 11. Toponomic position of *Chondrites* in turbiditic beds of different thickness

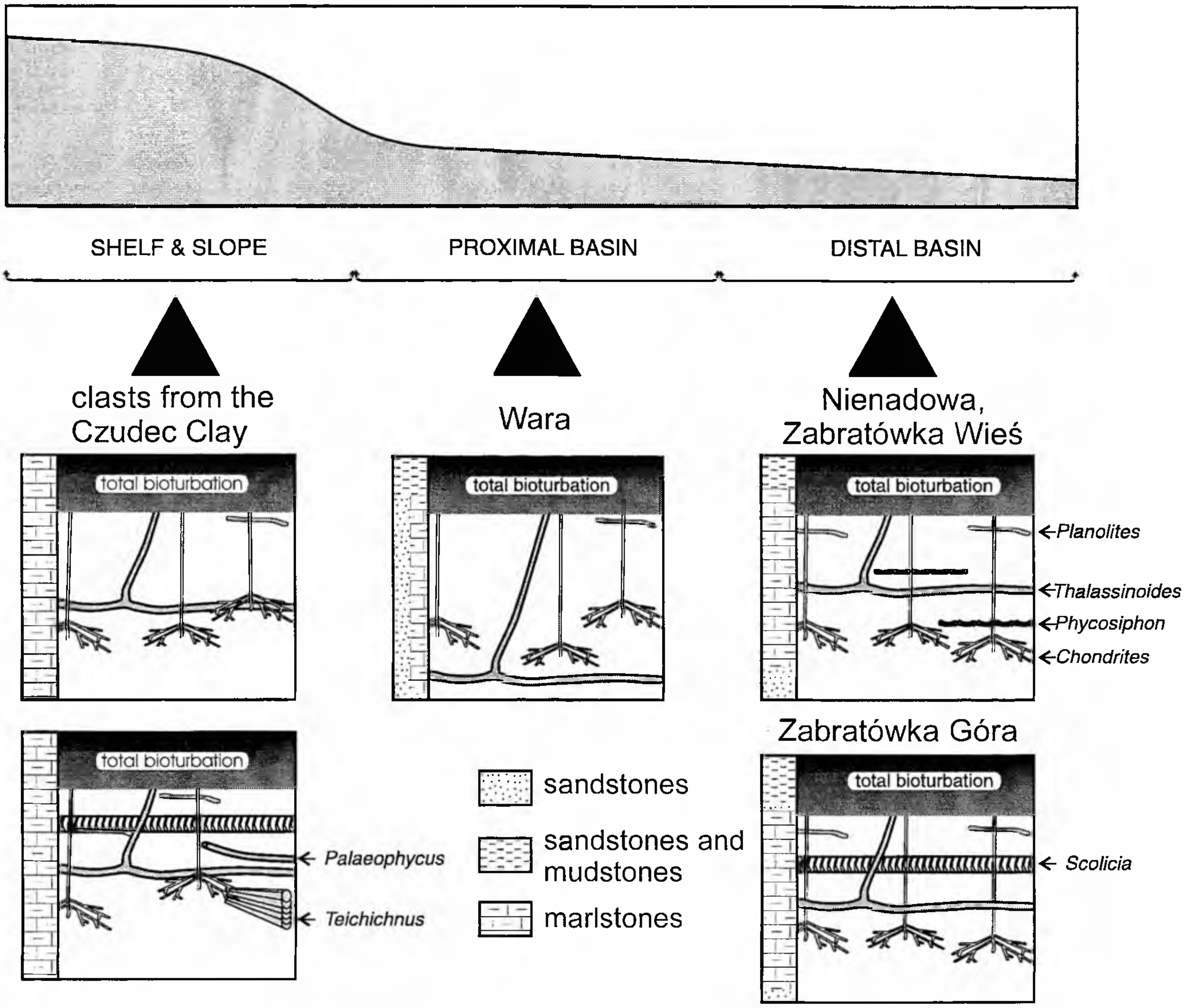

Fig. 12. Tiering patterns from different sections and their palaeoenvironmental location

these rocks (Fig. 12) can be reconstructed on the base of crosscutting relationships, similarly like in the Chalk (Ekdale & Bromley, 1991; Bromley, 1996).

