

The ichnological record across the Cretaceous/Tertiary boundary in turbiditic sediments at Uzgruň (Moravia, Czech Republic)

ALFRED UCHMAN¹, MIROSLAV BUBÍK² and RADEK MIKULÁŠ³

¹Institute of Geological Sciences, Jagiellonian University, Oleandry 2a, 30-063 Kraków, Poland; fred@ing.uj.edu.pl

²Czech Geological Survey, branch Brno, Leitnerova 22, 600 00 Brno, Czech Republic; bubik@cgu.cz

³Institute of Geology, Academy of Sciences of the Czech Republic, Rozvojová 135, 165 00 Praha 6, Czech Republic; mikulas@gli.cas.cz

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Abstract: The deep-sea, distal turbiditic deposits at Uzgruň have recorded no significant change of trace fossil diversity and ichnofabrics across the Cretaceous/Tertiary (K/T) boundary interval. There is no evidence of any ecological catastrophe that can be related to the K/T event. The trace fossil association is rather poor in diversity. This can be related to a general oligotrophy and poor preservation potential. The producers of the discussed trace fossils, dominated by *Chondrites intricatus* (Brongniart), *Chondrites targionii* (Brongniart), *Ophiomorpha annulata* (Książkiewicz), *Ophiomorpha rudis* (Książkiewicz), *Palaeophycus tubularis* Hall, *Planolites* isp., *Phycosiphon incertum* Fischer-Ooster, *Thalassinoides* isp. and *Trichichnus* isp. lived in a habitat, which had not been influenced by the event.

Key words: Cretaceous/Tertiary boundary, Western Carpathians, flysch, ichnology, ichnofabric.

Introduction

Trace fossils and ichnofabrics provide important data about the paleoenvironment, especially about oxygenation, food supply, rate of sedimentation, and paleodepth (Frey 1975; Ekdale et al. 1984a; Frey & Pemberton 1985; Pemberton 1992; Donovan 1994; Bromley 1996 and others). Therefore, they can be useful for multivariate studies on the Cretaceous/Tertiary (K/T) boundary. Examples already exist in the literature. In the Danish chalk, they indicate upward shoaling across the boundary, a local anoxia in the shallow part of the basin and oxygenated environment in the deeper part recorded in bioturbated marls of the Fish Clay (Ekdale & Bromley 1984). In Alabama, trace fossils excluded that the clastic deposits at the K/T boundary are catastrophic tsunami deposits, but they indicate rather sea-level changes (Savrdá 1993). In the deep-sea (but above CCD) deposits in NE Mexico, Ekdale & Stinnesbeck (1998) recognized at least three colonization episodes in clastics of the K/T boundary layers in, which indicate a long period of time between the possible extraterrestrial impact and extinction of the Cretaceous plankton. According to preliminary analyses of ichnofabric at the K/T boundary at Agost (SE Spain) by Rodríguez-Tovar (2001), a tiered ichnoassemblage with *Planolites*, *Thalassinoides*, *Chondrites* and *Zoophycos* occur there.

In this study, trace fossils and ichnofabrics are used for better understanding of paleoenvironment represented by the K/T interval from the Uzgruň section in the Western Carpathians.

Previous work and geological setting

The K/T interval in the Uzgruň section is situated in the left bank cut of an unnamed creek NNE of the Uzgruň settlement,

near Velké Karlovice close to the Czech-Slovak border (Fig. 1). The K/T section consists of two isolated outcrops close to each other (points No. 19 and 20 of Bubík et al. 1999). Correlation of both outcrops is easily possible because of the overlap of a characteristic interval. The composed section is about 9 m thick.

The sediments in the Uzgruň vicinity belong to the Rača Unit of the Magura Group of Nappes in the Outer Flysch Carpathians. Sediments of the Uzgruň section can be assigned to the Solán Formation. Multistratigraphy of the K/T boundary interval of the section was recently investigated and discussed by Bubík et al. (2002).

Trace fossils from the K/T boundary interval of the Carpathians have not been studied in detail yet. Uchman (1991) generally and briefly analysed the Incoceramian Beds (Senonian to Paleocene) of the Polish Carpathians but the K/T boundary has not been precised yet within this member. Ich-



Fig. 1. Location map. The Uzgruň locality is marked by an asterisk.

noassemblage of the Incoceramian Beds displays evidence of environmental stress (possible oligotrophy) and limited preservation potential in comparison to the Eocene formations, but this stress is not related to the K/T event. However, the trace fossil association of the Incoceramian Beds is similar to that of the Uzgruň section (see below).

The section shows characteristic flysch type lithology with prevailing grey-green, grey, and dark grey mudstones over siltstones and fine- to medium-grained greywacky sandstones. Analysis of the mudstones from the K/T boundary interval revealed quartz, plagioclase, mica, chlorite, kaolinite (and respectively calcite in the calcareous turbidite layers). Less frequently, thin layers of marlstones and rarely lutitic carbonates occur. The marlstones contain up to 45 % of carbonate. Turbiditic mudstones usually have less than 10 % of carbonate. Hemipelagic mudstones are solely non-calcareous. The lutitic carbonates are close to dolomitic limestones or dolomites. Carbonates and calcareous mudstones are restricted to the Maastrichtian part of the section.

