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TRACE FOSSILS IN THE CRETACEOUS–EOCENE FLYSCH OF THE SINOP-BOYABAT BASIN, CENTRAL PONTIDES, TURKEY

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Abstract: Sixty six ichnotaxa have been recognized in Barremian–Lutetian deep-marine deposits of the Sinop-Boyabat Basin, north-central Turkey, which evolved from a backarc rift into a retroarc foreland, with two episodes of major shallowing. The blackish-grey shales of the Çağlayan Fm (Barremian–Cenomanian) contain low-diversity traces fossils of mobile sediment feeders influenced by low oxygenation. One of the oldest occurrences of *Scolicia* indicates early adaptation to burrowing in organic-rich mud. The "normal" flysch of the Coniacian–Campanian Yemişliçay Fm bears a low-diversity *Nereites* ichnofacies influenced by volcanic activity. The Maastrichtian–Late Palaeocene carbonate flysch of the Akveren Fm contains a *Nereites* ichnofacies of moderate diversity, which is impoverished in the uppermost part, where tempestites indicate marked shallowing. The overlying variegated muddy flysch of the Atbaşı Fm (latest Palaeocene–earliest Eocene) bears an impoverished *Nereites* ichnofacies, which is attributed to oligotrophy and reduced preservation potential. The sand-rich siliciclastic flysch of the Kusuri Fm (Early–Middle Eocene) bears a high-diversity *Nereites* ichnofacies, except for the topmost part, where tempestites and littoral bioclastic limestone reflect rapid shallowing due to the tectonic closure of the basin. The turbiditic channel-fill and proximal lobe facies show a reduced trace-fossil diversity, but abundant *Ophiomorpha*, which is typical of the *Ophiomorpha rudis* sub-ichnofacies of the *Nereites* ichnofacies. The high abundance of *Ophiomorpha* in the Kusuri Fm and its low abundance in the Akveren Fm are related to plant detritus supply. The Kusuri turbiditic system was fed by a large delta, supplying rich plant detritus, whereas the Akveren system was fed by a carbonate ramp that supplied little or no such material. The extension of the *Nereites* ichnofacies into the tempestite-bearing neritic deposits at the top of both the Akveren and Kusuri formations indicates the capacity of the deep-water ichnofauna to survive in a rapidly-shoaling restricted basin. Only the topmost shoreface sandstones of the Akveren Fm show sporadic *Ophiomorpha* ?*nodosa*, a typical shallow-marine trace fossil.

Key words: ichnology, *Nereites* ichnofacies, bathymetry, turbidites, tempestites, rift, foreland.

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INTRODUCTION

The fossil record of macrobenthic life in deep-marine deposits, particularly flysch facies (*sensu* Dżułyński & Walton, 1965), is limited and commonly quite poor. This gap in the general knowledge of ancient deep-sea environments is filled in partly by studies of trace fossils. The corresponding literature indicates that the trace-fossil assemblages in deep-marine successions vary from basin to basin and also show considerable lateral and stratigraphic intrabasinal variation, which reflects varied ecological and taphonomic conditions, as well as the evolution of fauna (e.g., Książkiewicz, 1977; Seilacher, 1978; McCann, 1990; Crimes & Fedonkin, 1994; Uchman, 1999, 2003, 2004). The great variation in trace-fossil assemblages, to be recognized and understood, obviously requires wide sampling, and hence the importance of new ichnological case studies of deep-marine sedimentary successions.

The Sinop-Boyabat Basin of the Central Pontides, north-central Turkey (Fig. 1), contains a well-exposed succession of Cretaceous to Eocene deep-marine deposits, nearly seven thousands metres thick, which includes episodes of major shallowing and bears a record of the evolution of the basin from a backarc rift into a retroarc foreland, increasingly compartmentalized by thrust tectonics. The progressive change in basin configuration was accompanied by major changes in the sediment source and morphodynamic characteristics of the basin-filling turbiditic systems.

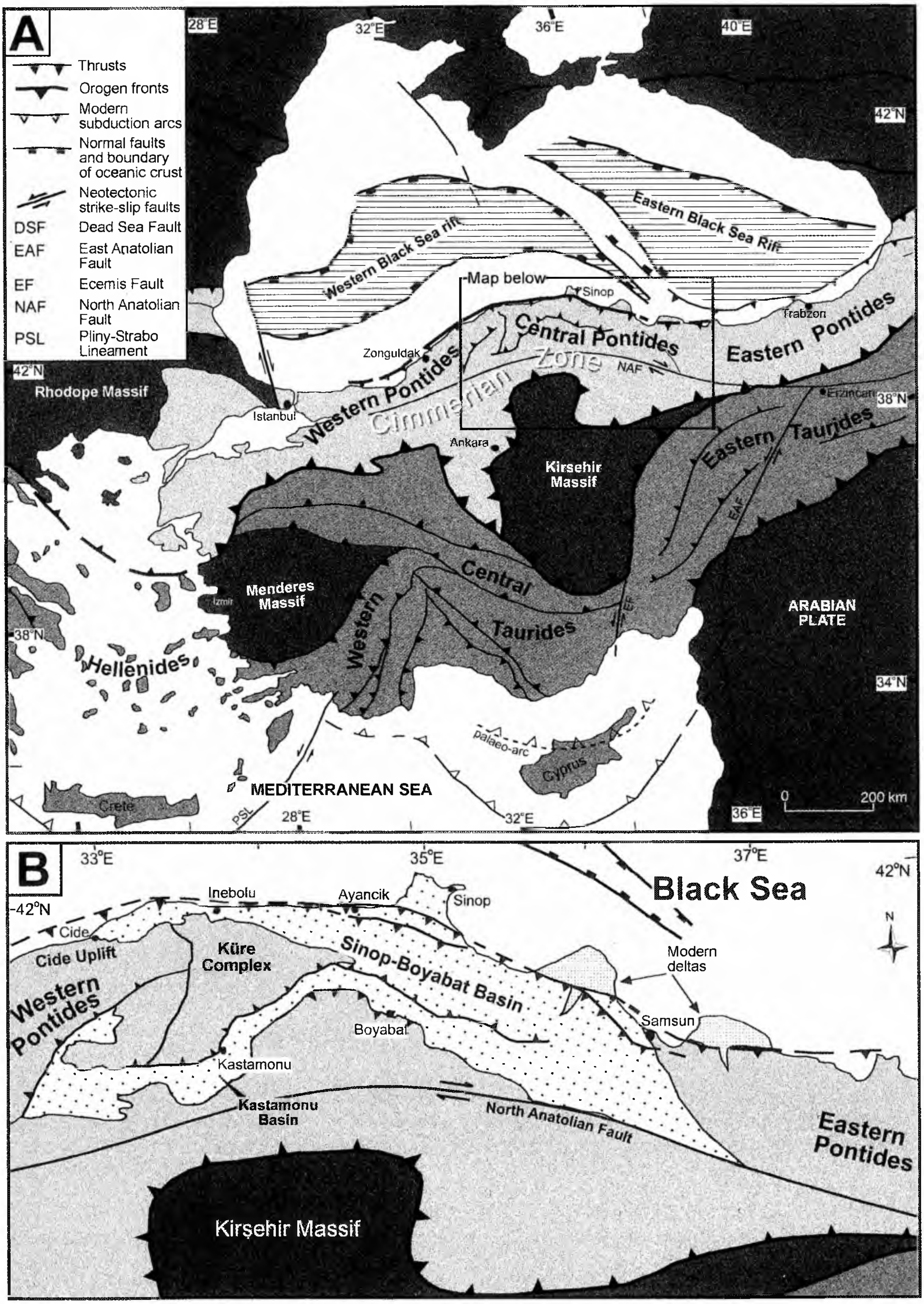


Fig. 1. A – Tectonic map of Anatolia and surrounding areas, showing the Pontide and Tauride orogenic belts and the Kırşehir Massif. **B** – A simplified map of the Central Pontides, showing the location of the Sinop-Boyabat Basin. Maps compiled with modifications from Robinson *et al.* (1996), Tüysüz (1999), Okay *et al.* (2001) and Nikishin *et al.* (2003)

The sedimentary succession bears abundant trace fossils, which have not been previously studied. The description and interpretation of these trace fossils is the primary aim of the present paper. The systematic study of ichnotaxa is illustrated with photographs taken directly at the outcrops, but some of the specimens are presently stored in the Institute of Geological Sciences of the Jagiellonian University (collection prefix 173P).

GEOLOGICAL SETTING

Regional tectonics and basin development

The Pontide and Tauride orogenic belts of Anatolia (Fig. 1A) were formed by the accretion of Africa-derived microcontinents to the Cimmeride margin of Eurasia in the Late Cretaceous–Palaeogene, during the Alpine orogeny (Şengör, 1987; Okay & Tüysüz, 1999; Görür & Tüysüz, 2001). The Jurassic suturing of Cimmeria, which marked the closure of the Palaeotethys ocean (Şengör, 1984), was followed by the accretion of the Kırşehir and Menderes massifs in the Late Cretaceous (Dilek & Rowland, 1993). When colliding with Eurasia, the large Kırşehir Massif (Fig. 1A) indented the Cimmeride margin and underwent anticlockwise rotation (Sanver & Ponat, 1981; Görür *et al.*, 1984; Tüysüz *et al.*, 1995; Kaymakcı *et al.*, 2003), which caused northward emplacement of the Central Pontide nappes. The subsequent accretion of Tauric microcratons to the Kırşehir and Menderes massifs, and directly to Eurasia farther to the east, completed the orogeny (Dilek & Moores, 1990).

The two-step continental accretion resulted in the Pontide and Tauride orogenic belts, respectively, and ended with a direct collision of the Arabian promontory of Africa with the Eurasian margin to the east (Fig. 1A). The accretion process was driven by a progressive northward subduction of the Neotethyan oceanic-plate slivers separating the microcontinents, with the subduction zone stepping backwards and eventually shifting in early Neogene to its present-day position in the Cyprean and Hellenic arcs (Fig. 1A). The accretion was gradual, diachronous and spatially non-uniform, whereby the Pontide orogenic belt continued to deform during the formation of the adjacent Tauride belt. The Pontide orogeny commenced in the Late Cretaceous time and culminated at the end of Eocene (Okay, 1989; Aydm *et al.*, 1995a, b; Okay & Şahintürk, 1997; Ustaömer & Robertson, 1997; Yılmaz *et al.*, 1997; Okay & Tüysüz, 1999; Gürer & Aldanmaz, 2002), whereas the Tauride orogeny began near the end of Cretaceous and lasted until the middle Oligocene in the central part of Anatolia (Andrew & Robertson, 2002), but until the Late Miocene in the western (Hayward, 1984; Collins & Robertson, 1998, 2000) and eastern parts (Michard *et al.*, 1984; Aktaş & Robertson, 1990; Dilek & Moores, 1990; Yılmaz, 1993; Yılmaz *et al.*, 1993; Sunal & Tüysüz, 2002).

