Trace fossils from Eocene turbiditic deposits: A case study from the Slovak-Moravian Carpathians

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Fosílne stopy v eocénnych turbiditických uloženinách: príklad zo Slovensko-moravských Karpát

Abstract: Well exposed, poorly bioturbated turbiditic sandstones of the Kýčera Beds (Zlín Formation; Eocene) in the Bieščary Quarry contain the deep-sea Nereites ichnofacies. The trace fossils *Ophiomorpha rudis, Halopoa annulata* and *Scolicia strozzii* are mainly common in thick-bedded sandstone packages. They represent the Ophiomorpha rudis ichnosubfacies. *Paleodictyon strozzii, Nereites irregularis,* and *Zoophycos brianteus* occur in a series of thin- to medium bedded fine grained turbiditic sandstones intercalated with mudstone shales. They belong to the Paleodictyon–Nereites ichnosubfacies. The sedimentological interpretation of the turbidity facies and the distribution of the trace fossils suggest that the recognized ichnosubfacies probably express a non-bathymetric facies trend from channel axis, levee to overbank or inter-channel/interlobe areas of a deep sea fan. The distribution and preservation of trace fossils depend mostly on lithology, sedimentation rate, erosion and amalgamation of beds in the proximal mid fan areas, bulldozing effect during colonization as well as on the hardly quantified effect of bottom oxygenation and supply of nutrients.

Key words: Western Carpathians, Eocene, turbidites, trace fossils, palaeoenvironment

1. INTRODUCTION

Trace fossils are important in palaeoecological interpretations of deep-sea fan environments because body macrofossils are rare and usually allochthonous in turbiditic sediments. On the contrary, the trace fossils are preserved in situ and they can help to better understand this still relatively unexplored habitat. Overall degree of bioturbation is highly variable, depending on the overall sedimentation rate and sediment type (e.g. intercalation of gravity-flow mudstones) and therefore producers of trace fossils may be restricted to a particular microhabitat within the deep-sea fan environment (e.g. Uchman, 2007; Heard & Pickering, 2008). Moreover, fluctuations in oxygenation of sediments are an important parameter controlling the trace-fossil diversity in turbidite successions (e.g. Föllmi & Grimm, 1990; Uchman, 2004). Therefore, trace fossils can provide clues to understanding basinal stagnation histories by documenting the changes in the levels of dissolved oxygen in the water at the sea floor (Kotlarczyk & Uchman, 2012).

The good outcrops, applicable for an ichnological study, are rather rare in the "flysch" deposits of the Outer Carpathians. Such an outcrop occurs in the abandoned Bieščary quarry, that is located in the region of the Veľké Rovné Valley in the Javorníky Mountains of the Slovak-Moravian Carpathians (Fig. 1). The quarry exploited Eocene turbiditic sandstones, which are more than 80 m thick and relatively rich in various sedimentary structures (Starek & Pivko, 2001) and trace fossils.

2. METHODS

The field research involved the evaluation of the sedimentary sequences, local enhancement of the outcrop by trenching, lithological and sedimentological study of the sequences, local bed-by-bed sampling, and investigation and description of tracefossil contents. Sampling for granulometric and petrographic analyses was made systematically from all levels of the quarry. Grain sizes and petrography of sandy and silty fraction were evaluated by microscopic study in thin section, coarser sediment was studied in macroscopic section. We used shape classification of particles sensu Powers (1953) and grain-size scale sensu Folk (1980). Palaeocurrent analysis included also the measurement of erosive current marks, current cross lamination, parting lineation and orientation of the long axis of intraclasts. Trace fossils were studied *in situ* on sandstone beds (full relief, hypichnia) and were not possible picked up with the exceptions of several samples. Occasional occurrences of trace fossils did not allow track of the continuity of bioturbation in whole section. For better study of the marginal channel and lamellae of spreite structure, fresh rock surfaces of *Zoophycos* lobes were gained by splitting of rock. Trace fossil dimensions were measured graphically by the ImageJ software.