The sedimentary succession across the K/T near Uzgruň can be characterized as alternation of thin-bedded muddy turbidites and hemipelagites. A few thicker sandy turbidites (up to 40 cm thick) occur close to the K/T boundary. Most of the sandstone beds show ripple-lamination and are up to few cm thick. Commonly the beds pinch out after a short distance. Silty-muddy turbiditic beds are very common. The coarsening-upward trend across the K/T boundary interval observed by Bubík et al. (1999) also occurs in the section scale. Turbidites consisting only of muddy intervals represent about 60 % of the total number of the turbidites in the Maastrichtian part, but only 30 % of the Paleocene part. Turbidites containing a sandy interval are more frequent in the Paleocene (25 %) than in the Maastrichtian part (7 %). Figure 6 contains a presumed comparison of the Uzgruň turbidites to turbidite models by Stow (1985), Piper (1978) and Bouma (1962).

In some thicker (5–10 cm thick) hemipelagites, thin silty layers occur besides typical turbidites; they display no sharp base but clear inverse gradation at the base and normal gradation at the top. Such layers may represent the sediments of bottom currents.

Relatively distinct erosion was observed in the upper part of the section approximately 2 m above the base of the Paleocene. On the distance of two meters, approximately 20 cm of the deposit (two turbidite rhythms) were removed by erosion.

The accumulation rate for the Uzgruň section cannot be calculated precisely because the only chronometric datum refers to the K/T boundary; but estimation can be made on the basis of biostratigraphy. Sediments of the documented section are separated from the underlying beds by a fault, which is covered by the stream bed as is evident from different successions in the opposite creek banks. The Maastrichtian part of the section is about 6 m thick. The segment of the section from the opposite bank, which is assigned to the *Micula prinsii* Zone (latest Maastrichtian), has the same or slightly greater thickness. The next closely situated outcrop, but separated by a local thrust, was dated to the older *Nephrolithus frequens* Zone. Nevertheless, on the basis of this field situation, it was possible to conclude that the *Micula prinsii* Zone from the Uzgruň

section is at least 20 m thick. Relating this value to the duration of the *M. prinsii* Zone from the North Atlantic of about 220 ky (Henriksson 1993), the average sedimentation rate reaches at least 9 cm/ky, and at least 3.6 cm/ky for hemipelagites in the compacted shale. This estimation is very tentative, but it implies relatively rapid deposition.

The completeness of the Uzgruň K/T section was evaluated using trace fossils, which can help in recognition of erosion (Wetzel & Aigner 1986). Foremost, an occurrence of trace fossils preserved as semi-reliefs due to scouring and casting indicate erosion at the base of turbidites. There are only a small number of beds in the Uzgruň section, which contain trace fossils of this sort. In most cases, the hemipelagic layer is preserved below the sole of the turbidites. Consequently, erosion has been relatively small on the deep-sea floor and the section is almost complete. Thick sandstone beds with flute casts may represent exceptions. Nevertheless, even in this case, the underlying bed has been eroded only partly. It seems that in most cases the erosion removed no more than a few millimeters of sediment, which can be deposited approximately within several tens of years.

Material and methods

Trace fossils and ichnofabrics have been investigated in the field and laboratory. Each bed has been examined. The soft fine-grained parts of the beds have been polished in the field using water-proof abrasive paper and running water. Differently oriented polished slabs have been easily obtained by means of this method. Trace fossils have been also observed on the parting and bedding surfaces. In this way, the ichnofabric and its change within a bed was analysed. The material has been documented in the field and later in the laboratory.

Synopsis of ichnotaxa

Twelve ichnospecies (see below) have been recognized in the investigated section. Cross-sections of the trace fossils on surfaces of the polished slabs are illustrated in Figs. 2 and 3.

Arthrophyucus cf. *tenuis* (Książkiewicz 1977) occurs gregariously as semi-reliefs of subhorizontal, hypichnial, convex ridges. The ridges are 1.0–1.5 mm wide and up to 35 mm long. They are straight, rarely branched and oriented in different directions. *Arthrophyucus tenuis* was previously described under the ichnogenus *Sabularia* (Książkiewicz, 1977). Uchman (1998) recommended that this ichnogenus should no longer be used and included *Sabularia tenuis* in the ichnogenus *Arthrophyucus* Hall on the basis of the very fine perpendicular striae, which, however, are commonly not preserved. The described form is smooth, but it displays the characteristic geometry and size of *A. tenuis*.