The northward subduction of Neotethys was accompanied by backarc extension that led to the formation of the Black Sea rift system (Fig. 1A) along the former Cimmerian suture in the Early Cretaceous time (Tüysüz, 1990, 1993; Okay *et al.*, 1994, 2001; Robinson *et al.*, 1996; Ustaömer & Robertson, 1997; Yılmaz *et al.*, 1997; Nikishin *et al.*, 2003). A volcanic arc initially extended from Georgia in the east to Bulgaria in the west (Peccarillo & Taylor, 1975; Eğin *et al.*, 1979; Akıncı, 1984; Tüysüz *et al.*, 1995), and the zone of volcanic activity was broadened by the backarc rifting and subsequent crustal break-up. The calcalkaline volcanism in the Central Pontides occurred mainly in the Coniacian to middle Campanian time (Tüysüz, 1993; Göncüoğlu *et al.*, 2000; Okay *et al.*, 2001). The crustal break-up in the Western Black Sea Rift is considered to have occurred in the late Cenomanian–Coniacian time (Görür, 1988; Okay *et al.*, 1994; Robinson *et al.*, 1995, 1996; Okay & Şahintürk, 1997; Meredith & Egan, 2002; Rangin *et al.*, 2002; Cloetingh *et al.*, 2003; Nikishin *et al.*, 2003), whereas the timing of crustal separation in the Eastern Black Sea Rift is more controversial, thought to have occurred at roughly the same time (Nikishin *et al.*, 2003) or possibly later, in Maastrichtian (Okay & Şahintürk, 1997) or even Palaeocene time (Robinson *et al.*, 1995, 1996).

The Sinop-Boyabat Basin (Figs 1B, 2) formed in Barremian time as an "abortive" southern sister of the "successful" Western Black Sea Rift (terminology after Ziegler, 1990, p. 177), failing to achieve crustal separation. Its tectonic history is summarized in Figure 3A–F. The SE-trending deep-water basin formed as an extensional graben, *ca.* 80 km wide and at least 200 km long, hanging structurally between the strongly subsiding Western Black Sea Rift to the north and the Central Pontide accretionary zone to the south. The basin underwent two main phases of rifting, in the Barremian to early Albian and the Santonian to early Campanian time, before becoming subject to orogenic compression in the late Campanian and being decoupled from the Black Sea extensional regime in the late Maastrichtian (Leren *et al.*, unpubl. data). In the earliest Eocene, the basin was split axially into two subparallel troughs by a structural pop-up ridge formed by the northward Erikli thrust combined with the antithetic Ekinveren back-thrust (Fig. 2 and Fig. 3E). The southern trough, referred to as the Boyabat Basin, was a wedge-top ("piggy-back") basin, initially subneritic and *ca.* 20 km wide, whereas the northern trough, referred to as the Sinop Basin, was *ca.* 30 km wide and acted as a bathyal foredeep basin (*sensu* DeCelles & Giles, 1996). The Sinop Basin was mildly affected by blind thrusts, until the northernmost one (the Balıfakı thrust in Fig. 2) turned the foredeep trough into another wedge-top basin in the Middle Eocene time (Fig. 3F). Both basins were tectonically inverted near the end of Eocene time, although alluvial sedimentation in the Boyabat Basin probably persisted into the Oligocene (Aydın *et al.*, 1995b). The thrusts have elevated large parts of the original basin to more than 1000 m above sea level, resulting in a remarkably good overall exposure.

Basin stratigraphy

The basin-fill succession consists of Early Cretaceous to Middle Eocene siliciclastic and calcareous deposits, with volcanic products in the lower part and a combined stratigraphic thickness of nearly 7 km (Fig. 3). The following review of the dynamic stratigraphy of the basin compiles the results of previous studies (Ketin & Gümüş, 1963; Gedik &

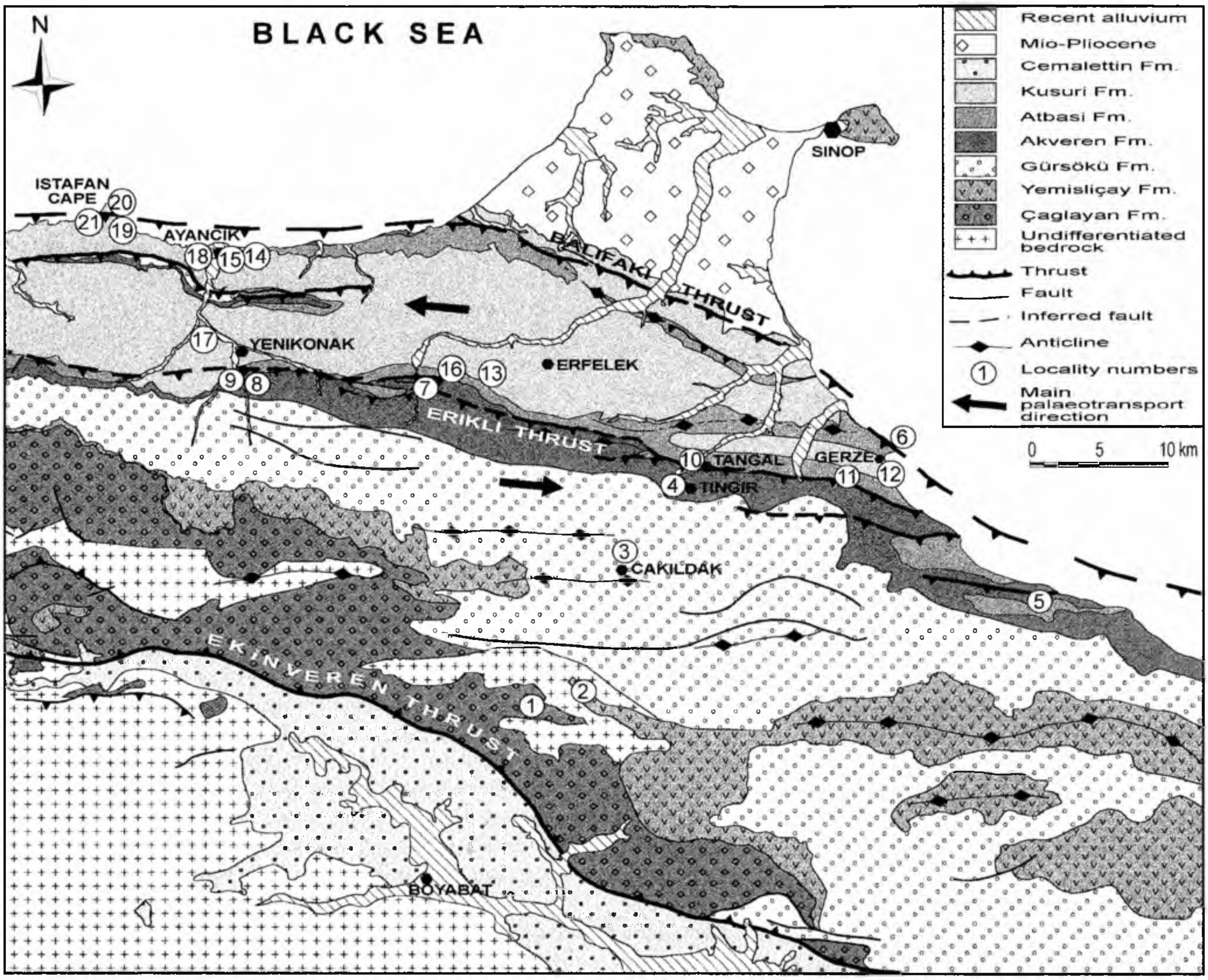


Fig. 2. Geological map of the main part of Sinop-Boyabat Basin, showing the areal distribution of the basin-fill formations (cf. Fig. 3); modified from Gedik and Korkmaz (1984), Barka *et al.* (1985) and Aydın *et al.* (1995b). Note that the northward Erikli thrust and the southward Ekinveren back-thrust turned the whole axial part of the basin into a pop-up ridge that split the original basin, at the beginning of Eocene, into a southern wedge-top trough (Boyabat Basin) and a northern foredeep trough (Sinop Basin). The Balýfaký thrust, farther to the north, formed in the mid-Eocene and converted the Sinop Basin into a wedge-top trough

Korkmaz, 1984; Gedik *et al.*, 1984; Aydın *et al.*, 1986, 1995a, b; Tüysüz, 1990, 1993, 1999; Görür & Tüysüz, 1997) and more detailed recent sedimentological research (Janbu *et al.*, 2003; Janbu *et al.*, unpubl. data; Leren, 2003; Leren *et al.*, unpubl. data). The review refers to the regional tectonic development summarized with literature references in the previous section (see also diagrams A–F in Fig. 3).

Bedrock. The basin bedrock unit (Fig. 3) is a thick succession of pre-rift platform carbonates, Late Jurassic to Early Cretaceous in age, which covered most of the Cimmeride margin of Eurasia. Similar shelf-type carbonate platforms were hosted by the microcratons subsequently accreted to the continental margin.

Çağlayan Formation. The onset of rifting and establishment of a deep-water basin is recorded by the Barremian–Cenomanian Çağlayan Fm (Fig. 3), which consists of calcareous turbidites embedded in blackish-grey mudshales (Fig. 4A), intercalated with olistostromal breccias and slide blocks of resedimented bedrock limestone. These deposits are locally up to 2000 m thick and their varied thickness reflects rugged fault-block topography of the early-stage rift basin. The sediment was derived from both margins of the basin, with the turbidity currents filling in the basin-floor relief and tending to flow westwards along the graben axis.

Kapanboğazı Formation. The sediment supply to the basin declined in the Cenomanian to earliest Coniacian time, when the Kapanboğazı Fm (Fig. 3) was deposited in a sand-starved deep-water environment. This formation is no more than 40 m thick and consists of reddish-grey, variegated mud shales interbedded with pelagic marls and minor thin calciclastic turbidites. The cessation of sediment supply indicates a post-rift phase of broader thermal subsidence that caused the contemporaneous shorelines to shift away from the graben.

Yemişliçay Formation. Another pronounced rifting pulse was recorded by the overlying Yemişliçay Fm (Conia-