In the first case, smeared *Thalassinoides*, *Planolites* and *Chondrites* occur against totally bioturbated background (Fig. 10). Trace fossils are elongated, probably owing to creep of sediment, and deformed by solution seams. *Chondrites* crosscuts *Thalassinoides* and *Planolites*.

In the second case, only a vague mottling is visible in totally bioturbated background (Fig. 10B). Some remnants of darker laminae are present.

In the third case, *Thalassinoides*, *Planolites*, *Chondrites*, *Scolicia*, *Palaeophycus*, ?*Teichichnus* and ?*Taenidium* occur against totally bioturbated background (Fig. 10C). *Scolicia* is crosscut by *Thalassinoides*, *Planolites* and *Chondrites*. ?*Taenidium* is crosscut by *Thalassinoides*, *Chondrites* and *Planolites*, though one *Thalassinoides* burrow is crosscut by ?*Taenidium*. *Chondrites* crosscuts ?*Teichichnus*, *Thalassinoides* and *Planolites*.

DISCUSSION

Complex ichnofabrics and deep bioturbation are typical of well-oxygenated environments (Bromley, 1996). Such a situation occurs in the Nienadowa Marl Member, however, its trace fossil community is much less diversified than in most thin-bedded and oxygenated siliciclastic Eocene flysch deposits (cf. Crimes, 1977; Książkiewicz, 1977b; Leszczyński & Seilacher, 1991; Uchman, 1992; Tunis & Uchman, 1996a, b). This concerns especially trace fossils occurring on soles of turbidites. The discussed trace fossil community is exclusively composed of a few common, mostly opportunistic ichnotaxa, i.e. *Thalassinoides*, *Chondrites*, *Planolites*, *Phycosiphon* and *Scolicia*, where the first mentioned three are most frequent. The low diversity could have been caused by diagenetic obliteration, which is usually stronger in calcareous than in siliciclastic sediments. However, the main cause of the situation seems to be strongly connected with the sedimentary environment. It can not be excluded that the conditions preferred opportunistic trace makers, which commonly produce simple burrows. The occurrence of abundant radiolaria in the investigated sediments indicates rather high productivity and eutrophic conditions in the upper part of the water column (cf. Brasier, 1995). Probably most food available for benthic organisms derived from pelagic runoff. Therefore, bioturbation concentrated near the sea-floor, in shallow tiers, where preservation potential of trace fossils is very low because of soupy sediment consistency. Bąk *et al.* (1997) recognized that foraminifers and radiolarians indicated increasing trophic levels from Early to Middle Eocene in the Skole Basin, and foraminifers are dominated by epifaunal and shallow infaunal forms. The possible increase of trophic level, however, contrasts with low content of organic matter, which is here deduced from the light colour of the deposits (Potter *et al.*, 1980). On the other hand, preservation of organic matter in well-oxygenated environments can be very poor. It is also possible that strongly polymictic sediment composition, with siliciclastic, carbonate, glauconite, and siliceous grains, partially prevented stronger burrowing specialization. It is known that glauconitic and heavy-mineral grains are not ingested by producers of shallow-water trace fossil *Macaronichnus*, because surface of such grains is not suitable for formation of nutritional organic film (Clifton & Thompson, 1978). Similar factors may have influenced ichnofauna in deep-sea environments of the Nienadowa Marl Member.

The trace-fossil assemblage of the Nienadowa Marl Member is neither similar to the expected flysch Nereites ichnofacies, which is typified by graphoglyptids and meandering deposit-feeders (Seilacher, 1967; Frey & Seilacher, 1980), nor to the other classical ichnofacies. It displays, however, some similarities to the trace fossil assemblage from the Lower–Middle Eocene calcareous turbidites of the Monte Solare in the Northern Apennines (Monaco, 1996). In the proximal turbidites of these deposits, *Thalassinoides* and *Ophiomorpha* occupy the deepest tier, *Chondrites* and *Palaeophycus* the middle tier, and *Chondrites* and *Planolites* the shallowest tier. In more distal turbidites, the deepest tier is composed of *Chondrites* and *Thalassinoides* and *Ophiomorpha*. *Nereites*, *Planolites*, *Taenidium* and *Zoophycos* occur in the shallower tiers. Thus, that tiering pattern differs mainly from that in the here discussed deposits in the occurrence of *Nereites*, *Zoophycos* and *Taenidium*, though *Phycosiphon* can be regarded as an equivalent of *Nereites* in the Nienadowa Marl Member.