Chondrites intricatus (Brongniart, 1823) (Figs. 2C, 3B) occurs as a system of tree-like branching, downward penetrating, markedly flattened tunnels, less than 1.0 mm in diameter. The tunnels form acute angles. In cross-sections it occurs as patches of circular to elliptical spots and short bars. Commonly, the fill of the trace fossil is darker than the host rock. For a more

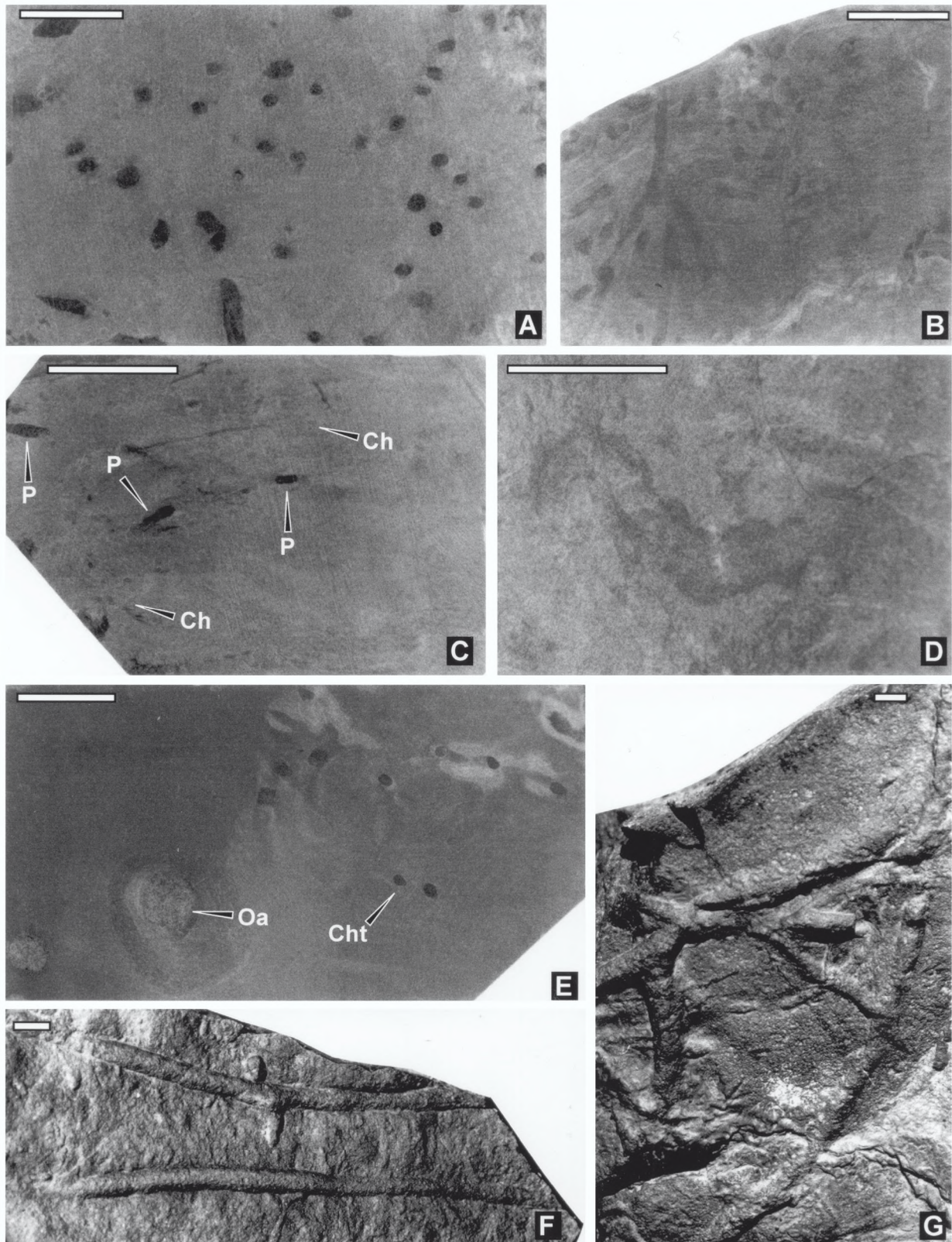


Fig. 2. Examples of trace fossils and ichnofabrics. **A** — *Chondrites targionii* against totally bioturbated background, horizontal section, turbiditic mudstone, ICH-10. **B** — *Chondrites targionii* in a laminated mudstone-siltstone, slightly oblique section, ICH-79. **C** — *Chondrites intricatus* (Ch) and *Planolites* isp. (P) against totally bioturbated background, horizontal to slightly oblique section, hemipelagic mudstone, ICH-7. **D** — *Nereites irregularis* from a hemipelagic mudstone, slightly oblique section, ICH-83. **E** — *Ophiomorpha annulata* (Oa) and ?*Chondrites targionii* (Cht) turbiditic siltstone, ICH-2, slightly oblique section. **F** — *Ophiomorpha annulata* on the sole of turbiditic sandstone, field photograph. **G** — *Ophiomorpha rudis* on the sole of thick-bedded turbiditic sandstone, field photograph. Scale bars = 1 cm.