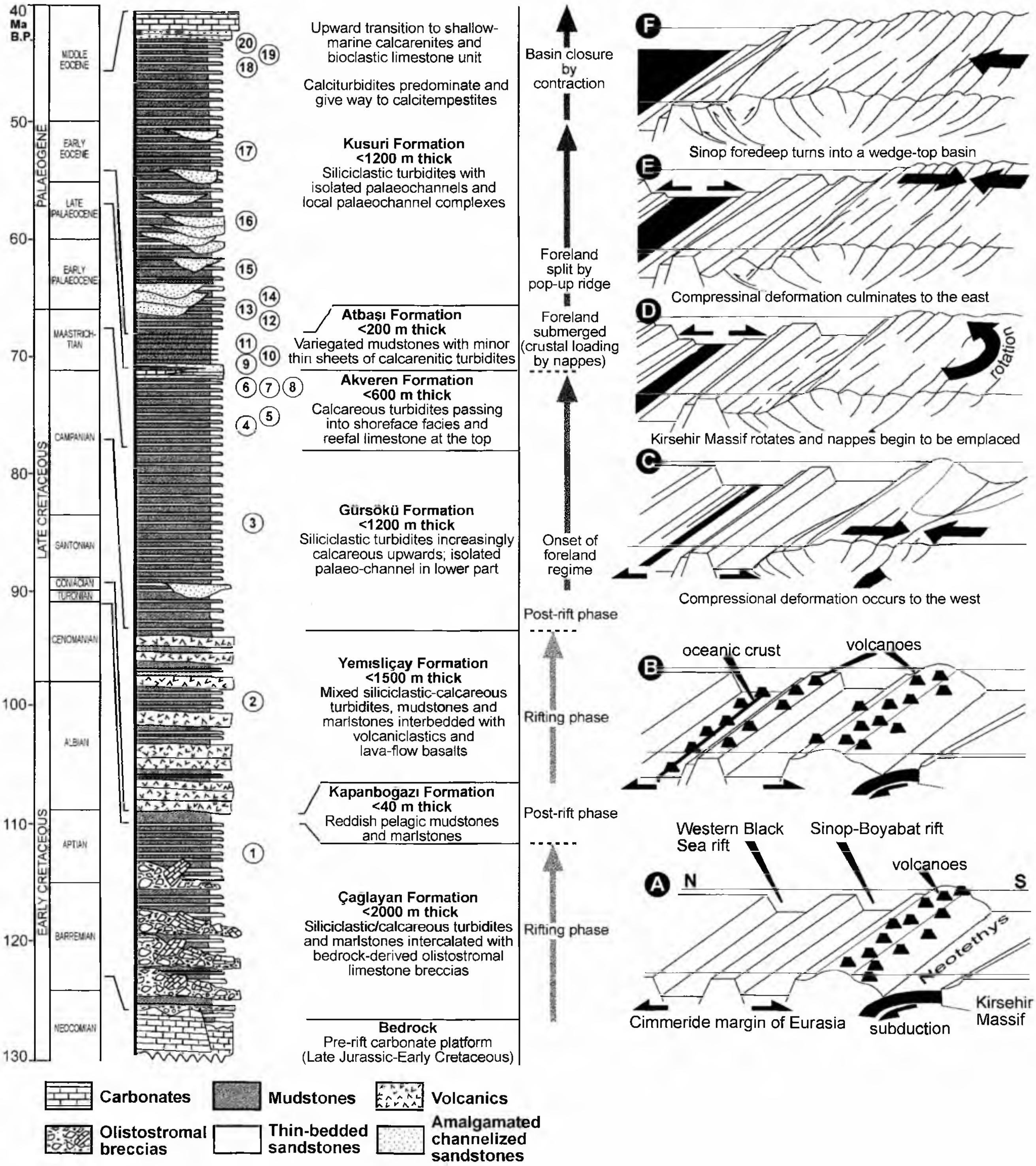


Fig. 3. Stratigraphy of the Sinop-Boyabat Basin (modified from Ketin & Gümüt, 1963; Gedik & Korkmaz, 1984; Aydın *et al.*, 1995b). The Eocene part of the profile pertains to the Sinop Basin (see caption to Fig. 2). The schematic cartoon on the right-hand margin of the profile (diagrams A–F) summarizes the tectonic history of the Sinop-Boyabat Basin, as described in the text

cian–Campanian), which is up to 1500 m thick and consists of turbidites with a mixed calci-volcaniclastic composition (Fig. 4B), interbedded with abundant pyroclastic deposits and lavaflow basalts. The sediment was still derived from both sides of the basin, but the northern margin was subsequently submerged below wave base and remained little active as a sediment source. The asymmetrical development of the basin is attributed to the crustal break-up and margin fault-block collapse in the adjacent Western Black Sea Rift (Fig. 3B).

Gürsökü Formation. The Sinop-Boyabat rift then became increasingly affected by orogenic thrust tectonics

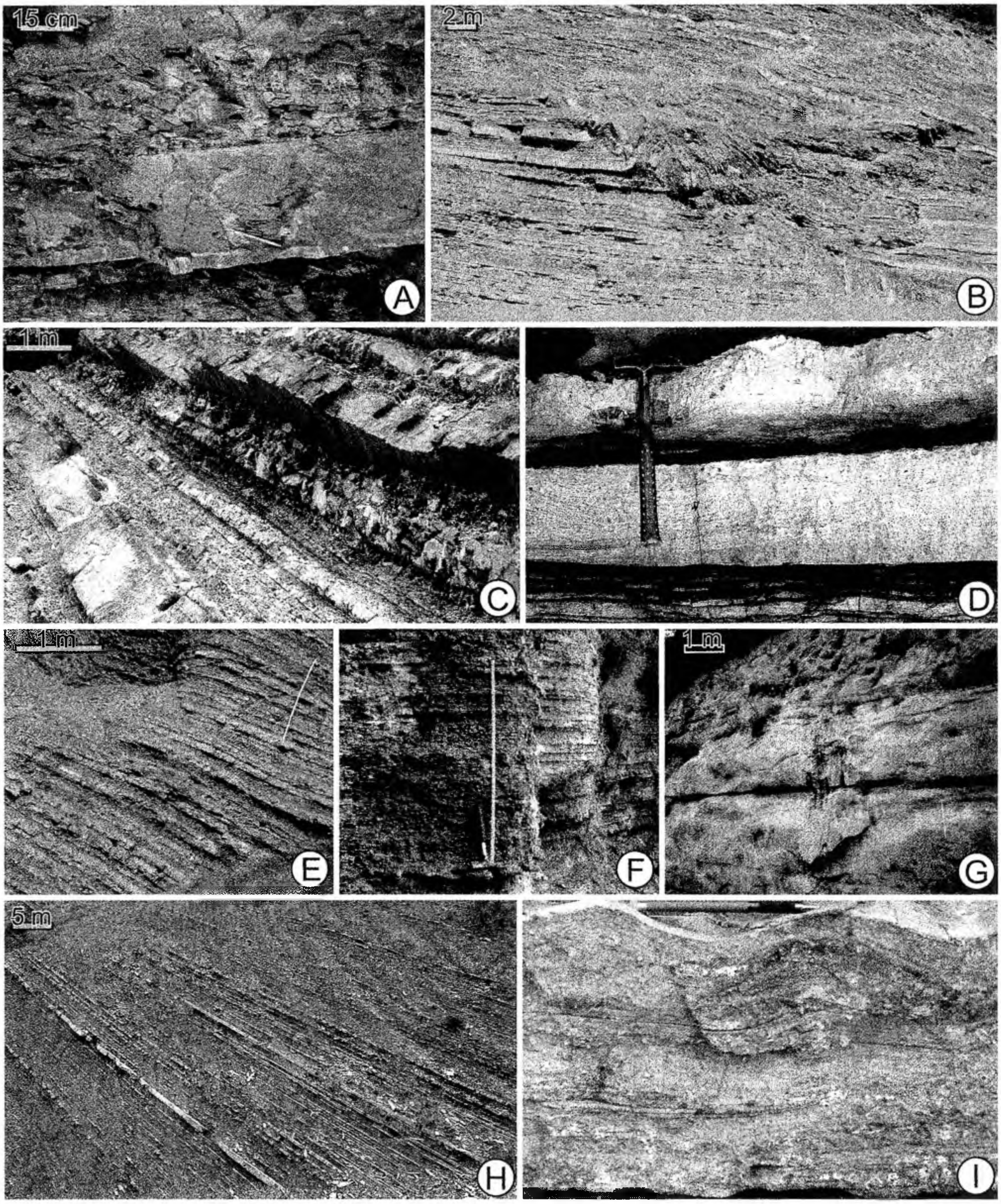


Fig. 4. Sedimentary facies of the basin-fill succession. **A** – tabular calcarenitic turbidite embedded in blackish-grey, ammonite-bearing shales in the upper part of Çağlayan Fm, locality 1; **B** – sheet-like volcaniclastic and mixed volcanic-calciclastic turbidites of the Yemişliçay Fm, cut by a thrust, at locality 2; **C** – sheet-like calciturbidites topped with marlstone and/or calcareous mudstone, Akveren Fm, locality 5; **D** – calcarenitic tempestites in the topmost part of Akveren Fm, showing sharp tops and internal hummocky and swaley stratification (coastal outcrop 15 km west of Istafan Cape); **E** – thin sheet-like calciturbidites and marlstone interbeds in the reddish-grey shales of the Atbaşı Fm, locality 10; **F** – thin siliciclastic turbidites alternating with grey mud shales in the lowermost part of Kusuri Fm, locality 12; **G** – channel-fill sandstone turbidites in the middle part of the Kusuri Fm, locality 18; **H** – sheet-like distal lobe turbidites in the middle part of the Kusuri Fm, locality 16; **I** – calcitempestite with a sharp, rippled top, internal plane-parallel stratification and 3-D vortex-ripple cross-lamination ("microhummocks"), in the topmost part of the Kusuri Fm at locality 20 (the pen is 15 cm). The locality numbers are as in Fig. 2 and Table 1

from the south, which effectively converted it into a retroarc foreland basin of the growing Central Pontides (Janbu *et al.*, unpubl. data). The compressional deformation in the basin commenced in Senonian time, with the deposition of the Gürsökü Fm (Campanian–Maastrichtian). This turbiditic succession, up to 1200 m thick (Fig. 3), consists of siliciclastic sediment increasingly richer in calcareous bioclastic admixture, supplied mainly from the west-southwest and spread eastwards along the basin axis (Leren *et al.*, unpubl. data). The formation consists of sheet-like turbidites, thin to moderately thick (Fig. 5A), and shows little evidence of channelized currents, except for an isolated palaeochannel in the lowermost part. Benthic forams indicate bathyal conditions, and the water depth was probably of several hundred metres. The system was supplied with sediment from a littoral to neritic ramp perched on the deep margin of the basin and spawning turbidity currents as a result of storms and earthquakes. High subsidence rates prevented seafloor shallowing, while the aggrading turbiditic system tended to retreat by back-lapping the basin margin (Leren *et al.*, unpubl. data). The siliciclastic sediment is chiefly of epiclastic volcanic provenance. The bioclastic admixture includes fragments of bivalves, brachiopods, bryozoans, echinoderms, forams, molluscs and red coralline algae, mainly crustose *Corallinaceae melobesieae* (Leren, 2003), which indicates derivation from a contemporaneous reefal platform dominated by foramol facies (*sensu* Lees & Buller, 1972). The eastward sediment transport and cessation of volcanism are attributed to the collision of the Kırşehir Massif with the Cimmeride margin, which commenced in the transition area of the Western-Central Pontides in Senonian time (Fig. 3C) and probably led to a shift of subduction process to the rear side of this large "indentor" block.