Powichrowski (1989) studied trace fossils of the Helminthoid Flysch (Upper Cretaceous–Paleocene) from the Ligurian Alps in Italy. He distinguished six trace fossil assemblages mostly in mixed siliciclastic-marly turbidites. Most of them contain *Nereites* (=*Helminthoida*), which does not occur in the Nienadowa Marl Member. However, the "*Chondrites-Scolicia-Thalassinoides* tiered assemblage" displays some similarities to the described trace fossil assemblage. Nevertheless, it occurs in thin-bedded sandy turbidites. The Powichrowski's "Graphoglyptid-*Helminthoida-Chondrites-Thalassinoides* tiered assemblage" occurs in siliciclastic-marly turbidites like in the studied sections, but graphoglyptids and *Nereites* (=*Helminthoida*) were not found in the Nienadowa Marl Member.

The Upper Cretaceous marly flysch deposits in the Northern Apennines (Scholle, 1971) and the Alps (Hesse, 1975; *personal observations*) contain abundant *Nereites* (formerly *Helminthoida*; discussion in Uchman, 1995).

It is very characteristic of the Nienadowa Marl Member and the flysch of Monte Solare that *Thalassinoides* penetrates deeper than *Chondrites* in the proximal sections and shallower than *Chondrites* in the distal sections (Fig. 12). Similar situation, where *Thalassinoides* penetrates deeper than *Chondrites*, was described in the Miocene Monterrey Formation in California. This was explained by the fact that the *Thalassinoides* tracemaker penetrates deeper than *Chondrites* in strongly cohesive sediment (Savrda & Bottjer, 1987). Such a situation is possible in calcareous turbidites, where an early diagenetic increase of cohesion can be expected. In the Chalk, *Chondrites* penetrates deeper than *Thalassinoides* (Ekdale & Bromley, 1991).

There are some differences between ichnoassemblages in particular sections, including the clasts from the Czudec Clay. *Phycosiphon*, which is present in more distal sections (Nienadowa, Zabratówka Wieś), is absent in the more proximal section at Wara. *Scolicia* is present in the distal basinal section (Zabratówka Góra) and in the slope- or shelf-derived clasts from the Czudec Clay. It is possible, that this trace fossil was produced by taxonomically different echinoids in these two different environments.

The slope- or shelf-derived clasts contain very diversified ichnofabrics. Most probably they derive from different environments. The *Thalassinoides-Planolites-Chondrites* ichnofabric with features indicating of sediment creeping (Fig. 10A) can be related to the basin slope. It is very similar to the ichnofabric from the shelf Chalk (Ekdale & Bromley, 1991; Bromley, 1996) or the Paleocene high-stand limestones from the eastern coast of the USA (Savrda, 1991). Some clasts contain much more composite ichnofabric than this from the basinal sections, with *Thalassinoides*, *Planolites*, *Chondrites*, *Scolicia*, *Palaeophycus*, ?*Teichichnus* and ?*Taenidium* (Fig. 10C). It can not be excluded that these clasts derive from an outer shelf. Almost homogenous ichnofabrics in some clasts (Fig. 10B) result probably from bioturbation in low-cohesion sediment and latter diagenetic changes.