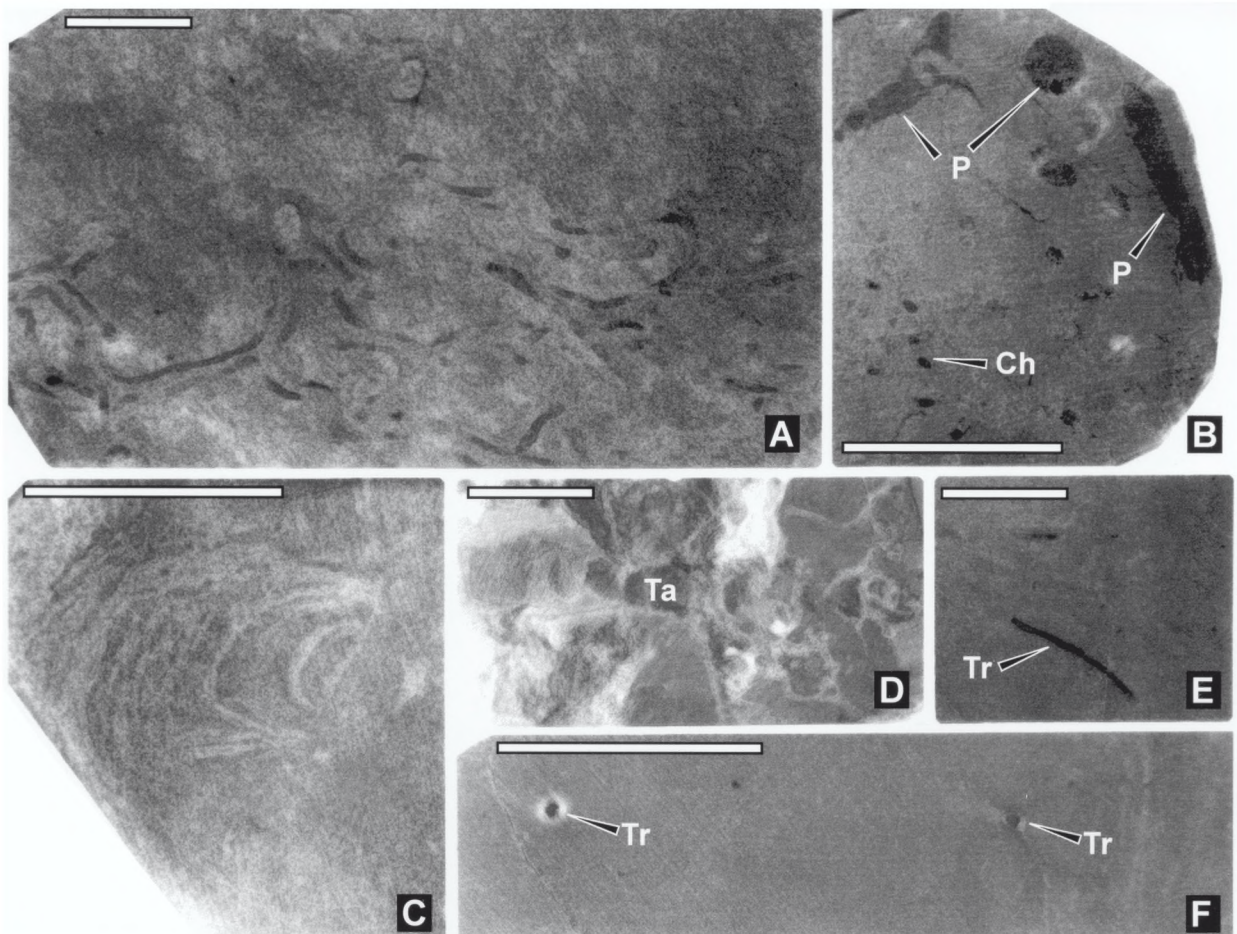


Fig. 3. Examples of trace fossils and ichnofabrics. **A** — *Phycosiphon incertum*, turbiditic siltstone, ICH-2, horizontal section. **B** — *Planolites* isp. (P) and *Chondrites intricatus* (Ch), hemipelagic mudstone, ICH-81, slightly oblique section. **C** — *Taenidium* isp. from a hemipelagic mudstone, ICH-83, horizontal section. **D** — *Taenidium* isp. (Ta) from a turbiditic laminated siltstone, ICH-92, slightly oblique section. **E** — *Trichichnus* isp. (Tr) against mottled background, hemipelagic mudstone, ICH-96, horizontal section. **F** — *Trichichnus* isp. (Tr) against mottled background, dark turbiditic siltstone to claystone, ICH-17, slightly oblique section. Scale bars = 1 cm.

extensive discussion of the ichnogenus *Chondrites* see Fu (1991) and Uchman (1999).

Chondrites targionii (Brongniart, 1823) (Fig. 2A,B,E) is represented by endichnial, tubular, flattened tunnels branched in a dendroid manner. Branches are commonly slightly curved. The tunnels are 1–2 mm wide. In cross-section it is similar to *C. intricatus*, but distinctly larger.

Nereites irregularis (Schafhäütl, 1851) (Fig. 2D) is a tightly to loosely meandering, rarely spirally coiled endichnial trace fossil, 2–5 mm wide. It is composed of a central, light-coloured faecal string, and a dark envelope zone. The faecal string occupies about 40 % of the width. For more information on *Nereites* see Uchman (1995a) and Mángano et al. (2002).