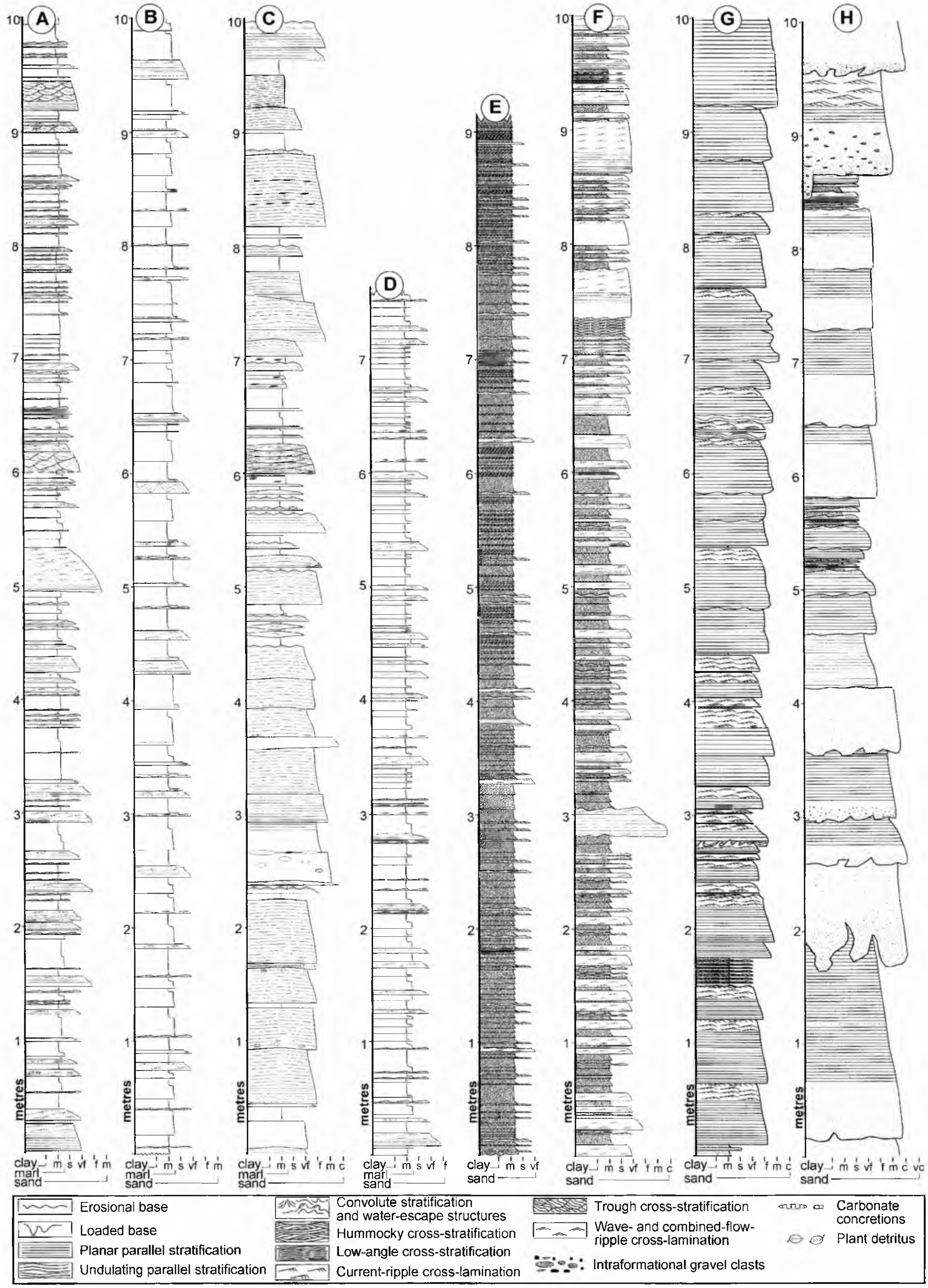
Akveren Formation. As the Kırşehir Massif was pushed further to the north and rotated counter-clockwise, the Central Pontide nappes began to be emplaced northwards and affect the foreland basin (Fig. 3D), whereby a littoral, foramol-type carbonate platform expanded along the basin's shallowly submerged southwestern margin. The Akveren Fm (Fig. 3) of Maastrichtian to Late Palaeocene age is up to 600 m thick and consists of calciclastic sheet-like turbidites, mainly thin to moderately thick, capped with marlstone and/or calcareous mudstone (Fig. 4C). This turbiditic succession shows an upward thickenning of beds (Figs 5B, C), eastward palaeocurrent directions and an evidence of rapid shoaling in the uppermost part (Fig. 3). The sediment was derived by storm-generated density currents from a distally-steepened carbonate ramp, which eventually became homoclinal and advanced far into the shallowing basin (Leren *et al.*, unpubl. data). The ignition of turbidity currents declined as the basin floor aggraded to neritic and littoral water depth and became increasingly influenced by waves. The shallowing is recorded by the uppermost 50 m of the formation, where turbidites give way to tempestites (Fig. 4D) and the associated benthic forams indicate neritic water depth; the topmost shoreface calcarenites overlain by reefal limestone unit are littoral deposits. The marked decrease in subsidence rate corresponding to the Akveren Fm suggests that the basin by this time was decoupled from the extensional subsidence regime of the Western Black Sea Rift.

Atbaşı Formation. The overlying Atbaşı Fm (latest Palaeocene–earliest Eocene) consists of deep-water variegated mudstones, *ca.* 200 m thick, intercalated with thin calciclastic turbidites (Figs 4E, 5D). Benthic forams indicate subneritic bathymetry. The rapid deepening of water and sand-starved basin conditions are attributed to a broad subsidence of the foreland as a result of the crustal loading by nappes (Fig. 3D; Nikishin *et al.*, 2003), which coincided with the Thanetian eustatic sea-level rise (Haq *et al.*, 1988).

The continental collision subsequently culminated in the Eastern Pontides, where the Late Palaeocene accretion of a supra-subductional volcanic arc (the Elazığ Magmatic Complex) to the Eurasian margin marked the local climax of the Pontide orogeny (diagram E in Fig. 3). The concurrent accretion of the Munzur-Bolkar block to the southeastern side of the Kırşehir Massif was followed by the accretion of the Bitlis-Pütürge block to the Elazığ margin, which marked the onset of the Tauride orogeny also to the east. The full-scale onset of the Tauride orogeny caused further contraction in the Central Pontide foreland, with reversal of pre-existing normal faults and thin-skinned thrust tectonics (Aydın *et al.*, 1995b). In the Early Eocene, the Erikli thrust in combination with the Ekinveren back-thrust (Fig. 2) formed a structural pop-up ridge that split the Sinop-Boyabat Basin longitudinally into two subparallel troughs – the northern Sinop Basin and the southern Boyabat Basin (Janbu *et al.*, unpubl. data).

Kusuri Formation. The Early to Middle Eocene Kusuri Fm, deposited in the Sinop Basin (Fig. 3), is a turbiditic succession up to 1200 m thick that records an abundant supply of siliciclastic sediment from the east (Janbu *et al.*, unpubl. data). The feeder is thought to have been a large fluvio-deltaic system draining the adjacent Eastern Pontide foreland. The relatively mud-rich lower part of the succession is interspersed with thin turbidites (Figs 4F, 5E), whereas the sand-rich middle part contains solitary and multistorey turbiditic palaeochannels, 20–25 m deep and a few hundred metres wide (Figs 4G, 5H), associated with sheet-like overbank deposits, levees and terminal lobes (Figs 4H, 5E, F). The mud-rich upper part contains sheet-like turbidites that are increasingly calcareous, with a rapid upward transition into neritic calci-tempestites (Fig. 4I) and littoral bioclastic limestones at the top (Fig. 3). This latest part of the succession, deposited north of the Balýfaký thrust (Fig. 2), shows clear structural evidence of the progressive closure of the basin by the growth of an asymmetrical syncline in front of this young thrust (Janbu *et al.*, unpubl. data). The shallowing of water from bathyal to neritic depth is corroborated by the benthic microfauna.

The coeval Eocene succession in the adjacent Boyabat Basin, referred to as the Cemalettin Fm, is *ca.* 900 m thick and similarly siliciclastic, rich in sand and gravel derived from the east. Its lower part consists of sub-neritic mudstones intercalated with minor turbidites, whereas the sand-rich upper part shows an overall shallowing punctuated by relative sea-level rises, with episodes of Gilbert-type delta progradation and sublittoral to nearshore deposits overlain by thick gravelly alluvium. The succession apparently recorded a shift of the fluvial feeder system from the eastern part of the Sinop Basin to the adjoining Boyabat Basin.


A
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m s vf f m c vc
Erosional base
Loaded base
Planar parallel stratification
Undulating parallel stratification
Convolute stratification and water-escape structures
Hummocky cross-stratification
Low-angle cross-stratification
Current-ripple cross-lamination
Trough cross-stratification
Wave- and combined-flow-ripple cross-lamination
Intraformational gravel clasts
Carbonate concretions
Plant detritus

Table 1

Localitites in the Sinop-Boyabat Basin at which trace fossils have been studied
(the locality numbers refer to the map in Fig. 2 and stratigraphic profile in Fig. 3)

Locality	Formation	Outcrop location
1	Çağlayan	Outcrop section 2 km north of Bürnük town, along the main road between the cities of Boyabat and Sinop
2	Yemişliçay	Outcrop 7-8 km north of Bürnük town, along the same main road
3	Gürsökü	Outcrop along the main road *ca.* 400 m north of Çakıldak village
4	Akveren	Outcrop along the main road between the villages of Tingir and Tangal
5	Akveren	Outcrop along the main road between Sinop and Samsun, at the road's large U-turn around a deep gorge *ca.* 10 km SE of Gerze
6	Akveren	Coastal outcrop along the northwestern pier in Gerze
7	Akveren	Outcrop section near the waterfalls *ca.* 6 km west of Erfelek town
8	Akveren	Outcrop *ca.* 2 km south of Yenikonak, on the main road between Ayancık and Kastamonu
9	Atbaşi	Same area as locality 8; outcrop 300 m to the west across the river
10	Atbaşi	Outcrop along the main road in Tangal village
11	Atbaşi	Outcrop along a dirt road *ca.* 2 km south of Gerze
12	Kusuri	Coastal outcrop SE of the eastern pier in Gerze harbour
13	Kusuri	Outcrop *ca.* 3 km west of Erfelek along the road to the waterfalls, directly across the river
14	Kusuri	Outcrop *ca.* 2 km east of Ayancık town, along the main road to Sinop
15	Kusuri	Outcrop along the main road in Ayancık town, east of the river
16	Kusuri	Outcrop at the earth-dam construction site *ca.* 5 km west of Erfelek
17	Kusuri	Outcrop along the main road near the Ikisu bridge, south of Ayancık
18	Kusuri	Coastal outcrop directly west of the town of Ayancık
19	Kusuri	Abandoned quarry near the harbour in Çaylıoğlu village
20	Kusuri	Outcrop along the road from Çaylıoğlu to abandoned quarry on Istafan Cape
21	Kusuri	Coastal outcrop south of the Sorma Cape, *ca.* 2 km west of Çaylıoğlu

The two basins were gradually closed and inverted by contraction in the Late Eocene to Early Miocene time, during the climax and final stages of the Tauride orogeny. Paratethyan shallow-marine deposits of Miocene age occur only in the area of Sinop peninsula (Fig. 2), outside the inverted basin, where they overlie bedrock with a major unconformity and are dominated by shell-rich bioclastic limestones (Görür *et al.*, 2000).

The localities studied

The following description of trace fossils pertains to the Cretaceous–earliest Eocene succession shared by the two basins, and to the subsequent Eocene succession deposited in the Sinop Basin (Kusuri Fm). Trace fossils have been studied in two dozens of the best outcrop sections, the main of which are listed in Table 1. Their geographic location and stratigraphic position are indicated in Figures 2 and 3, respectively. The trace-fossil descriptions refer to these localities and also indicate specimens that are stored at the Institute of Geological Science, Jagiellonian University.