CONCLUSIONS

The Nienadowa Marl Member, composed mainly of different marly, mixed siliciclastic-marly, or siliciclastic thin-bedded turbidites, is deeply burrowed and deposited in well-oxygenated environment. Investigated trace fossil assemblage is poorly diversified, and composed of opportunistic ichnotaxa. This is probably due to environmental preference of opportunistic burrowing behaviour, related to possible increase of the trophic level and strong sediment heterogeneity, as well as to preservational potential. The trace fossil assemblage cannot be related to any classic ichnofacies. It displays some similarities to the ichnoassemblage from the Eocene calcareous flysch of Monte Solare in the Northern Apennines (Monaco, 1996). The analysis of bioturbation depth allows to conclude that *Thalassinoides* penetrates deeper than *Chondrites* in proximal turbidites and shallower than *Chondrites* in distal turbidites. Ichnofabrics and trace-fossil tiering patterns are different in the basinal sections of the Nienadowa Marl Member and in the slope to shelf environment represented by marlstone clasts in the debris-flow deposits of the Czudec Clay. Application of the toponomic position for recognition of tiering pattern is limited in the case of deeply-burrowed thin-bedded flysch, because of overprinting of deep-tier trace fossils on ichnofabrics of older turbidites.

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REFERENCES

Bąk, K., Bąk, M., Geroch, S. & Manecki, M., 1997. Biostratigraphy and paleoenvironmental analysis of benthic Foraminifera and radiolarians in Paleogene variegated shales in the Skole Unit, Polish Flysch Carpathians. *Ann. Soc. Geol. Polon.*, 67: 135–154.

Brasier, M. D., 1995. Fossil indicators of nutrient level. 1: Eutrophication and climate change. In: Bosence, D. W. J. & Allison, P. A. (eds.), *Marine Palaeoenvironmental Analysis from Fossils. Geol. Soc. Spec. Publ.*, 83: 113–132.

Bromley, R. G. & Ekdale, A. A., 1986. Composite ichnofabric and tiering burrows. *Geol. Magaz.*, 123: 49–65.

Bromley, R. G., 1996. *Trace Fossils. Biology. Taphonomy and Applications.* Chapman & Hall, London, 361 pp.

Clifton, H. E. & Thompson, J. K., 1978. *Macaronichnus segregatis*: A feeding structure of shallow marine polychaetes. *J. Sediment. Petrol.*, 48: 1293–1302.

Crimes, T. P., 1977. Trace fossils of an Eocene deep-sea fan, northern Spain. In: Crimes, T. P. & Harper, J. C. (eds.), Trace fossils 2. *Geol. J. Spec. Issue*, 9: 71–90.

Einsele, G., 1991. Submarine mass flow deposits and turbidites. In: Einsele, G., Ricken, W. & Seilacher, A. (eds.), *Cycles and Events in Stratigraphy*. Springer, Berlin, p. 313–339.

Ekdale, A. A. & Bromley, R. G., 1991. Analysis of composite ichnofabrics: an example in Uppermost Cretaceous chalk of Denmark. *Palaios*, 6: 232–249.

Frey, R. W. & Seilacher, A., 1980. Uniformity in marine invertebrate ichnology. *Lethaia*, 23: 183–207.

Geroch, S. & Nowak, W., 1984. Proposal of zonation of the Late Tithonian–Late Eocene, based upon arenaceous Foraminifera from the Outer Carpathians, Poland. In: Oertli, H. J. (ed.), *Benthos '83: 2nd International Symposium on Benthic Foraminifera, Pau (France), April 11-15, 1983.* Bull. Centres Rech. Explor.-Prod. Elf Aquitaine, Memoirs. Elf-Aquitane, ESSO REP and TOTAL CFP, Pau & Bordeaux, 6, pp. 225–239.

Hesse, R., 1975. Turbiditic and non-turbiditic mudstones of Cretaceous flysch sections of the East Alps and other basins. *Sedimentology*, 22: 387–416.

Kern, J. P., 1978. Paleoenvironment of new trace fossil from the Eocene Mission Valley Formation, California. *J. Paleont.*, 52: 186–194.

Kotlarczyk, J., 1988. Problemy sedymentologii, stratygrafii i tektoniki Karpat Przemyskich oraz ich najbliższego przedpola. (In Polish only). In: Kotlarczyk, J. (ed.), *Przewodnik 59 Zjazdu Polskiego Towarzystwa Geologicznego. Karpaty Przemyskie.* Wydawnictwa AGH, Kraków, pp. 23–62.

Książkiewicz, M., 1977a. The tectonics of the Carpathians. In: *Geology of Poland. Volume IV. Tectonics.* Wydawictwa Geologiczne, Warszawa, pp. 476–620.