3. GEOLOGICAL POSITION AND SEDIMENTOLOGICAL CHARACTERIZATION

The Bieščary quarry sedimentary succession belongs to the Magura Nappe of the Flysch belt in the NW part of the Western Carpathians (Fig. 1A), which was formed mostly during
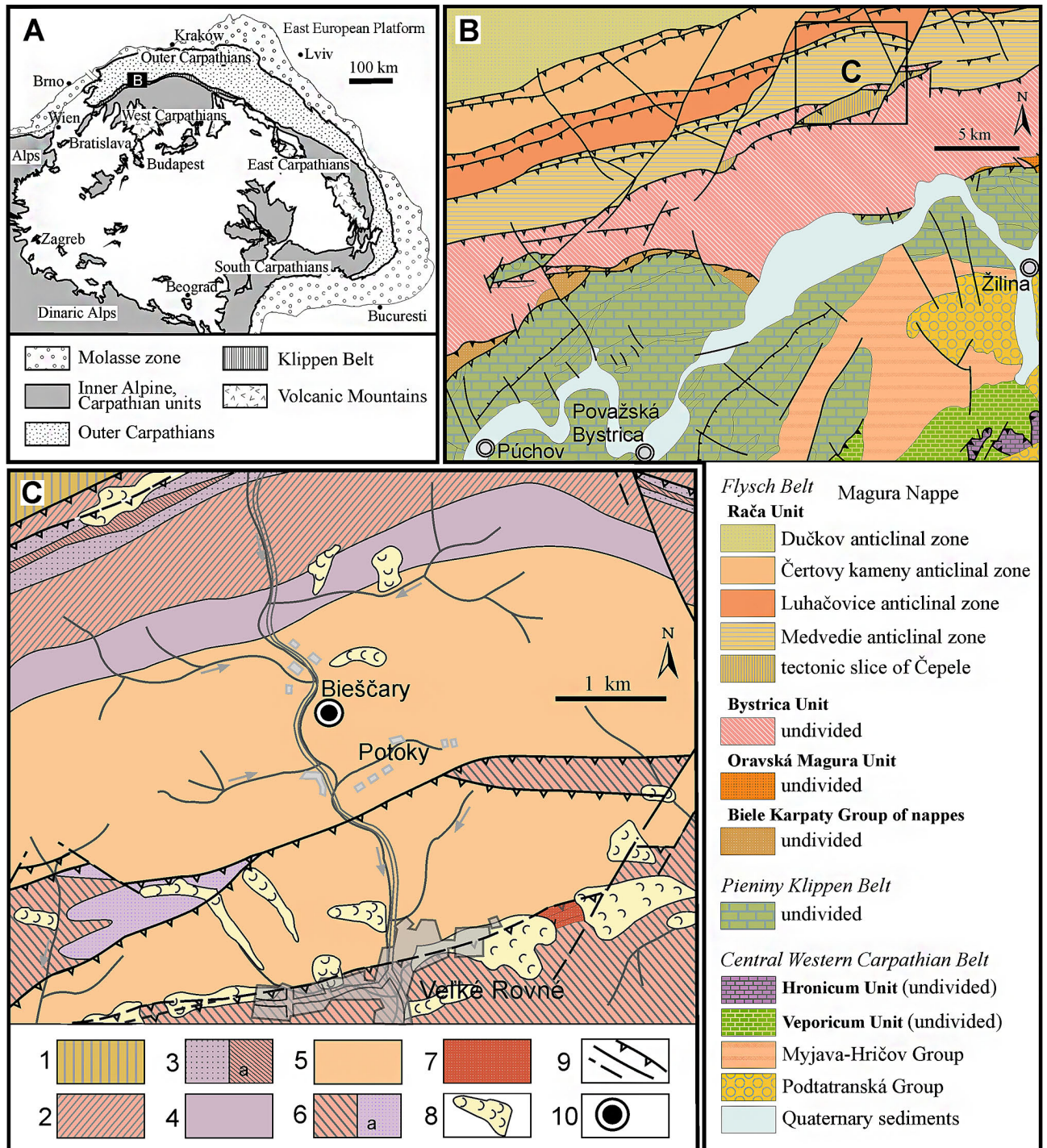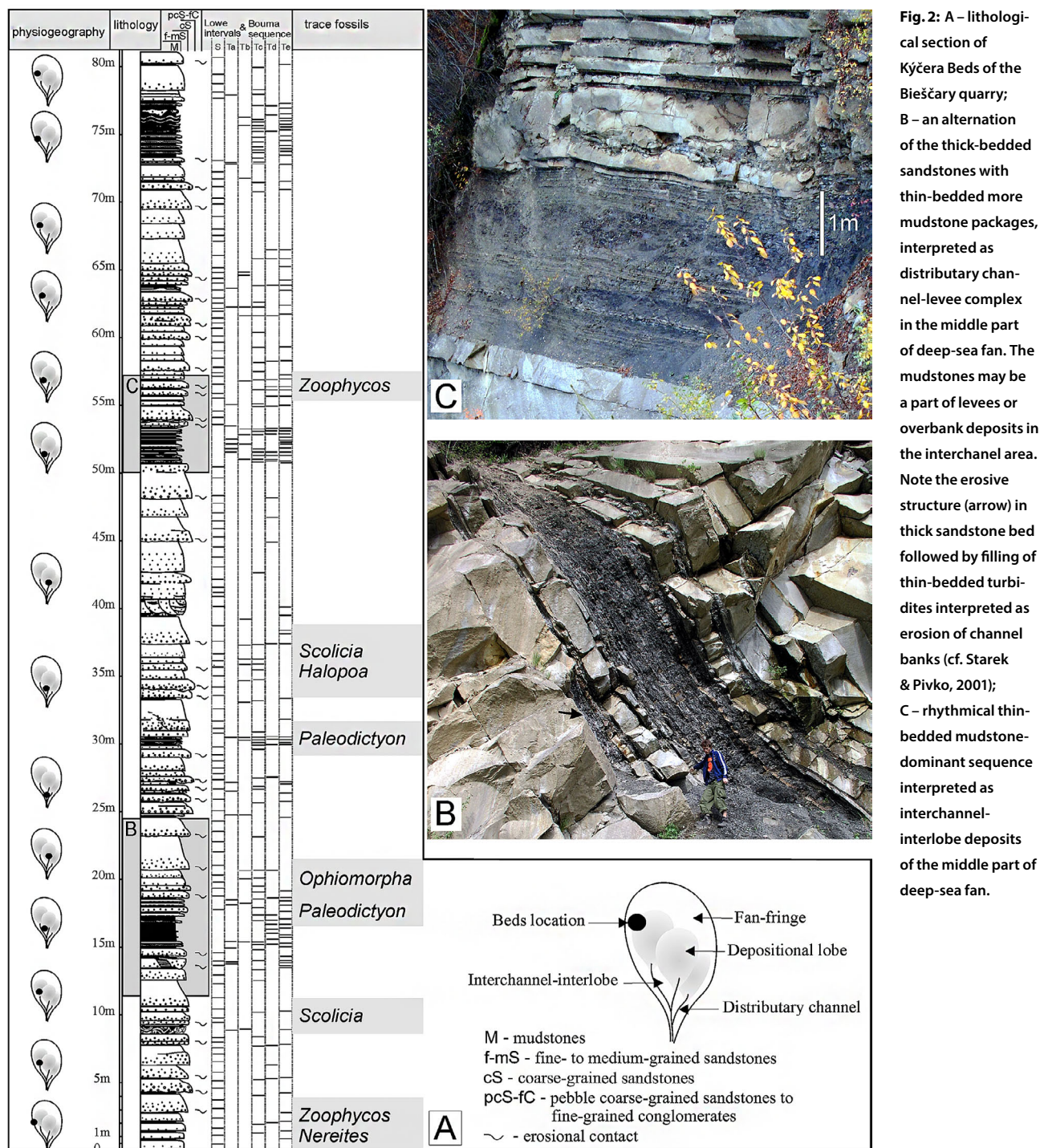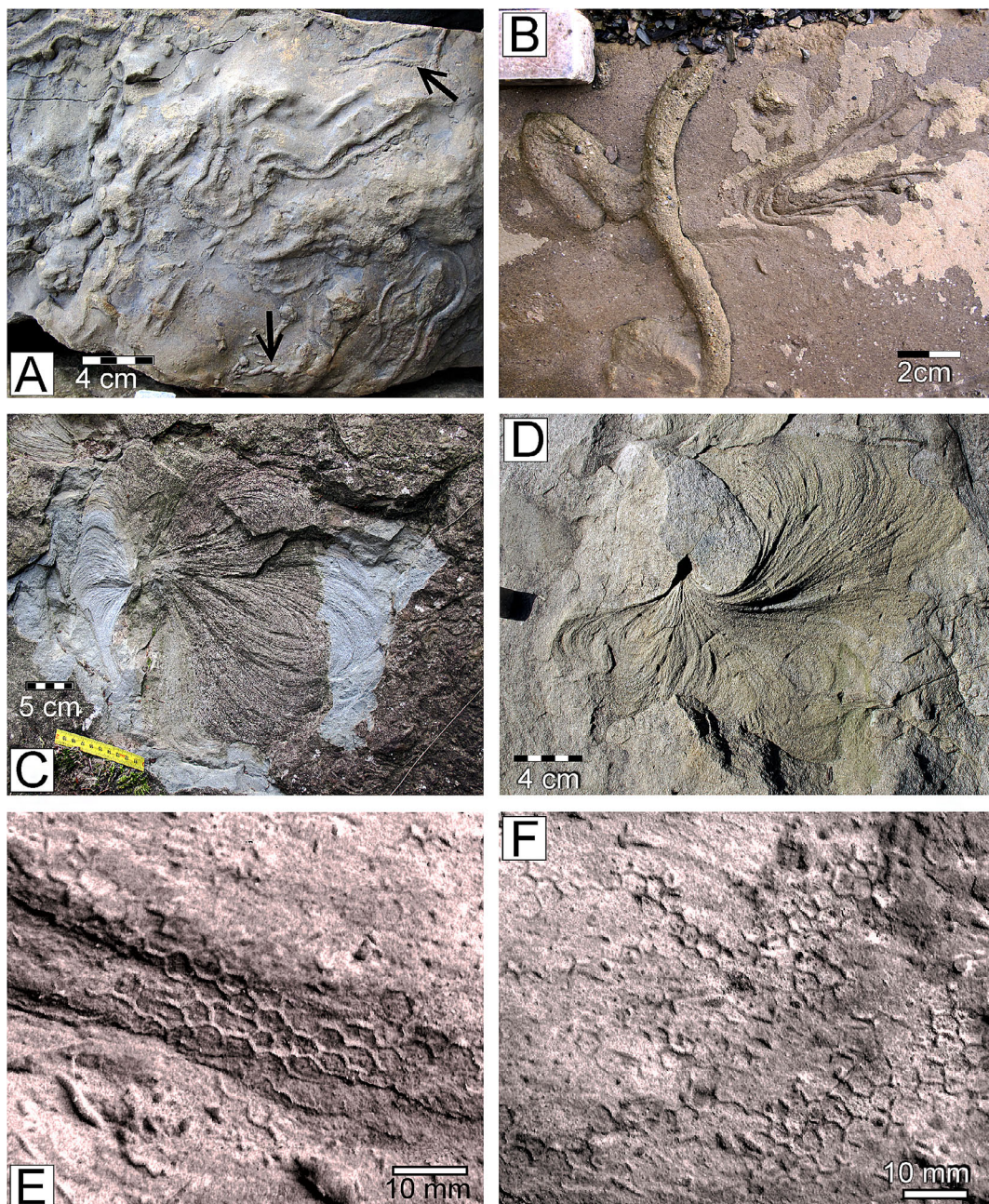
Fig. 1: A – location of study area within the Alpine-Carpathian orogen; B – tectonic sketch of the Middle Váh Valley (after Mello et al., 2005, modified); C – geological sketch of the outcrop area in the Veľké Rovné (after Mello et al., 2005, modified). Key to geology: 1 – Babiše Member: fine-grained laminated quartz glauconitic sandstones; 2 – Bystrica Member (Zlín Formation): fine-grained laminated quartz glauconitic sandstones, Bystrica-type claystones (flysch) (Middle Eocene); 3 – Lower Beloveža Member (Beloveža Formation): Riečky-type sandstones to fine-grained conglomerates (without glauconite) with thin-bedded flysch intercalations (Paleocene – Middle Eocene), a- red and green claystones; 4 – Upper Luhačovice Member (Luhačovice Formation): quartz sandstones with glauconite and with Riečky-type sandstones (Lutetian); 5 – Kýčera Member (Zlín Formation): fine- to medium-grained lithic greywacke sandstones (sandy flysch) (Middle – Late Eocene); 6 – Bystrica Member (Zlín Formation of the Bystrica Unit): Bystrica-type claystones, glauconitic sandstones (flysch) (Middle Eocene – Early Priabonian), a- quartz sandstones with glauconite and with Riečky-type sandstones; 7 – Beloveža Formation: red claystones, thin bedded flysch, green-grey and dark claystones, fine-grained sandstones and siltstones, coarse-grained sandstones; 8 – deluvial slope sediments, lithofacies undivided slope sediments and debris (Pleistocene – Holocene); 9 – faults and nappe thrust lines of main tectonic units; 10 – a position of the outcrop (GPS: N49°18'34.21" E18°34'17.39").