SYSTEMATIC DESCRIPTION OF TRACE FOSSILS

For the purpose of their description, the trace fossils have been divided into the morphological groups defined by

Fig. 5. Example portions of sedimentological logs showing main facies assemblages of the basin-fill succession. **A** – Gürsökü Fm, locality 3; **B** – middle part of Akveren Fm, locality 5; **C** – upper part of Akveren Fm, locality 8; **D** – Atbaşı Fm, locality 10; **E** – lowermost part of Kusuri Fm, locality 12; **F** – distal lobe turbidites in the lower part of the Kusuri Fm, locality 17; **G** – proximal lobe turbidites in the middle part of the Kusuri Fm, locality 16; **H** – channel-fill turbidites in the middle part of the Kusuri Fm, locality 18. The locality numbers are as in Fig. 2 and Table 1

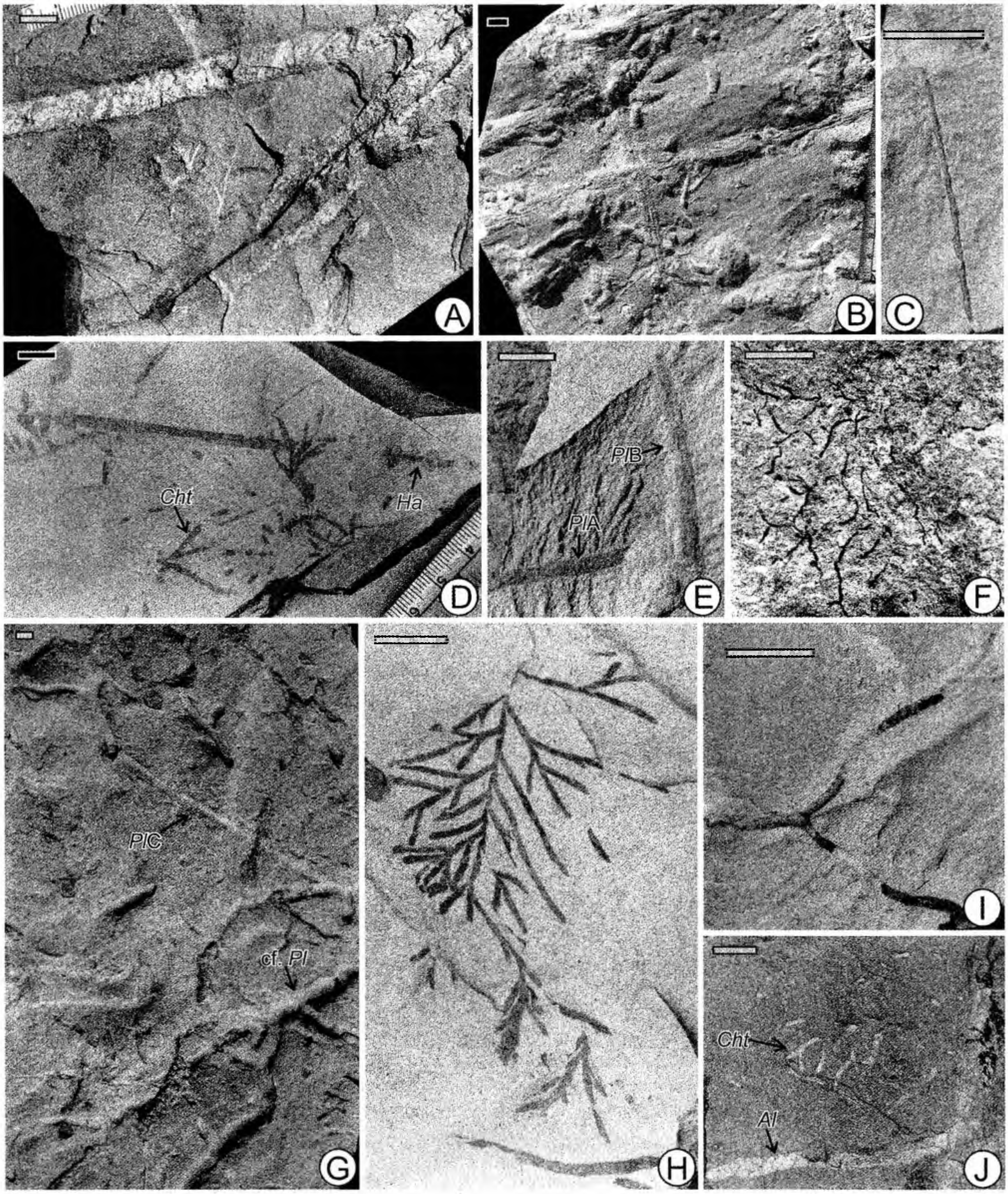


Fig. 6. Simple and branched trace fossils. **A** – *Alcyonidiopsis* isp., parting surface of turbiditic sandstone, Kusuri Fm, locality 19; **B** – *Halopoa imbricata*, turbidite bed sole, Akveren Fm, locality 7; **C** – *Trichichnus linearis*, vertical fracture surface of turbidite marlstone capping, Akveren Fm, locality 5, specimen 173P6; **D** – *Chondrites targionii* (*Cht*) and *Halimedides annulata* (*Ha*), horizontal parting surface of turbidite marlstone capping, Akveren Fm, locality 5, specimen 173P1; **E** – *Planolites* isp. form A (*Pl*A) and form B (*Pl*B), parting surface of black mud shale, Çağlayan Fm, locality 1; **F** – *Pilichnus dichotomus*, form A, horizontal parting surface of turbidite marlstone capping, Akveren Fm, locality 5, specimen 173P7; **G** – *Planolites* isp. form C (*Pl*C) and cf. *Planolites* isp. (cf. *Pl*), sole of sandstone turbidite, Yemişliçay Fm, locality 2; **H** – *Chondrites intricatus*, horizontal parting surface of turbidite marlstone capping, Akveren Fm, locality 5; **I** – *Pilichnus dichotomus*, form B, horizontal parting surface of turbidite marlstone capping, Akveren Fm, locality 5, specimen 173P2; **J** – *Chondrites targionii* (*Cht*) and *Alcyonidiopsis* isp. (*Al*), parting surface of sandstone turbidite, Kusuri Fm, locality 19. The scale bars are 1 cm. The locality numbers are as in Fig. 2 and Table 1, and the specimen numbers refer to collection at the Institute of Geological Science, Jagiellonian University

Książkiewicz (1977), with further modifications by Uchman (1995). Common ichnotaxa are only briefly described, as they are characterized more extensively in the earlier publications by Uchman (1995, 1998, 1999).

SIMPLE AND BRANCHED STRUCTURES

Alcyonidiopsis Massalongo 1856
*Alcyonidiopsis*isp.
Figs 6A, J

Description: Horizontal, epichnial cylinders preserved in full relief in sand bed and filled with a lighter-coloured, pelleted finer sediment that locally shows indistinct menisci. The cylinders are 4–10 mm wide and the pellets are about 1 mm in diameter.
Remarks: *Alcyonidiopsis* is considered to be a feeding burrow of polychaetes, and is known from Ordovician to Miocene deposits (Chamberlain, 1977; Uchman, 1995, 1998).
Occurrence: Kusuri Fm, locality 20 (Fig. 2, Table 1).

Arthrophycus Hall 1852
?*Arthrophycus* cf. *tenuis* (Książkiewicz 1977)

Description: Subhorizontal, gregarious hypichnial ridges, 1–1.5 mm wide and up to 35 mm long, preserved in convex semirelief. They are straight, rarely branched, and are oriented in various directions.
Remarks: *Arthrophycus tenuis* was earlier described under the ichnogenus name *Sabularia* (Książkiewicz, 1977). Uchman (1998) disqualified this ichnogenus and included *Sabularia tenuis* in the ichnogenus *Arthrophycus* Hall on the basis of characteristic, very fine perpendicular striae (although these are commonly not preserved). The form described here is smooth, but shows the characteristic geometry and size of *A. tenuis*. This ichnospecies was reported from Valanginian (Książkiewicz, 1977) to Middle Miocene deposits (Uchman & Demírcan, 1999). More recently, Rindsberg and Martin (2003) suggested that the post-Palaeozoic forms described as *Arthrophycus* probably belong to other ichnogenera, as they differ in the internal structure of the fill.
Occurrence: Yemislicay Fm, locality 2 (Fig. 2, Table 1).

Chondrites Sternberg 1833
Chondrites intricatus (Brongniart 1823)
Fig. 6H

Description: A system of downward-penetrating, tree-like branching and markedly flattened tunnels, up to 1 mm in diameter. The tunnels are commonly straight and show phobotaxis. There are first-, second- and rarely third-order branches, diverging at acute angles. In cross-sections, this form shows patches of circular to elliptical spots and short bars. The trace infill is commonly darker than the host sediment, although this is not the case in the Kusuri Fm, where the infill tends to be lighter-coloured.
Remarks: *Chondrites* is a feeding system of unknown tracemakers, attributed to infaunal deposit feeders (e.g., Osgood, 1970). Kotake (1991b) has suggested that this ichnotaxon is produced by surface ingestors, packing their faecal pellets inside burrows. According to Seilacher (1990) and Fu (1991), the tracemaker of *Chondrites* may be able to live in dysaerobic conditions as a chemosymbiotic organism. A more detailed discussion of ichnogenus *Chondrites* is given by Fu (1991) and Uchman (1999).
Occurrence: Akveren Fm, locality 5; Kusuri Fm, localities 12 and 20 (Fig. 2, Table 1).

Chondrites targionii (Brongniart 1828)
Figs 6D, J

Description: Endichnial, horizontal to oblique, flattened tubular tunnels, 1.8–2 mm wide, with a dendroid branching pattern and commonly slightly curved branches. In the Akveren Fm, the tubular tunnels filled with dark-grey mud are well visible in the whitish-grey host marlstone. In the Kusuri Fm, the tunnel fillings are lighter in colour than the host mudrock.
Remarks: See *Chondrites intricatus* above.
Occurrence: Akveren Fm, locality 5; Kusuri Fm, localities 12 and 20 (Fig. 2, Table 1).

Halimedides Lorenz von Liburnau 1902
Halimedides annulata (Vialov 1971)
Fig. 6D

Description: Endichnial, horizontal, straight and flattened cylinder, 2–2.5 mm wide and at least 80 mm long, with two chamber-like widenings that are 5 mm wide, 3 mm long and 5 mm apart.
Remarks: The chambers of *Fustiglyphus*, considered to be a junior objective synonym of *Halimedides*, are interpreted as possible brood structures (Stanley & Pickerill, 1993), and a similar interpretation pertains to *Hormosiroidea florentina* Schaffer (Uchman 1995), another junior objective synonym of *Halimedides*. The present case is consistent with this interpretation. For discussion of *Hormosiroidea*, see Uchman (1998, 1999).
Occurrence: Akveren Fm, locality 5 (Fig. 2, Table 1); collection specimen 173P1.

Halopoa Torell 1870
Halopoa imbricata Torell 1870
Fig. 6B

Description: Hypichnial, nearly straight and non-branched cylindrical trace fossils, 6–11 mm wide, preserved in full relief, but lacking distinct margins. The trace surfaces are covered with longitudinal, thin, discontinuous wrinkles.
Remarks: *Fucusopsis* Palibin in Vassoevich (1932) is considered to be a junior objective synonym of *Halopoa* Torell 1870, and *F. angulata* Palibin in Vassoevich (1932) is considered to be a junior objective synonym of *H. imbricata* Torell 1870 (Uchman, 1998). The unknown tracemaker was probably a deposit-feeder, specialized in reworking of turbiditic sand, and the longitudinal striations resulted from the pushing of sediment (Uchman, 1998).
Occurrence: Akveren Fm, locality 7; Kusuri Fm, locality 17 (Fig. 2, Table 1).