Książkiewicz, M., 1977b. Trace fossils in the Flysch of the Polish Carpathians. *Palaeont. Polon.*, 36: 1–208.

Leszczyński, S. & Seilacher, A., 1991. Ichnocoenoses of a turbidite sole. *Ichnos*, 1: 293–303.

Meischner, K. D., 1964. Allodapische Kalke, Turbidite in Riff-nahen Sedimentationsbecken. In: Bouma, A. H. & Brouver, A. (eds.), *Turbidites. Developments in Sedimentology*, 3. Elsevier, Amsterdam, pp. 156–191.

Monaco, P., 1996. Ichnofabric as a tool to identify turbiditic or tempestitic substrates: two examples from Jurassic and Middle Eocene in the Central Apennines (Italy). *Comunicación de la II Reunión de Tafonomía y fosilización. Zaragoza, 13-15 June*, University of Zaragoza, Zaragoza, pp. 247–253.

Morgiel, J. & Szymakowska, F., 1978. Paleocene and Eocene stratigraphy of the Skole Unit. (In Polish, English summary). *Państw. Inst. Geol., Biul.*, 310: 39–71.

Potter, P. E., Maynard, B. J. & Pryor, W. A., 1980. *Sedimentology of Shale. Study Guide and Reference Source.* Springer, New York, 310 pp.

Powichrowski, L. K., 1989. Trace fossils from the Helminthoidal Flysch (Upper Cretaceous–Paleocene) of the Ligurian Alps (Italy): development of deep marine ichnoassociations in fan and basin plain environments. *Eclog. Geol. Helv.*, 82: 385–411.

Rajchel, J., 1990. Litostratygraphy of the Upper Paleocene and Eocene deposits in the Skole Unit. (In Polish, English summary). *Zeszyty Naukowe AGH, Geologia*, 48: 1–112.

Ricken, W. & Elder, W., 1991. Diagenetic modification of calcareous beds – an overview. In: Einsele, G., Ricken, W. & Seilacher, A. (eds.), *Cycles and Events in Stratigraphy.* Springer, Berlin, pp. 430–449.

Savrda, C. E. & Bottjer, D. J., 1987. Trace fossils as indicators of bottom-water redox conditions in ancient marine environments. In: Bottjer, D. J. (ed.), *New concepts in the use of biogenic sedimentary structures for paleoenvironmental interpretation. Volume and Guidebook.* Pacific Section of the Society of Economic Paleontologists and Mineralogists, Los Angeles, pp. 3–26.

Scholle, P., 1971. Sedimentology of fine-grained deep-water carbonate turbidites, Monte Antola Flysch (Upper Cretaceous), northern Apennines, Italy. *Bull. Geol. Soc. Amer.*, 82: 629–658.

Seilacher, A., 1967. Bathymetry of trace fossils. *Marine Geol.*, 5: 413–426.

Smith, A. B. & Crimes, T. P., 1983. Trace fossils formed by heart urchins – a study of *Scolicia* and related traces. *Lethaia*, 16: 79–92.

Toumarkine, M. & Luterbacher, H., 1985. Paleocene and Eocene planktic foraminifera. In: Bolli, H. M. *et al.* (eds.), *Plankton stratigraphy.* Cambridge University Press, Cambridge, pp. 87–154.

Tunis, G. & Uchman, A., 1996a. Trace fossil and facies changes in the Upper Cretaceous–Middle Eocene flysch deposits of the Julian Prealps (Italy and Slovenia): consequences of regional and world-wide changes. *Ichnos*, 4: 169–190.

Tunis, G. & Uchman, A., 1996b. Ichnology of the Eocene flysch deposits of the Istria Peninsula, Croatia and Slovenia. *Ichnos*, 5: 1–22.

Uchman, A., 1991. Diversified tiering patterns in Paleogene flysch trace fossils of the Magura nappe, Carpathians Mountains, Poland. *Ichnos*, 1: 287–292.

Uchman, A., 1992. Trace fossils of the Eocene thin- and medium-bedded flysch of the Bystrica Zone of the Magura Nappe, in Poland. (In Polish, English summary). *Przegl. Geol.*, 40: 430–436.