Ophiomorpha annulata (Książkiewicz, 1977) (Figs. 2E,F, 4) is an exichnial, hypichnial or rarely epichnial, straight to slightly winding, vertical, oblique to horizontal, cylindrical, walled trace fossil preserved in full-relief, 3–9 mm in diameter. It is filled mostly with sandy material. In flysch deposits this trace fossil rarely displays a wall covered with small oval knobs, which are characteristic of the ichnogenus *Ophiomorpha* (Uchman, 1995a).

Ophiomorpha rudis (Książkiewicz, 1977) (Fig. 2G) is preserved as vertical to subvertical cylindrical, walled or unwalled, sand-filled, rarely branched tunnels, 9–15 mm in diameter. Some branches penetrate horizontally along bedding surfaces. The exterior part of the tunnels is smooth or displays indistinct, irregular sandy granules. *Ophiomorpha rudis* penetrates up to 30 cm through at least a few turbidites.

Palaeophycus tubularis Hall, 1847 is an endichnial horizontal, branched, smooth, thinly lined, winding cylindrical burrow on the lower bedding surface, 3–10 mm in diameter. For discussion of *Palaeophycus* see Pemberton & Frey (1982) and Keighley & Pickerill (1995).

Planolites isp. (Fig. 2C) are variably oriented, but mostly horizontal, cylindrical trace fossils without wall, 3–6 mm in diameter. In cross-sections, they appear as oval spots contrasting in colour against the surrounding rock. They are preserved also on the soles of sandstone beds in full-relief. For discussion of *Planolites* see Pemberton & Frey (1982) and Keighley & Pickerill (1995).

Phycosiphon incertum Fischer-Ooster, 1858 (Fig. 3A) is observed in horizontal polished slabs as curved endichnial lobes,

2 mm wide and up to 20 mm long, encircled by a marginal tunnel, which is 0.7–1.0 mm wide. In vertical cross-sections it occurs as patches of dark, elongated spots, about 1 mm in diameter, surrounded by a light mantle. More information about *Phycosiphon* can be found in Wetzel & Bromley (1994).

?“*Rotundusichnium*” *zumayense* (Gómez de Llarena, 1946) consists of spirally coiled, partially overlapping endichnial ribbons inclined toward the centre of the spiral. Only a single, poorly preserved spiral, 30–35 mm wide, has been found. For discussion of this ichnospecies see Uchman (1998).

Taenidium isp. (Fig. 3D) is an oblique to horizontal, un-walled, simple, tubular meniscate trace fossil, in which menisci display different colour than the host rock. It is 10 mm wide. *Taenidium* was discussed by D’Alessandro & Bromley (1987) and Keighley & Pickerill (1994), who regarded it as a burrow of vagile deposit-feeding organisms, but Locklair & Savrda (1998) suggested that at least some *Taenidium* were produced by a sessile worm maintaining a connection to the sediment surface or shallow subsurface and keeping pace with sediment accumulation.

Thalassinoides isp. are walled or unwalled trace fossils composed of cylindrical, mostly horizontal branched tunnels, which are 10–20 wide. They were observed mostly in vertical or oblique cross-sections, where they occur as spots distinctly larger than in the case of *Planolites* isp. For discussion of *Thalassinoides* see Frey et al. (1984) and Ekdale (1992).

Trichichnus isp. (Fig. 3E,F) is a vertical to oblique, rarely horizontal, straight to curved, simple or rarely branched, very thin, cylindrical trace fossil, which is less than 1 mm in diameter. It is filled with pyritic, commonly weathered material. For discussion of *Trichichnus* see Fillion & Pickerill (1990) and Uchman (1995a, 1999).

Zoophycos isp. (Fig. 4) was found only on the base of a thick sandstone bed where it is preserved as a concave funnel structure with radially arranged spreite. The funnel is about



Fig. 4. *Zoophycos* isp. from the Uzgruň section. Hypichnial concave form. The straight ridge in the upper left corner belongs to *Ophiomorpha annulata*.

40 mm wide. The spreite laminae are straight to slightly arcuate. *Zoophycos* s.l. is generally assumed to be the trace of an as yet undiscovered deposit-feeder. For discussion of this ichnogenus see Ekdale (1992) and Bromley & Hanken (2003). The latest cited authors suggested that the upper helical part of a large Pliocene *Zoophycos* from Rhodes, Greece, is a deposit-feeding structure, and lateral lobes developing from its lower part are sulphide wells for chemosymbiotic bacteria.

Form A is a simple horizontal tubular trace fossil with pelleted wall, 2–3 mm wide. It was ascertained in only one layer of hemipelagic mudstone (ICH101).

Description of ichnofabrics

The ichnofabrics are mainly composed only by a few ichnotaxa; they include *Chondrites intricatus*, *Planolites* isp. and *Trichichnus* isp., whereas *Ophiomorpha annulata*, *Phycosiphon incertum*, and *Chondrites targionii* are a less common, but still frequent and characteristic component of the ichnoassemblage. The remaining ichnotaxa are rare. They occur only in single beds. Ichnofabrics occur in almost all beds. The distribution of trace fossils is shown in Fig. 5.