Planolites Nicholson 1873
Planolites isp.
Figs 6E, G

Description: Horizontal, cylindrical trace fossils with sharp margins, but no distinct walls. They include four morphotypes, all preserved in full relief. Form A (Fig. 6E) is visible on a parting surface as a nearly straight simple band, 3 mm wide, with very slight windings. It is filled with material darker than the host sediment. Form B (Fig. 6E) is a slightly arcuate and strongly flattened simple cylinder, about 5 mm wide, filled with sediment that looks macroscopically the same as the host deposit. Form C (Fig. 6G) occurs as hypichnial, simple and nearly straight cylinders, about 5 mm in diameter and 30–40 mm long, plunging in the soles of sandstone turbidites. These cylinders have smooth surfaces, and it cannot be precluded that form C is just another preservational variety of form B. Form D occurs as nearly straight, smooth hypichnial ridges, about 3 mm wide.

Remarks: *Planolites* is a facies-crossing trace fossil, produced probably by a range of mostly deposit-feeding animals; for discussion, see Pemberton and Frey (1982) and Keighley and Pickerill (1995).

Occurrence: Çağlayan Fm, locality 1 (*Planolites* isp. forms A and B); Yemişliçay Fm, locality 2 (*Planolites* isp. form C); Akveren Fm, locality 5 (*Planolites* isp. form D); for localities, see Fig. 2 and Table 1.

cf. *Planolites* isp.
Figs 6G, 17A

Description: Hypichnial cylindrical ridges, 6–11 mm wide, preserved in semirelief, winding and rarely branched.

Remarks: Preservation in semirelief does not allow to establish the presence or absence of walls and the kind of infill, which renders the distinction between *Planolites* and *Palaeophycus* practically impossible. The trace fossil is tentatively classified as *Planolites*.

Occurrence: Yemişliçay Fm, locality 2 (Fig. 2, Table 1).

Pilichnus Uchman 1999
Pilichnus dichotomus Uchman 1999
Fig. 6F, I

Description: Form A (Fig. 6F) is an typical example of this ichnospecies. It occurs as orizontal system of very thin, branched, endichnial cylinders. The cylinders are 0.2–0.4 mm wide and up to 15 mm long, and are filled with ferruginous dark sediment that renders them well-visible in the host white marlstone. Form B (Fig. 6I) is an endichnial, horizontal cylinders, 1.2 mm wide, winding and dichotomously branched; preserved in full relief and filled with ferruginous sediment.

Remarks: The ferruginous filling resulted probably from weathering of framboidal pyrite. In the form B, the size is much larger than in the typical form A.

Occurrence: Akveren Fm, locality 5 (Fig. 2, Table 1). Form A, collection specimen 173P7; form B: collection specimen 173P2.

Trichichnus Frey 1970
Trichichnus linearis Frey 1970
Fig. 6C

Description: Steeply vertical to oblique cylinders, up to 1 mm in diameter, straight to winding and rarely branched, filled with sediment rich in iron sulfides or hydroxides.

Remarks: For discussion of this ichnogenus, see Uchman (1999).

Occurrence: Akveren Fm, locality 5 (Fig. 2, Table 1); collection specimen 173P6.

Ophiomorpha Lundgren 1891
Ophiomorpha ?nodosa Lundgren 1891
Fig. 8A

Description: Horizontal, straight tubular traces preserved in full relief, exposed on parting surfaces of wave-worked sandstones. The tubes are 35–45 mm in diameter and at least 400 mm long, covered with granulate irregularities. In the coastal outcrop west of Türkeli, some smaller forms, 5–8 mm in diameter, with distinct ovoid knobs, occur on a tempestites sole.

Remarks: The isolated occurrences on a bed sole and parting plane reveal no vertical shaft, but the tube wall irregularities seem to be sandy mud granules typical of *Ophiomorpha nodosa*, slightly altered by diagenesis. *Ophiomorpha nodosa* is a characteristic trace fossil of the shallow-marine *Skolithos* ichnofacies. It is produced by decapod crustaceans, mainly callianassid shrimps, which form a system of deep vertical shafts and horizontal galleries in sand substrate (e.g., Frey *et al.* 1978; Ekdale, 1992). Some taxonomic problems related to *Ophiomorpha* are discussed by Schlirf (2000), who has opted for its inclusion in *Spongeliomorpha* Saporta.

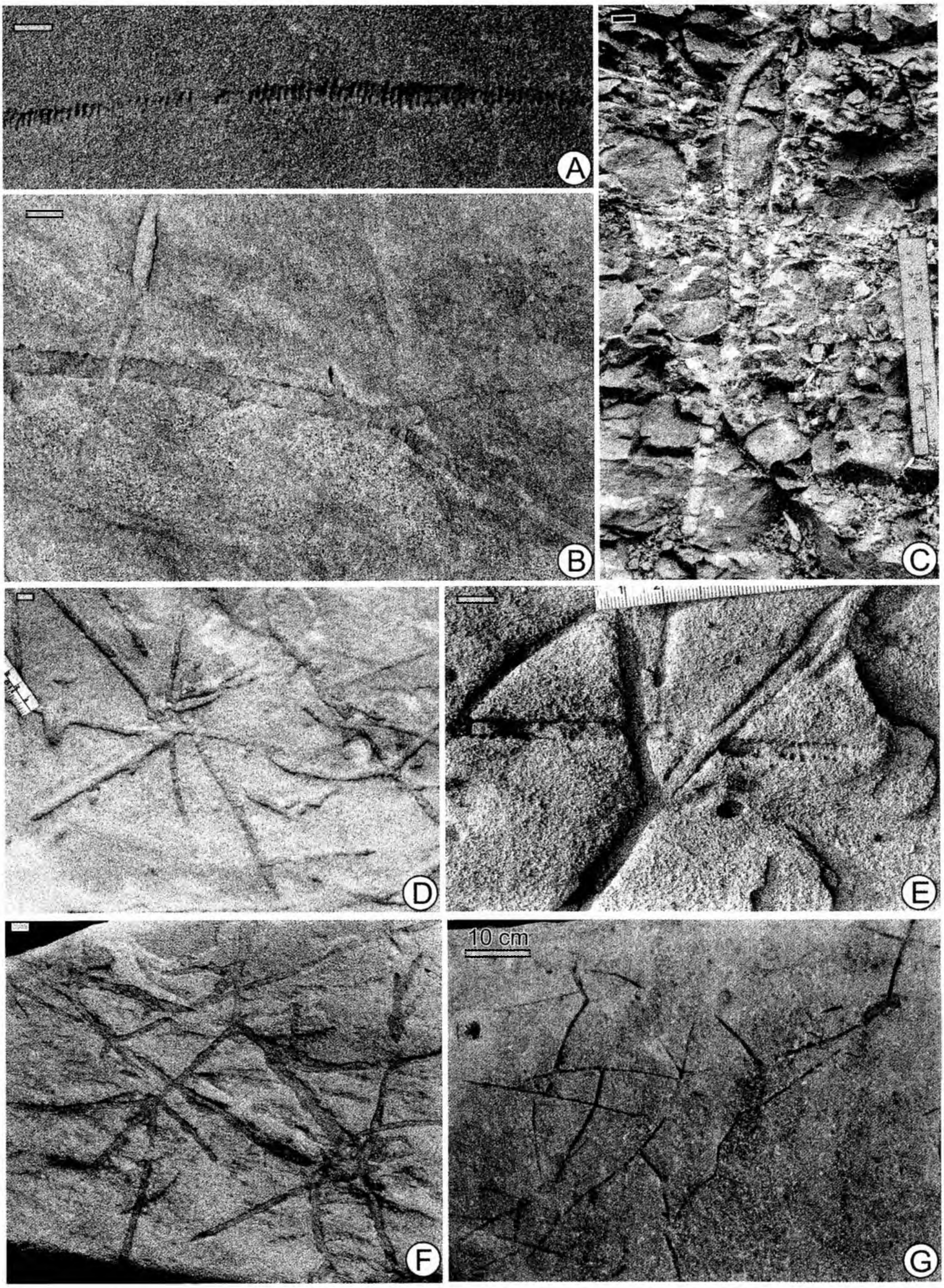
Occurrence: Topmost part of Akveren Fm, locality 6 (Fig. 2, Table 1) and coastal outcrop directly west of Türkeli village (locality *ca.* 15 km west of the Istafan Cape in Fig. 2).

Ophiomorpha annulata (Książkiewicz 1977)
Figs 7A–G, 8D, 9B, 14B, 15C, 17G, 18B, 19D

Description: In the Akveren Fm, this trace fossil occurs as smooth, straight subvertical tunnels, 4–7 mm in diameter, penetrating through sandstone-marlstone or sandstone-shale beds up to at least 20 cm thick and spreading laterally on their soles as straight cylinders, solitary or sporadically branched. In the Atbaşı Fm, the trace fossil occurs also as sand-filled, vertical or oblique and slightly curved cylinders, 7 mm in diameter, penetrating through purple-grey mud-shale beds at least 26 cm thick (Fig. 7C). In the Kusuri Fm, this trace fossil shows a whole range of preservational varieties. The most common are hypichnial, smooth and nearly straight cylinders, 2.3–7.0 mm in diameter, preserved in full relief and occasionally branched (Figs 7B, 15C, 17G, 18B, 19D). Some of the vertical or oblique cylinders penetrate through beds up to 120 cm thick and locally show distinct walls. Elongate, sandy mud granules, about 2 mm long and 1 mm wide, are visible in places along the external part of the wall (Fig. 7A, D–F), with the granule longer axes being more or less perpendicular to the axis of the cylinder itself. Some cylinders display meniscate back-filling (Fig. 7B). The menisci are deep and consist of alternating incremental portions of thicker sand and thinner sandy mud. Branching is relatively rare, mainly Y-shaped (Figs 7D–F) and sporadically T-shaped (Fig. 7G), with no evidence of swelling at the branching point. The branches locally form knots, where several branches converge (Figs 7D, F).

Remarks: The occurrences of *Ophiomarpha annulata* in the Kusuri Fm belong among the best examples of this ichnospecies, because of their abundance, wide morphological spectrum and very good preservation. This ichnotaxon has commonly been reported as *Granularia*, without specific designation, and was also described as *Sabularia simplex* (Książkiewicz, 1977). The latter ichnospecies was defined as consisting of smooth cylindrical tunnels, straight or occasionally branched (see also Tunis & Uchman, 1992). However, there are intergradations between smooth and pelleted forms (Tunis & Uchman, 1996), as is the case in the

Fig. 7. *Ophiomorpha annulata* in Kusuri Fm and Atbaşı Fm (C). **A** – horizontal form with granulated wall, on parting surface of sandstone turbidite, locality 21; **B** – a meniscate form cross-cut by a smooth form, on sandstone turbiditic sole, locality 21; **C** – a smooth form penetrating mudstone beds, vertical section, locality 9; **D** – smooth and granulated forms making a knot, weathered sole of thick sandstone turbidite, locality 18; **E** – branching, granulated and smooth forms, weathered upper surface of thick sandstone turbidite, locality 18; **F** – smooth and granulated forms making a knot, weathered sole of thick sandstone turbidite, locality 18; **G** – a system of horizontal forms, weathered upper surface of thick sandstone turbidite, locality 18. The scale bars in A–F are 1 cm. The locality numbers are as in Fig. 2 and Table 1


A
B
C
D
E
F
10 cm
G

Kusuri Fm, and this trace fossil has thus been included in the ichnogenus *Ophiomorpha* (Uchman, 1995, 1998, 1999, 2001). These burrows are thought to be traces of crustaceans that penetrated the substrate in search for deeply buried plant detritus. The production and preservation of pellets was probably related to the substrate consistency and the sediment texture and packing.
Occurrence: Akveren Fm, locality 5; Atbaşı Fm, locality 9; Kusuri Fm, localities 12–21 (Fig. 2, Table 1); collection specimens 173P16, 17 & 25.