Fig. 2: A – lithological section of Kýčera Beds of the Bieščary quarry; B – an alternation of the thick-bedded sandstones with thin-bedded more mudstone packages, interpreted as distributary channel-levee complex in the middle part of deep-sea fan. The mudstones may be a part of levees or overbank deposits in the interchanel area. Note the erosive structure (arrow) in thick sandstone bed followed by filling of thin-bedded turbidites interpreted as erosion of channel banks (cf. Starek & Pivko, 2001); C – rhythmical thin-bedded mudstone-dominant sequence interpreted as interchannel-interlobe deposits of the middle part of deep-sea fan.

the Late Alpine tectonic stages. In the Magura Nappe, the Rača, Bystrica and Krynica (= Orava-Magura) tectono-facies units are distinguished from the north to south (Birkenmajer & Oszczypko, 1989; Mello et al., 2011). In the Rača Unit, the sedimentation advanced from the Soláň Formation (Campanian – Early Paleocene), through the Beloveža Formation (Early Paleocene – Middle Eocene) and the Luhačovice Formation (Middle Eocene) to the Zlín Formation (Early to Late Eocene, maybe younger - Oszczypko-Clowes, 2001). The Zlín Formation is divided into the Vsetín, Babiše (Teťák, 2005), Kýčera and

Bystrica beds (Mello et al., 2011). In the Bieščary quarry (Fig. 1C), over 120 beds of the sandstones of the Kýčera Beds are exposed. They are about 80 m thick (Fig. 2A). The thick-bedded (up to 2.5 m thick), mostly fine- to medium-grained sandstones of the Magura Sandstone-type (e.g. Stráník, 1965; Teťák, 2008) are interbedded with thin-bedded sequences (Figs. 2A–C). The sandstones represent lithic greywackes which often contain a large amount of coalified plant detritus, micas and mud intraclasts (cf. Starek & Pivko, 2001; Teťák, 2008). Mudstone beds are usually some cm to several dm thick. Sedimentary structures

in the sandstones are relatively abundant. In thicker sandstone beds (>10 cm), massive bedding is the most common (S3 interval *sensu* Lowe, 1982), with intervals showing a uniform size fraction, locally fining upwards with a relatively sharp transition to siltstone and mudstone intervals, or with a thin normally graded interval (Ta – *sensu* Bouma, 1962) in the basal part. The graded interval is usually formed by a poorly sorted fine-grained conglomerate to coarse-grained sandstone, or by a sandstone with dispersed coarser clasts. Poorly developed parallel lamination and cross-beddings are represented subordinately in thicker beds. The lower bedding surfaces are mostly plain, with common small-size erosional current marks and occasional load casts. The amalgamations of beds are frequent (cf. Starek & Pivko, 2001). These sandstone beds reflect deposition from high-density turbidite currents. Thin sandstone beds (<10 cm

thick) are usually a component of thin-bedded packages with the prevalence of mudstones. These sandstones show frequent occurrence of the Bouma intervals (Ta-e) (*sensu* Bouma, 1962), typical of medium-grained turbidites, or T1-8 (*sensu* Stow & Shanmungam, 1980) as well as E1-3 intervals (*sensu* Piper, 1978), typical of fine-grained turbidites.

The sedimentary succession is interpreted as a mid-fan lobe complex of a deep-sea fan with alteration of distributary channels-proximal lobes and interchannel-interlobe parts (Starek & Pivko, 2001; cf. also Staňová & Soták, 2002, 2007; Potfaj et al., 2002; Teťák, 2008, 2010). The palaeocurrent system of these deposits is directed from the E-NE to W–SE (Starek & Pivko, 2001), which accords to the palaeocurrent measurements within the Magura Sandstone-type facies in a wider area of the Javorníky Mts (Teťák, 2008).

4. TRACE FOSSILS

Six ichnospecies were identified in the section. The trace fossils were documented by photography *in situ* and from the scree.

Halopoa annulata (Książkiewicz, 1977)

Only three specimens of *H. annulata* were found at the locality (Figs. 3A, B) on the lower bedding surface in the scree. Burrows are from 5 to 7 mm in diameter and show first order branches, longitudinal striae and constrictions. The constricted parts are interpreted as basal parts of shallow U-shaped burrows of deposit feeders (Uchman, 1998). The constricted parts were formed by rhythmic burrowing in one direction. Branches were formed when the producer changed directions of burrowing (Uchman, 1998). *Halopoa* co-occurs with *Scolicia strozzii* (Fig. 4A). *Halopoa* is referred to tracemakers that colonised newly emplaced turbidite deposits (Wetzel & Uchman, 2001). Ichnotaxonomical revision of this ichnospecies is provided by Uchman (1998).