Uchman, A., 1995. Taxonomy and palaeoecology of flysch trace fossils: The Marnoso-arenacea Formation and associated facies (Miocene, Northern Apennines, Italy). *Beringeria*, 15: 1–115.

Wetzel, A. & Aigner, T., 1986. Stratigraphic completeness: Tiered trace fossils provide a measuring stick. *Geology*, 14: 234–237.

Wetzel, A. & Bromley, R. G., 1994. *Phycosiphon incertum* revisited: *Anconichnus horizontalis* is its junior subjective synonym. *J. Paleont.*, 68: 1369–1402.

Streszczenie

ICHNOLOGIA EOCEŃSKIEGO FLISZU SILIKOKLASTYCZNO-MARGLISTEGO Z OGNIWA MARGLI Z NIENADOWEJ (OG) (JEDNOSTKA SKOLSKA, POLSKIE KARPATY FLISZOWE)

Jacek Rajchel & Alfred Uchman

Opisano asocjację skamieniałości śladowych z ogniwa margli z Nienadowej (og) formacji hieroglifowej (fm) w jednostce skolskiej oraz z klastów i porwaków margli występujących w iłach z Czudca tej jednostki (Fig. 1, 2). Ogniwo margli z Nienadowej (og) jest ważnym horyzontem korelacyjnym w jednostce skolskiej, mimo znacznego zróżnicowania facjalnego i miąższościowego (kilka do kilkunastu metrów, maksymalnie do 70 m).

Wiek ogniwa margli z Nienadowej (og), jak i współwystępujących z nim iłów z Czudca określono na przełom wczesnego i środkowego eocenu, na podstawie otwornic (Rajchel, 1990).

Utwory ogniwa margli z Nienadowej (og) zawierają różnorodne turbidyty i interturbidyty. Miąższość ławic wynosi średnio od 5 do 30 cm. Turbidyty zbudowane są ze zwięzłych margli, margli ilastych, zapiaszczonych i skrzemionkowanych oraz piaskowców, także z glaukonitem. Interturbidyty wykształcone są jako margle oraz wapniste lub bezwapniste mułowce (Fig. 3–6).

Iły z Czudca tworzą szereg soczew o miąższości do 10 m, zazębiających się z ogniwem margli z Nienadowej (og) (Fig. 2, 3). Są to osady podmorskich, kohezyjnych spływów grawitacyjnych (*debris flow*). Zawierają one klasty i porwaki ławic margli, zbliżonych litologią do utworów ogniwa margli z Nienadowej (og), pochodzące przypuszczalnie ze skłonu lub głębszego szelfu basenu skolskiego.

W utworach ogniwa margli z Nienadowej (og) występuje stosunkowo słabo zróżnicowana ichnoasocjacja złożona z następujących skamieniałości śladowych (Fig. 7–10): *Chondrites targionii*, *Palaeophycus* isp., *Phycosiphon incertum*, *Planolites* isp., *Scolicia* isp., ?*Taenidium* isp., ?*Teichnichnus* isp. i *Thalassinoides suevicus*. *Chondrites*, *Planolites* i *Thalassinoides* występują we wszystkich badanych profilach (Figs. 3–6). *Phycosiphon* występuje tylko w profilach Nienadowa i Zabratówka Wieś, a *Scolicia* tylko w profilu Zabratówka Góra.

Mułowce i margle z górnej części ławic turbidytowych są całkowicie zbioturbowane. Na zbioturbowanym tle, miejscami widoczne są *Planolites* i *Chondrites*. Intensywność bioturbacji maleje w dół ławic, gdzie występują *Planolites*, *Chondrites*, *Scolicia*, *Thalassinoides* i *Phycosiphon*. W dolnej części ławic zachowane są często pierwotne struktury sedymentacyjne, głównie laminacja przekątna i pozioma. Na spągach ławic rzadko występują *Planolites*, nieoznaczalne "guzki" lub półreliefy *Thalassinoides*. Lokalnie, *Chondrites* penetruje wypełnienia *Thalassinoides* i *Planolites*.