The green hemipelagites are totally bioturbated. Against mottled background *Planolites*, *Phycosiphon incertum*, *Chondrites intricatus* and *Trichichnus* are visible. *Planolites* and *Phycosiphon incertum* are cross-cut by *Chondrites*, and they are all together penetrated by *Trichichnus*. Some *Planolites* are densely reworked preferentially by *Chondrites intricatus*, which follows exactly the *Planolites* filling. Rarely, *Chondrites targionii*, sand-filled *Ophiomorpha annulata*, or ?“*Rotundusichnium*” *zumayense* are present.

Underlying grey turbiditic mudstones are also totally bioturbated at least in the upper part. *Planolites* and *Phycosiphon incertum* occur mostly in the upper part, and *Chondrites intricatus*, *Chondrites targionii* and *Trichichnus* all over the layer, including the lower part, where primary laminations may be preserved. The latter three ichnotaxa can be found, but much less abundant, in the underlying siltstones or even in the top of turbiditic sandstones. In rare cases, *Planolites* occurs on the soles of thin sandstone beds in full relief. In some beds, relatively rare *Nereites irregularis* can be found. *Thalassinoides* and *Palaeophycus* cross-cut by at least *Chondrites* and *Trichichnus* occur most often in siltstones.

Ophiomorpha annulata is often present on soles of turbiditic sandstones, but crosses also turbiditic and hemipelagic mudstones cutting all other trace fossils. Commonly it penetrates through a few adjacent turbidites to a depth of at least 20 cm and occurs in full-relief along the base of a 40 cm-thick sandstone bed. *Ophiomorpha rudis* occurs in the same way. In one case (ICH55) *O. annulata* follows the fill of *O. rudis*. Rare *Arthropycus* cf. *tenuis* occurs exclusively on the sole of a thin sandstone bed.

Interpretation of the ichnofabrics

The cross-cutting relationships express a vertical partitioning of trace fossils in sediments, that is tiering, which can be

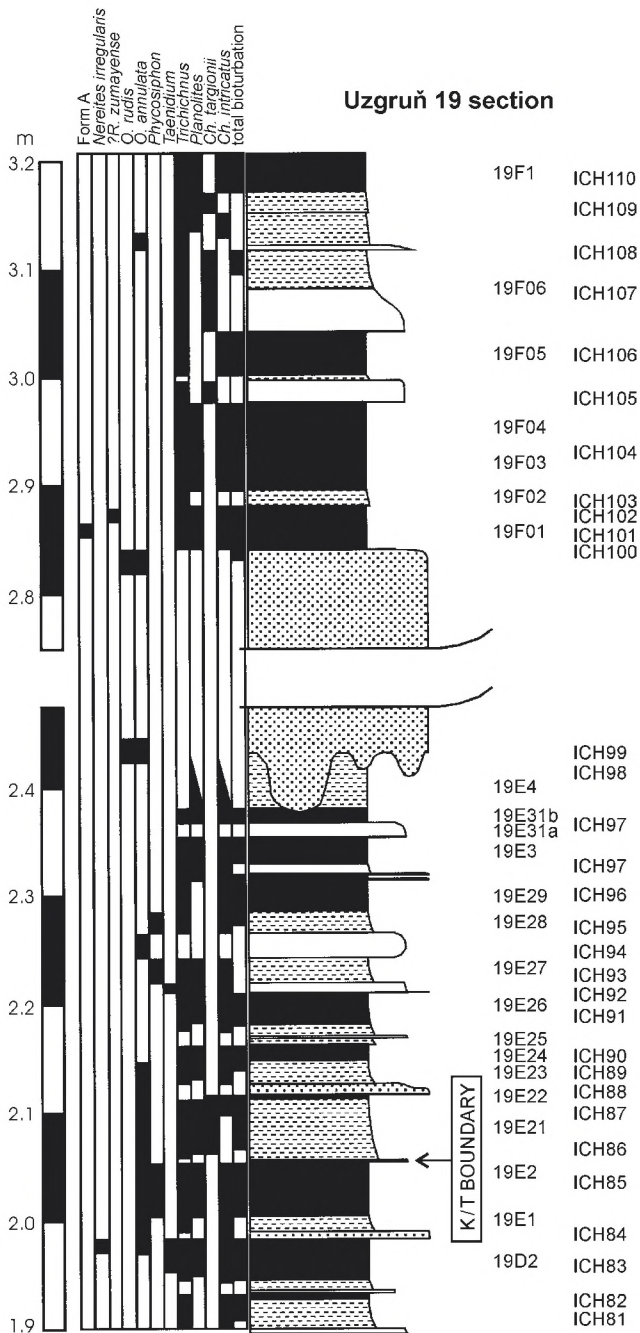


Fig. 5. Distribution of trace fossils in the investigated section. **ICH** — ichnologically investigated samples, housed in the Institute of Geology, AS CR, Praha; **19D2–19F1** — biostratigraphic samples as published by Bubík et al. (2002), presented herein for the comparison to the position of the ichnological samples.