Nereites irregularis (Schafhäutl, 1851)

The up to 5 mm thick, fine-grained sandstone layer, with poorly preserved *N. irregularis*, covers a bed with *Zoophycos* (Figs. 3C, 4C). Contours of studied specimens are identical with the endichnial *N. irregularis* from Poland (Sromowce Beds, Senonian; Uchman, 1998; fig. 56). The epichnial, horizontal, irregularly
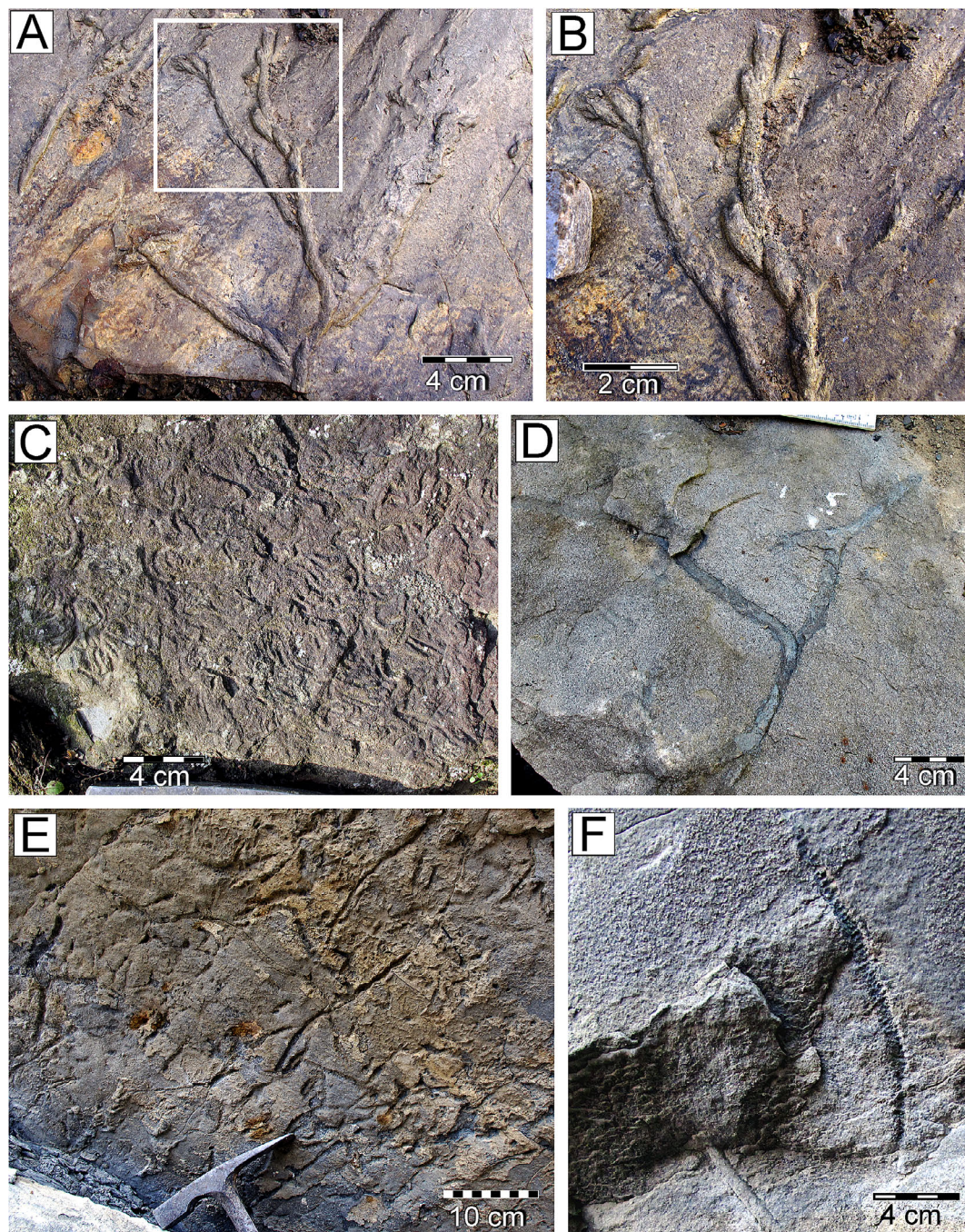

Fig. 3:
A – sole with *Halopoa annulata* **and scratching marks; B – detail on branching and wrinkles on** *Halopoa annulata* **(magnified part of Fig. 3A); C – poorly preserved** *Nereites irregularis*; **D –** *Ophiomorpha rudis* **in full relief; E – lower bedding plane with rich occurrences of** *Ophiomorpha rudis*; **F – detail view on** *Ophiomorpha rudis*. **Specimen below is without preserved pelleted wall. Upper specimen contains tiny nodes incorporated to the wall.**

meandering burrow was sharply outlined and weathered out internal tunnels (up to 3 mm wide). The *Nereites* burrows occur probably one above the other in several thin layers. The weathered surface through these layers seemingly shows overlapping burrows. The convex external zones of burrow are 1–2 mm wide. The ichnogenus *Nereites* is generally interpreted as a burrow of deposit feeders, displaing a central tunnel enveloped by a zone of reworked sediment (Uchman, 1995). *Nereites irregularis* occurs in deep-sea deposits (Uchman, 1995; Demírcan, 2008) of calcareous pelagic sediments (Seilacher, 1986). *Nereites* ranges from the Mesozoic to the Quaternary (Uchman, 1998 and citation therein). Ichnotaxonomic revision and morpholological features of *Nereites* ichnospecies were provided by Rindsberg (1994) and Uchman (1995).