Ophiomorpha rudis (Książkiewicz 1977)
Figs 8B–G, 9A, 12C

Description: Sand-filled cylinders 5–22 mm in diameter, walled or unwalled, straight or curved and occasionally branched, penetrating sediment beds vertically or obliquely, or extending horizontally along a bedding surface. The tunnel exterior is smooth, but in some cases shows irregular, indistinct sandy granules or is covered with fine oblique ridges. The granules are elongated perpendicular to the cylinder axis, and some cylinders show meniscate backfilling. The cylindrical tunnels commonly penetrate through several turbidites, exceeding a total thickness of 80 cm in some cases. Some of the host beds consist of coarse-grained pebbly sand (Fig. 8B, C). In one case, the tunnel forms a wide U-shaped burrow in a sandstone bed 50 cm thick (locality 18, Fig. 8F, G). The fine oblique ridges occur in unwalled tunnels (Fig. 9A). The ridges themselves are straight, less than 1 mm wide and up to 4 mm long, and are parallel, with a spacing of about 1.5 mm. They are oriented at an angle of 63–67° to the tunnel axis. The tunnel branching points show swelling (Fig. 9D), similar as in *Thalassinoides suevicus*.
Remarks: In comparison to *O. rudis*, *O. annulata* is typically two times smaller, and displays more regular granules, more straight horizontal tunnels, and more rare branches. This highly varied trace fossil was described as *Sabularia rudis* by Książkiewicz (1977), but was subsequently reclassified as *Ophiomorpha* on the basis of the pelleted walls preserved in some segments of the burrow system (Uchman, 1995, 1998, 2001). These are probably traces of crustaceans that penetrated the substrate in search for deeply buried plant detritus. *Ophiomorpha rudis* is known from deposits of Tithonian to Miocene age (Tchoumatchenco & Uchman, 2001). Its cccurrence in the Kusuri Fm are some of the best thus far reported, because of their abundance, good presevation and wide morphological spectrum.
Occurrence: Kusuri Fm, localities 17 and 18 (Fig. 2, Table 1).

Thalassinoides Ehrenberg 1944
Thalassinoides suevicus (Rieth 1932)
Figs 9B–E, 19D

Description: Three preservational varieties of this trace fossil have been recognized. Form A is an endichnial, Y-shaped cylinder, 12–18 mm in diameter, with distinct, even or uneven margins, preserved in full relief in a marlstone bed. The tunnel widens to about 30 mm at the point of bifurcation and is filled with coarser arenitic sand (Fig. 9E). Form B is a similar, Y-branched endichnial cylinder, 10–20 mm in diameter, with distinct, even or uneven margins and locally with a thin wall, preserved in full relief in siltstone or sandstone bed. It is filled with coarser sand and slightly widened at the branching point (Fig. 9B, D). Form C consists of Y-shaped hypichnial cylinders, 10–15 mm in diameter, with distinct margins and the branching point swollen to a width of 35 mm (Figs 9C, 19D).
Remarks: This is a very common trace fossil, produced by scavenging and deposit-feeder crustaceans. For discussion of *Thalassinoides*, see Frey *et al.* (1984) and Bromley (1996).
Occurrence: Form A found in Akveren Fm, localities 5 and 7; form B in Kusuri Fm, locality 13; form C in Akveren Fm, locality 7, and Kusuri Fm, locality 18 (Fig. 2, Table 1).

Thalassinoides ispp. indet.
Fig. 9E

Description: Hypichnial cylinder, 16 mm in diameter and probably branched, plunging in a sandstone bed and preserved in full relief on a bedding plane, where it co-occurs with *Megagrapton irregulare*. Elsewhere, hypichnial mounds and short ridges of similar size, preserved in semirelief, can be interpreted as washed-out and cast parts of *Thalassinoides* burrow system. The same pertains to an inclined, sand-filled endichnial cylinder, 20 mm in diameter, found in a turbidite-capping marlstone.
Remarks: Poor preservation does not allow more exact determination.
Occurrence: Akveren Fm, localities 5, 7 and 8 (Fig. 2, Table 1).

RADIAL STRUCTURES

Lorenzinia Gabelli 1900
Lorenzinia ?apenninica Gabelli 1900
Fig. 9G

Description: Straight, short hypichnial ridges, 7–14 mm long and 2 mm wide, radiating from a central flat area, with 5 ridges within half-circle. The ridges are slightly elevated near the central area, which is about 12 mm across, and the whole trace fossil is about 40 mm across.
Remarks: *Lorenzinia* is a complex graphoglyptid (agrichnial) trace fossil typical of flysch deposits; for discussion, see Uchman (1998).
Occurrence: Kusuri Fm, locality 18 (Fig. 2, Table 1).

Lorenzinia isp.
Fig. 9F

Description: Hypichnial short ridges radiating from a central flat area. Only a part of the original trace is preserved. In half a circle there are about 15 ridges. The ridges are up to 6 mm long and 1.5 mm wide. They are slightly elevated close the central area. The central area is about 14 mm in diameter, and the whole trace fossil is about 22 mm across.
Remarks: For discussion of *Lorenzinia* see Uchman (1998).
Occurrence: Kusuri Fm, locality 18 (Fig. 2, Table 1).

SPREITEN STRUCTURES

Lophoctenium Richter 1850
Lophoctenium minimum Fu 1991
Fig. 9I–J

Description: Epichnial, horizontal structures resembling ice-growth pattern on glass. The structure consists of a straight or curved, indistinct branched stem and straight to curved, densely-packed side probes branching out obliquely from the stem. The stems and their branches are up to 30 mm long, and the probes are less than 1 mm wide and up to 4 mm long. The stem and probes form twigs 5–10 mm wide.
Remarks: *Lophoctenium* is the trace of a deposit-feeding organism. This is the third known occurrence of *L. minimum*, supplementing the type material from the Palaeocene flysch of San Telmo near Zumaya, NE Spain (Fu, 1991), and from the Palaeocene variegated shales of the Magura Nappe in Lipnica Mała, the

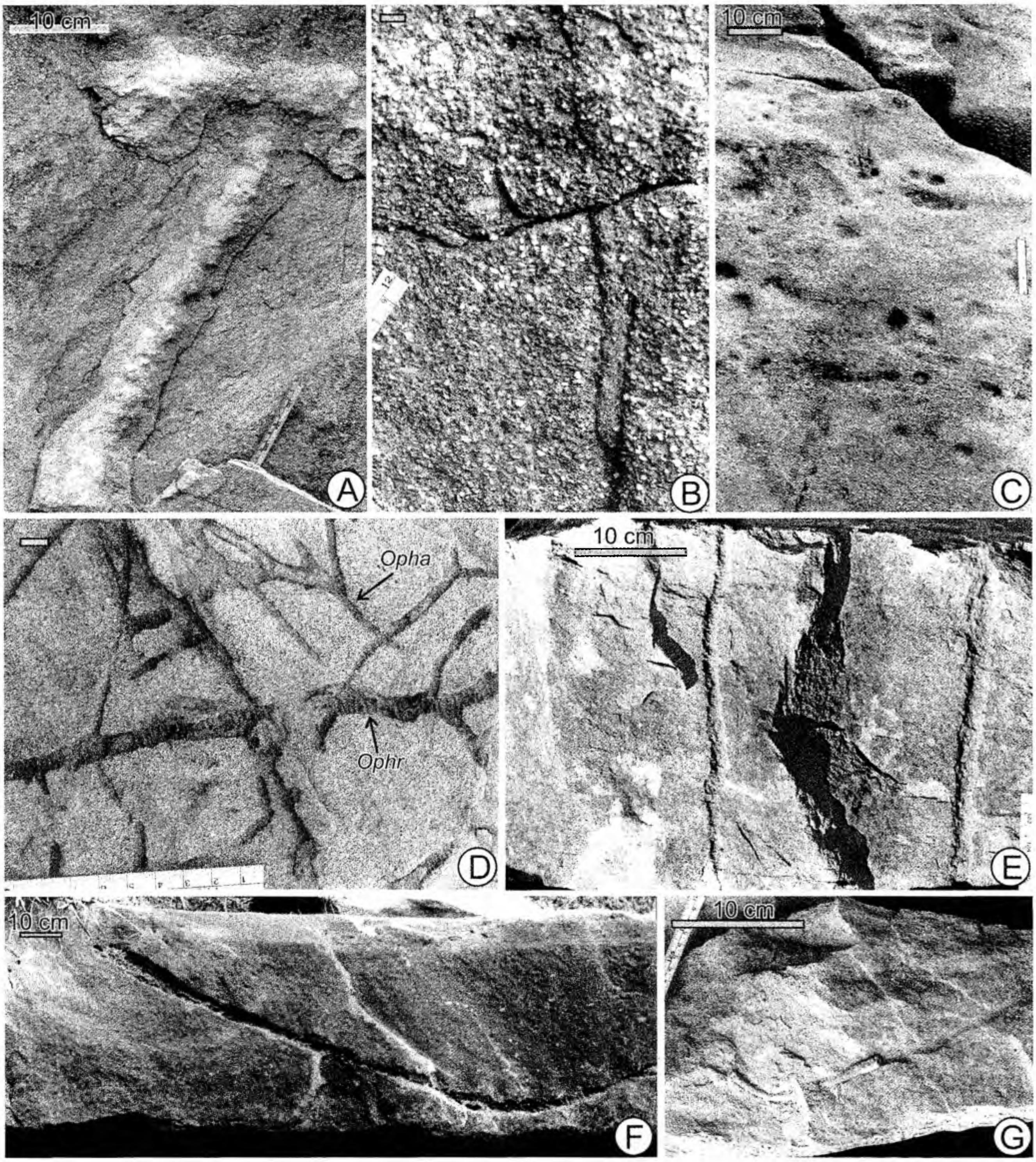


Fig. 8. *Ophiomorpha* in Akveren Fm (**A**) and Kusuri Fm (**B–G**). **A** – *Ophiomorpha ?nodosa*, on sole of thick calcarenitic tempestite, locality 6; **B, C** – *Ophiomorpha rudis* penetrating vertically to obliquely a thick, coarse-grained, pebbly sandstone turbidite, locality 18; **D** – *Ophiomorpha rudis* (*Ophr*) and *O. annulata* (*Opha*) on a weathered, horizontal parting surface of thick sandstone turbidite, locality 18; **E** – *Ophiomorpha rudis* penetrating thick sandstone turbidite, locality 18; **F, G** – a bow-shaped *Ophiomorpha rudis* penetrating sandstone turbidites, localities 18 (**F**) and 17 (**G**). The scale bars in **B** and **D** are 1 cm. The locality numbers are as in Fig. 2 and Table 1