interpreted to some extent as for continuously deposited pelagic sediments (e.g. Ekdale & Bromley 1991). According to this scheme, *Ophiomorpha annulata* occupies the deepest tier. *Trichichnus* can be placed in a shallower tier, but deeper than the tier of *Chondrites*. *Planolites* and *Phycosiphon* occupy further distinctly shallower tiers. The shallowest tiers are represented by a totally bioturbated zone produced by highly vagile benthos; its activity is not recorded as trace fossils (Bro-

mley 1996). Occurrence of crisp trace fossils such as *Ophiomorpha annulata*, *Chondrites* or *Trichichnus* in hemipelagic, totally bioturbated mud is an overprint of deep tiers from the overlying beds (Fig. 6).

The above-outlined picture, however, is static and cannot be explained by a simple shift of tiers in response to sediment accumulation. Foremost, the accumulation of sediment is mostly incidental due to turbidity currents, which interrupt long periods of pelagic and hemipelagic sedimentation. The model of sequential colonization can be applied for flysch deposits (Wetzell & Uchman 2001), in which changes of the benthic communities with time is stressed. Following that idea, after deposition the turbiditic sediments contain the highest amount of food and oxygen, which decrease with time. Firstly, they are colonized by motile deposit feeders, which are represented by *Phycosiphon incertum* and *Planolites*. In rare beds, they are followed by *Nereites irregularis*, which is produced by a more efficient and systematic bioturbator. In the meantime, the near surface sediment is continuously reworked by several animals, the activity of which produces only total bioturbation, not recorded as distinct trace fossils, but as so-called bio-deformational structures which only destroy pre-existing sedimentary structures. At the beginning, they rework the top of the turbiditic sediments, that is the turbiditic muds, and then the settled pelagic and hemipelagic sediments, which are subjected to long period of continuous reworking. When the food content has been significantly exploited and oxygenation of the sediment decreased as hemipelagic sedimentation is quite rapid, the burrowers are followed by *Chondrites*, which is produced by opportunistic animals using chemoautotrophic microorganisms (Seilacher 1990; Fu 1991). They penetrated deeply down into fine-grained sediment within the anaerobic zone. *Chondrites* is followed by *Trichichnus*, which displays similar, but even more opportunistic behaviour (Uchman 1995a). *Ophiomorpha annulata* is produced by a crustacean, which does not depend on the change of food and oxygen content in fresh turbidites, but it exploits microorganisms and/or organic matter matured by microorganisms in buried turbidites, especially along their sandy base, generally in the anaerobic zone. It maintains an open burrow for the supply of oxygenated water. They are typical multi-layer colonizers *sensu* Uchman (1995b), which probably survive turbiditic flows. In each stage, the near-surface sediment is reworked by different bioturbators. The geometry of *Chondrites*, *Trichichnus* and *Ophiomorpha* indicate that their producers are very inefficient sediment reworkers, which, indeed, corresponds well to the presumed ethology of their traces.

The totally reworked zone at the top of turbidite-hemipelagic couplets, contrasting in colour to surrounding rock, is distinguished in flysch deposits as a spotty layer (Uchman 1999). It contains mostly hemipelagic or pelagic sediments, which, however, are mixed together with turbiditic sediments by bioturbation. Below, where distinct trace fossils typically occur, the elite layer is distinguished (Uchman 1999). The totally bioturbated top of turbiditic mudstone is separated as the upper elite layer. The upper elite layer and the spotty layer can be regarded as equivalent of the mixed layer from Recent deep-sea pelagic sediments (Ekdale & Berger 1978; Berger et al. 1979). The zone with distinct trace fossils in turbiditic deposits