Ophiomorpha rudis (Książkiewicz, 1977)
Ophiomorpha rudis is preserved in the full relief. The best observable specimens are found in the full relief on bedding planes (Fig. 3D, E). Several up to 60 cm long, vertically oriented specimens were documented in cross sections of sandstone beds (Fig. 3F). Horizontal, mostly smooth, lined, cylindrical burrows, occasionally with pelleted walls, are present. Tiny sandy pellets situated on the wall are dark coloured. Branching is at sharp angles and the tunnels are swollen in the area of branching. The diameter of burrows ranges from 4 to 11 mm. *Ophiomorpha* is interpreted as a dwelling structure of crustaceans (Bromley, 1996 and citation therein). *O. rudis* is a typical deep water, flysch *Ophiomorpha* (Uchman, 1995), which appeared since the Tithonian (Uchman, 2009). *O. rudis* belongs to post-depositional trace fossils, which means that the producers burrowed after deposition (Uchman & Wetzel, 2012).

Paleodictyon strozzii (Meneghini, 1850)
Three specimens of *P. strozzii* are hypichnial, strongly deformed hexagonal nets in sandstone beds (Fig. 4E, F). In one specimen, string width ranges from 0.81 to 0.98 mm, and the mesh width ranges from 5.2 to 7.4 mm. This specimen shows morphometric parameters between *P. delicatulum* or *P. strozzii,* according to Uchman (1995). Other two specimens of *P. strozzii* have a string width from 0.36 to 0.95 mm and a mesh width from 3.6 to 4.6 mm. *Paleodictyon* is a three-dimensional hexagonal and pre-depositional structure, that was formed several mm beneath the sediment-water interface. *Paleodictyon* is usually sketched as a system of tunnels arranged in a hexagonal pattern, communicating with bottom by short shafts (Seilacher, 2007), as also documented by present-day observations (e.g. Gaillard, 1991; Uchman, 1995 and citation therein). *Paleodictyon* is interpreted as a farming structure of an unknown producer which is utilized for cultivation and trapping micro-organisms (Seilacher, 1977). *Paleodictyon* is regarded to a typical graphoglyptid (e.g. Bromley, 1996; Miller, 2014) belonging to the Nereites ichnofacies. *Paleodictyon* occurs from the Cambrian (Crimes & Anderson, 1985) to the present-day (Gaillard, 1991).

Scolicia strozzii (Savi and Meneghini, 1850)
Scolicia strozzii is a hypichnial, smooth, bilobate meandering structure consisting of two ridges and a median groove.

Commonly, it is deformed by load casts and other deformational structures (Fig. 4A). Width of *S. strozzii* varies from 10 to 15 mm in the same specimen. The parallel ridges are semicircular in cross-section and their diameters vary also. *Scolicia strozzii* is interpreted as a shallow-tier, pre-depositional trace fossil that was preserved as a cast of washed out *Scolicia*. The size and shape of the ridges and the median groove depend on the depth and strength of the erosion of *Scolicia* (Uchman, 1995). *Scolicia* belongs to the Ophiomorpha rudis ichnosubfacies (Uchman, 2009). *Scolicia* was produced by spatangoid echinoids that burrowed to the depths of 20 cm and shallower (Goldring et al., 2007). The oldest deep water *Scolicia* comes from Tithonian turbidite deposits of the Kostel Formation in Bulgaria (Tchoumatchenco & Uchman, 2001).

Zoophycos brianteus Massalongo, 1855
Mass occurrences of several hundred overlapping *Zoophycos* were found on the upper bedding plane in the lowermost part of the studied sequence. *Zoophycos* is a helical-like structure. Its apex is situated in the middle of the helix and protrude primary lamellae. Lamellae are hooked in clockwise direction. Primary lamellae were produced by helical shifting of U- or J-shaped burrow. On cross section views of *Zoophycos* lobes are spreite structure visible. The height of this burrow system and spreite structure was not detected at the locality. In the upper part of the section (Fig. 2A), only two specimens were found. *Zoophycos brianteus* (Figs. 4C, D) does not have extended tongue-like lobes and displays more or less circular outline with gently undulated margins, whose width varies from 18 to 43 cm. The marginal tube is 3 to 4 mm wide and visible only in non-weathered specimens. *Zoophycos* is interpreted as a deposit feeding structure that originated from a simple J- or U-shaped burrow, which was successively helically coiled around the central axis (e.g. Olivero & Gaillard, 2007). The oldest *Zoophycos* is documented from Precambrian/Cambrian strata of the White Inyo Mountains (Crimes, 1987), lowermost Cambrian strata of eastern California Wood Canyon Formation in the Death Valley region (Alpert, 1977; Sappenfield et al., 2012) and south-central Sweden, shore at Hjälmsäter (Jensen, 1997). Expected producers of *Zoophycos* include sipunculids (Wetzel & Werner, 1981), polychaetes, arthropods and hemichordates (Ekdale & Lewis, 1991). Modern deep water *Zoophycos*-like structures are formed by surface ingestors of organic detritus (e.g. Kotake, 1991; Löwemark & Schäfer, 2003). *Zoophycos* occurs in shallow water deposits in the Palaeozoic. Deep sea occurrences are most typical in the post Palaeozoic (Seilacher, 2007).