Pionowe rozmieszczenie skamieniałości śladowych w grubszych ławicach turbidytowych odzwierciedla pierwotną piętrowość penetracji w osadzie. W przypadku cieńszych ławic, skamieniałości śladowe głębszych pięter, na przykład *Chondrites*, mogą sięgać do starszych turbidytów i nakładać się na wcześniej uformowane struktury bioturbacyjne (Fig. 11). Ogranicza to możliwość rozpoznawania piętrowości w cienkich ławicach turbidytowych na podstawie pozycji toponomicznej. Na podstawie pozycji toponomicznej i stosunków przecinania się skamieniałości śladowych ustalono, że *Chondrites* zajmuje najgłębsze piętro. Wyjątkiem jest profil w Warze (Fig. 3), charakteryzujący się bardziej proksymalnymi facjami, gdzie *Thalassinoides* penetruje głębiej niż *Chondrites*. Płytsze piętra zajmują *Scolicia*, *Phycosiphon* i *Planolites* (Fig. 12).

Klasty i porwaki margli z iłów z Czudca zawierają skamieniałości śladowe i struktury bioturbacyjne, pochodzące prawdopodobnie z głębszego szelfu i skłonu. Margle z klastów są całkowicie zbioturbowane według trzech zasadniczych stylów. W pierwszym przypadku (Fig. 10A), kontury *Thalassinoides*, *Planolites* i *Chondrites* są zamazane i często zdeformowane przez rozpuszczanie i pełznięcie osadu. W drugim przypadku, nie ma rozpoznawalnych skamieniałości śladowych (Fig. 10B). W trzecim przypadku występują *Thalassinoides*, *Planolites*, *Chondrites*, *Scolicia*, *Palaeophycus*, ?*Teichichnus* i ?*Taenidium* (Fig. 10C). Wymienione skamieniałości śladowe przecinają się według stałych reguł, pozwalających na odtworzenie piętrowości (Fig. 12).

Zespoły skamieniałości śladowych w poszczególnych profilach różnią się nieco między sobą, w zależności od zmian facjalnych (Fig. 12).

Głęboka bioturbacja (przypuszczalnie do 25 cm), oraz złożone *ichnofabrics*, wskazują na dobre natlenienie osadów ogniwa margli z Nienadowej (og). Ichnoasocjacja tego ogniwa jest jednak zdecydowanie mniej zróżnicowana niż ichnoasocjacje eoceńskich, silikoklastycznych osadów fliszowych. Dotyczy to głównie skamieniałości śladowych zachowanych na spągach ławic turbidytowych. Częściowym wytłumaczeniem tego zjawiska mogą być procesy diagenetyczne, silniejsze w osadach węglanowych niż w silikoklastykach, zamazujące pierwotne struktury. Prawdopodobnie, zasadniczą przyczyną ograniczającą różnorodność ichnotaksonomiczną były czynniki ekologiczne, preferujące zachowanie ichnofauny oportunistycznej. Przyczyną oportunizmu mogła być obfitość pożywienia (eutrofia) dostarczanego z toni wodnej. O wzroście warunków troficznych świadczy duża ilość radiolarii w ogniwie margli z Nienadowej (og). Pożywienie gromadziło się na dnie, w najwyższych partiach osadu, gdzie potencjał zachowania penetracji jest bardzo niski. Niska zawartość materii organicznej, zaznaczona jasnymi barwami skał nie zaprzecza tej tezie, gdyż jej ilość przechodząca do stanu kopalnego może być bardzo niska w dobrze natlenionym środowisku. Ponadto, osady ogniwa margli z Nienadowej (og), zawierające różnorodne ziarna węglanowe, silikoklastyczne i glaukonitowe, mogły nie sprzyjać organizmom przystosowanym do penetracji w jednym typie osadu.

Omawiany ichnozespół nie przypomina ichnofacji Nereites, właściwej osadom fliszowym. Podobny jest on jedynie do ichnoasocjacji z eoceńskich turbidytów kalkarenitowo-kalcylutytowych z Monte Solare w Apeninach Północnych (Monaco, 1996). Pewne podobieństwa istnieją również w odniesieniu do fliszu helminthoidowego Alp Liguryjskich (górna kreda–paleocen; Powichrowski, 1989).