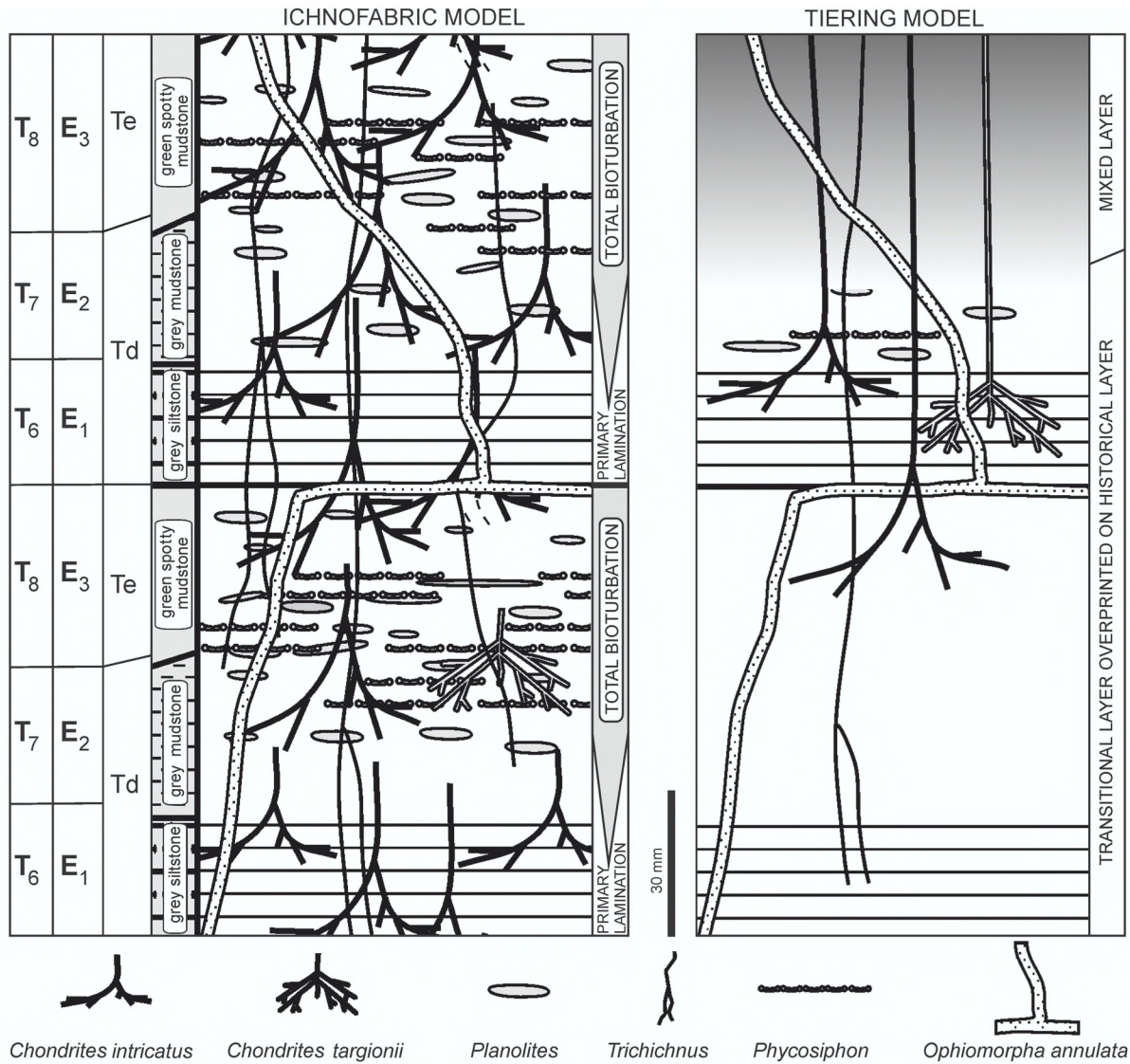


Fig. 6. Models of ichnofabrics and tiering pattern. Left column contains a presumed comparison to turbidite models by D.A.V. Stow (1986; T6-T8), D.J.W. Piper (1978; E1-E3) and A.H. Bouma (1962; Td-Te).

with primary lamination is distinguished as middle elite layer, and the exichmial elite layer is distinguished for trace fossils penetrating in buried turbidites (Uchman 1999). The middle and exichmial elite layers are an equivalent of the transitional layer in the recent pelagic sediments (Ekdale et al. 1984b).

The thickness of the mixed layer in the Recent deep-sea sediments of the Atlantic and Pacific ranges from 3 to 8 cm, and the transitional layer is 20–35 cm thick (Ekdale & Berger 1978; Berger et al. 1979; Ekdale et al. 1984b). Taking into account compaction, the thickness of the spotty layer from Uzgruň corresponds to these values.

Discussion and conclusions

The described and interpreted ichnofabrics indicate long, changing in time colonization of the deep-sea floor after deposition of each turbidite. A layer of oxygenated sediment of

changing thickness existed after each turbidite event. There is no evidence of anaerobic or dysaerobic environment in the shallow subsurface layer or on the sea-floor. The trace fossil association is rather poor in diversity. This can be related to a general oligotrophy and poor preservation potential. The latter can be caused by the small number of turbiditic sandstone beds; their deposition pre-requisite to scour and cast and, hence, preserve pre-depositional burrows formed in the mixed layer. The oligotrophy is probably indicated by a small number of true deposit-feeders, represented in most beds only by *Planolites* and *Phycosiphon incertum*. Amount of benthic food is not equal to the organic matter content, because some of it is refractory.

There is no significant change of diversity or ichnofabric across the K/T boundary beds. Above, *Nereites irregularis* occurs for the first time in the studied section in a few single beds, and ?“*Rotundusichnium*” *zumayense* in one bed (Fig. 5). *Nereites irregularis* is very common in the Carpathian flysch

in the Upper Cretaceous-Paleogene units (e.g. Książkiewicz 1977 under *Helminthoida labyrinthica*) and "*Rotundusichnium*" *zumayense* is common in some Paleocene units (Uchman, unpublished). Their occurrence in the Uzgruň section is rather incidental than related to any event around the K/T boundary. In any case, there is no evidence of any ecological catastrophe that can be related to the K/T event. The producers of the discussed trace fossils are rather independent of ecosystems that were influenced by the event.

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