5. DISCUSSION

5.1. Ichnofacies

Trace fossils association from the Bieščary section, comprising *Halopoa annulata, Nereites irregularis, Ophiomorpha rudis, Paleodiction strozzii, Scolicia strozzii* and *Zoophycos brianteus,* represents a deep water assemblage of trace fossils of the Nereites ichnofacies (Seilacher, 1967). These traces were often observed

in turbidite facies of deep-sea fans (e.g., Seilacher, 1974; Crimes et al. 1981; Uchman, 1991).

Graphoglyptids (*Paleodictyon, Nereites*) found at the locality are preserved mainly in thin- to medium-bedded sediments (Fig. 2) which implies that they are mainly shallow-tier structures, non-destructed by the deep erosion of the following pebble-sandy turbidite currents. The mud-rich palaeoenvironment allowed colonization by producers of graphoglyptids. On the contrary, *Ophiomorpha rudis, Scolicia strozzii* and *Halopoa annulata* are usually preserved even in more dynamic, coarser-grained environments with surface erosion of the substrate (Figs. 4A, B). These trace fossils represent deeper-tiers, and their producers prefered more sandy environments. They were found mainly in the thick-bedded sandstone packages interpreted as fillings of distributary channels to proximal lobe environments of a deep sea fan (Fig. 2) (cf. Heard & Pickering, 2008). The Nereites ichnofacies can be divided into the Ophiomorpha rudis ichnosubfacies (*sensu* Uchman, 2009; Rajchel & Uchman, 2012), the Paleodictyon ichnosubfacies and the Nereites ichnosubfacies (*sensu* Seilacher, 1974).

The Ophiomorpha rudis subichnofacies occurs in thick-bedded sandstones from channels and in the most proximal depositional lobes of deep-sea fans (e.g. Heard & Pickering, 2008; Uchman, 2009), where frequent erosion and high rates of sedimentation prevent development and preservation of graphoglyptids. These high-energy settings with abundance of organic particles in the water column and good oxygenation, locally, may contain traces (e.g. *Ophiomorpha, Thalassinoides, Skolithos*) typical of the shallow water Skolithos ichnofacies. The co-occurrence of deep-sea and shelf trace fossils could be caused by the transport of tracemakers by storm-induced or other downslope currents from shallower to deeper areas (Föllmi & Grimm, 1990; Wetzel, 1984, 2008) or may represent a resident fauna adapted to deep-water environments (Uchman & Demírcan, 1999).

The Paleodictyon ichnosubfacies occurs in medium- to thin bedded sandy turbidites and is mostly present in the proximal parts of the outer fan (e.g. Uchman, 1995, 2001).

The Nereites ichnosubfacies is represented by fodinichnia (deposit feeders) and tends to occur in mud-rich thin-bedded distal turbidites (Seilacher, 1974) between the frontal splays and the basin plain. These deposits, referred to as hemiturbidites (Stow & Wetzel, 1990), show characteristic intermediate between fine-grained turbidites and pelagites. However, the relatively limited number of findings of graphoglyptids within the studied section does not allow precise differentiation of the Paleodictyon and the Nereites subichnofacies.

Roughly, the Ophiomorpha rudis–Paleodictyon–Nereites ichnosubfacies may represent a bathymetric trend from the inner to the outer fan (Uchman, 2007). However, graphoglyptids, typical of the Paleodictyon and the Nereites ichnosubfacies, also occur in levee and crevasse-splay deposits of the channel complex as well as in the muddy interchannel- to interlobe area in more proximal position of the deep-sea fan complex (Buatois et al., 2001; Heard & Pickering, 2008; Olivero et al., 2010).

The medium- to thin-bedded fine-grained turbidite sequences, locally with a prevalence of mudstones, which are

documented at the Bieščary Quarry, do not represent the area of deposition in the outer fan. These sequences usually not exceed the thickness of 2–5 m and occur in close association with massive sandstones of distributary channels and proximal depositional lobes. An increased abundance of pelagites or strongly bioturbated hemiturbidite mudstones, which are typical of outer regions of deep-sea fans (Ekdale and Bromley, 1984; Uchman & Wetzel, 2012), was not observed within these thin-bedded, mud-rich sequences. The detected Ophiomorpha rudis – Paleodictyon/Nereites ichnosubfacies in the turbidite sequence at the Bieščary quarry therefore probably express a non-bathymetric trend from the channel axis, levee to overbank or inter-channel/interlobe areas (e.g. Uchman, 2009; Monaco et al., 2010; Olivero et al., 2010).

Halopoa annulata was found in the sandstone turbidite bed that is interpreted within the evaluated sequence as a part of the channel-levee complex in the middle fan. *Halopoa* occurs there along with *Scolicia* in thick-bedded sandstones, which are associated with thin-bedded fine-grained turbidite beds with *Paleodictyon strozzii*. Demírcan (2008) documented *H. annulata* from distal middle fan of turbiditic sandstone of the late Eocene formations in the SW Thrace, Turkey.

Zoophycos brianteus at the Bieščary locality occurs in the medium-bedded turbidite sequence interpreted as a lobe fringe. The wide bathymetric range of *Zoophycos* complicates a precisely palaeoenvironmental determination of the Zoophycos ichnofacies, however, this ichnofacies was defined as a typical deep-water association. The Zoophycos ichnofacies is characteristic in muddy sands environments with organic matter and deficient of oxygen influenced by occasional turbidite events (MacEachern et al., 2007). In general, preserving of graphoglyptids is lower than preserving of trace fossils typical of the Zoophycos ichnofacies. From this point of view, determination of ichnofacies to a large extent depends on the level of preservation potential of trace fossil (e.g. Uchman & Wetzel, 2012).

5.2. Distribution of trace fossils
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Distribution of trace fossils as well as the intensity of bioturbation are highly variable in deposits of the Bieščary quarry, mainly depending on the overall sedimentation rate, erosion, intercalation of gravity-flow mudstones, bottom oxygenation or supply of food. The cross-cutting relationships between trace fossils are probably a result of the upward movement of tiers during accretion of sediment and also of the sequential colonization of event layers over time (e.g. Wetzel & Uchman, 2001).

Fluctuation in the oxygenation of sediments is an important parameter controlling the trace-fossil diversity in turbidite successions. The occurrence of burrows in sediments indicates the presence of at least some oxygen in the sea floor. However, some beds or packages of beds are not colonized, although the long interturbidite period is usually sufficient for the colonization. This may result from erosion of the delicate, mostly shallow graphoglyptids by turbidity currents or may be related to anoxic events (e.g. Uchman, 2004). On the other hand, turbidites can deliver oxygen to the sea floor and enable colonization of the substrate. Moreover, the distributary channels and depositional

lobes of deep sea fans are regarded as a food-rich area (Olivero et al., 2010). *Zoophycos* occurs in the environment with lowered oxygen levels and sufficient organic debris accumulation in largely persistent low-energy regimes (Frey & Seilacher, 1980).

Despite the relatively good exposition of turbiditic section, it should be noted that the estimation of bioturbation index as well as the exact distribution of trace fossils within the sequence may be affected in that many lower bedding surfaces remains inaccessible to investigation.

In some beds, the ichnofabrics are markedly dominated by a single trace fossil, usually *Scolicia* (Fig. 4A) which often covers the entire bed surface. This can reflect the invasion of their producer and related to the bulldozing effect *sensu* Thayer (1979), when relatively large burrowers prevent or reduce colonization of the substrate by immobile suspension-feeders. Uchman (1995) described this phenomenon in deep-sea environments. The monospecific assemblage may also result from erosion of the substrate by turbidity currents, when the uppermost tier with more diverse species of trace fossils has been removed. Then, the presence of trace fossils, preserved as semi-relief on the sole of a turbidite, belonging to a specific tier depending on the depth of erosion below a turbidite (Wetzel & Aigner, 1986). *Scolicia strozzii* was situated in middle-tier, but it is also associated with graphoglyptids in the shallow-tier (Demírcan, 2008).

6. CONCLUSION

Six ichnospecies comprising *Ophiomorpha rudis, Halopoa annulata, Paleodictyon strozzii, Nereites irregularis, Scolicia strozzii* and *Zoophycos brianteus* were identified in the Eocene turbidity succession at the Bieščary quarry. This trace fossil association represents, in general, a deep water assemblage of the Nereites ichnofacies. The ichnogenera *Ophiomorpha, Scolicia* and *Halopoa* were recognized mainly in the thick-bedded sandstone packages interpreted as fillings of distributary channels to the proximal lobes of a deep sea fan and fall within the Ophiomorpha rudis ichnosubfacies. Graphoglyptids (*Paleodictyon, Nereites*) represent the Paleodictyon/Nereites ichnosubfacies and were found mainly in more clayey sequences with thin- to medium-bedded fine-grained turbidites interpreted as levee and crevasse-splay deposits to more muddy inter-channel deposits of the deep sea fan. Given the sedimentological interpretation of the turbidity facies and distribution of the ichnospecies within them, we suppose that the detected Ophiomorpha rudis – Paleodictyon/Nereites ichnosubfacies in the Bieščary quarry section could not be equated with bathymetric trend from the inner to the outer fan. These ichnosubfacies probably display a non-bathymetric trend from the channel axis, levee to overbank or inter-channel/interlobe areas of the deep sea fan. The distribution and preservation of trace fossils were controlled mostly by: (a) lithology, occurrence of mudstone layers within coarser-grained turbidite beds; soles of sandstone beds allow a better preservation of traces as non-lithified clays; (b) the overall sedimentation rate as well as erosion and amalgamation of beds in the proximal mid fan area; (c) "the bulldozing effect" influenced colonization of substrate; and (d) the oxygen content and the amount of food. These

palaeoenvironmental conditions could not be accurately quantified when the trace fossil occurrence is rare in the sequence. The analysed ichnospecies represent different life strategies and together with sedimentological analyses could help to precise interpretation of the depositional palaeoenvironment. *Halopoa* represents a vagile deposit feeder and *Scolicia* represents an omnivore in sandy sediment, both occurring several centimetres below the surface and probably at the same depth (Fig. 4A). *Nereites* is a grazing trail (pascichnion) on the sea floor with fine-grained substrate, with enough food and oxygen. *Paleodictyon* reflects the conditions of a slow sedimentation rate, whereby this structure was produced in the uppermost parts of the sediment column. *Zoophycos* (agrichnion or fodinichnion of hemi-sessile deposit feeder) occupied the deep tier of substrate and its occurrence indicates regularly alternating conditions with and without food and lowered oxygen levels. *Ophiomorpha* (domichnion, fodinichnion) is a permanent dwelling and also feeding structure in relatively coarser grained well oxygenated substrate.

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