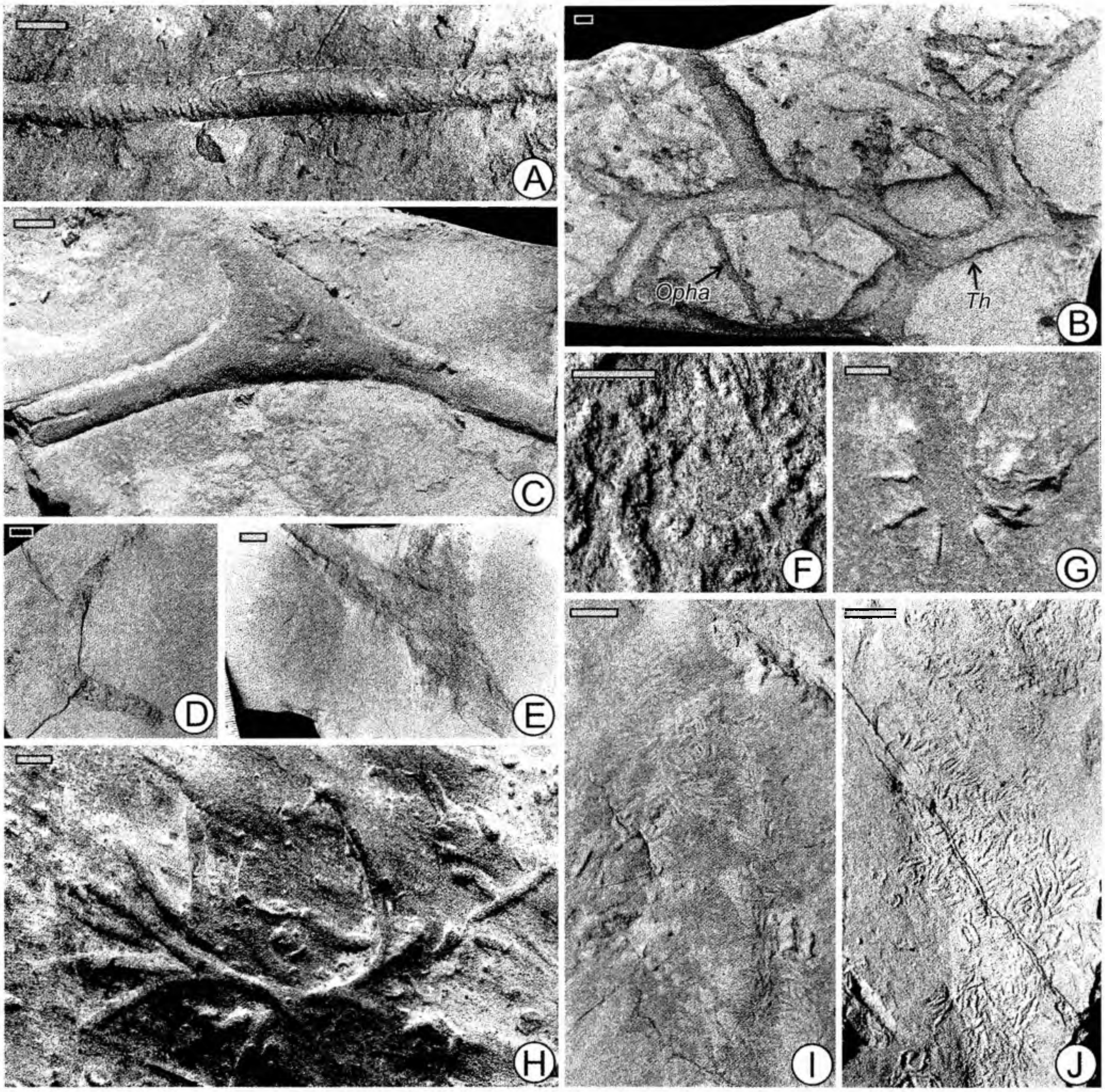


Fig. 9. Branched, radial and spreiten trace fossils. **A** – *Ophiomorpha rudis* with casts of scratch-marks, sandstone turbidite sole, Kusuri Fm, locality 18; **B** – *Thalassinoides suevicus* form C (*Th*) and *Ophiomorpha annulata* (*Opha*), horizontal parting surface of sandstone turbidite, Kusuri Fm, locality 18; **C** – *Thalassinoides suevicus* form C, calcarenitic turbidite sole, Akveren Fm, locality 7. **D** – *Thalassinoides suevicus* form B, horizontal parting surface of sandstone turbidite, Kusuri Fm, locality 13; **E** – *Thalassinoides suevicus* form A, horizontal parting surface of turbidite marlstone capping, Akveren Fm, locality 5; **F** – *Lorenzinia* isp., turbidite sandstone sole, Kusuri Fm, locality 18; **G** – *Lorenzinia ?apenninica*, sandstone turbidite sole, Kusuri Fm, locality 18; **H** – cf. *Phycodes* isp., Akveren Fm, calcarenitic turbidite sole, locality 5. **I, J** – *Lophoctenium minimum*, horizontal parting surface of turbidite marlstone capping, Akveren Fm, locality 7. The scale bars are 1 cm. The locality numbers are as in Fig. 2 and Table 1

Polish Carpathians. The latter occurrence was described as *Lophoctenium* aff. *comosum* Reinh. Richter by Książkiewicz (1977), and was included in *L. minimum* by Fu (1991).
Occurrence: Akveren Fm, locality 7 (Fig. 2, Table 1); collection specimen 173P11.

Phycodes Richter 1850
?*Phycodes* isp.
Fig. 10A, B

Description: Endichnial, horizontal to oblique, sand-filled curved cylinders in a shale bed below a sandstone turbidite. The cylinders are about 5 mm in diameter and form a bunch converging into a stem, with some of them overlapping.
Remarks: *Phycodes* is the trace of a deposit-feeding organism, and the cylinders are successive probes extended into the sediment; for discussion, see Fillion and Pickerill (1990).
Occurrence: Atbaşı Fm, locality 9 (Fig. 2, Table 1).

cf. *Phycodes* isp.
Fig. 9H

Description: Hypichnial, straight to slightly curved, smooth semi-cylindrical ridges forming a palmate bunch converging into a stem. The ridges are about 5 mm wide and up to 40 mm long, and there are 6 ridges in the bunch. The stem is about 30 mm long and 5 mm wide, and has the same morphology as the ridges. Near the stem, there are also some morphologically similar ridges unconnected with it, but probably belong to the same trace fossil. The trace fossil is preserved in semirelief.
Remarks: *Phycodes* typically contains a larger number of probes in the bunch.
Occurrence: Akveren Fm, locality 5 (Fig. 2, Table 1).

Phycosiphon Fischer-Ooster 1858
Phycosiphon incertum Fischer-Ooster 1858
Fig. 11B

Description: Epichnial, small horizontal lobes, up to 4 mm across, encircled by a narrow marginal tunnel less than 1 mm wide.
Rermarks: This trace fossil, produced by a deposit-feeder, is common in fine-grained deep-marine and deep shelf deposits. More information about *Phycosiphon* can be found in Wetzel and Bromley (1994).
Occurrence: Akveren Fm, localities 5 and 7 (Fig. 2, Table 1).

Phycosiphon isp.
Fig. 11A

Description: Endichnial, mostly horizontal trace fossil visible on a parting surface as dark meandering band, 1–2 mm wide. First- and second-order meanders are locally distinguishable, the former poorly developed and the latter more distinct. In places, the meanders are crowded in patches, where they tend to overlap. The second-order meanders are 5 to 10 mm wide and have an amplitude of 5 to 9 mm.
Remarks: The trace fossil bears some resemblance to *Cosmorhaphe* Fuchs, but the latter is more regular and never crowded in patches. There is more similarity to a large *Phycosiphon* where only the marginal tunnel is preserved. The marginal tunnel in *Phycosiphon* forms similar meanders, referred to as the "antler shape", and the spreite structure encircled by the tunnel is commonly not preserved.
Occurrence: Çağlayan Fm, locality 1 (Fig. 2, Table 1); collection specimen 173P9.

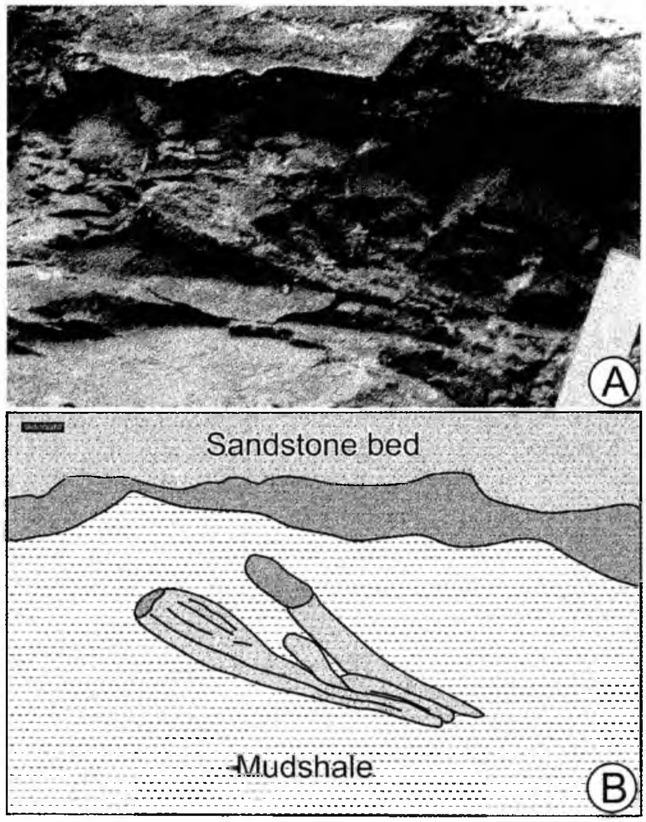


Fig. 10. ?*Phycodes* isp. in a reddish-grey mud shale, Atbaşı Fm, locality 9. **A** – field photograph. **B** – sketch from A. The scale bar is 1 cm

Phymatoderma Brongniart 1849
Phymatoderma isp.
Figs 11C–E

Description: Two morphotypes of this ichnogenus have been recognized. Form A consists of curved endichnial bands, 5–7 mm wide and 18–25 mm long, extending from a stem as an asymmetrical bunch (Figs 11C, D). The bands have uneven width and margins, occur as endichnial full reliefs in a marlstone capping of a turbidite and have a darker filling that is more clayey than the host whitish sediment (marl). Form B occurs at the top of a turbiditic sandstone (Fig. 11E) and consists of endichnial bands about 10 mm wide and up to 32 mm long, spreading out from a stem as an asymmetrical bunch.
Remarks: *Phymatoderma*, revised by Fu (1991) is thought to be a burrow system produced by deposit-feeders.
Occurrence: Form A found in the Akveren Fm, locality 5, collection specimen 173P5; form B found in the Kusuri Fm, locality 17 (Fig. 2, Table 1).

Zoophycos Massalongo 1855
Zoophycos isp.
Figs 11F–H

Description: Two morphotypes of this ichnogenus have been found. Form A, seen in a vertical cross-section of a fine-grained calcarenitic turbidite, is an endichnial structure composed of a subvertical central shaft and helicoidal whorls (Fig. 11H). The axial shaft is slightly curved and about 140 mm long, thinning upwards from 9 to 3 mm. There are 21 whorls, each up to 3 mm thick, descending obliquely from the axis. The whorls are progressively

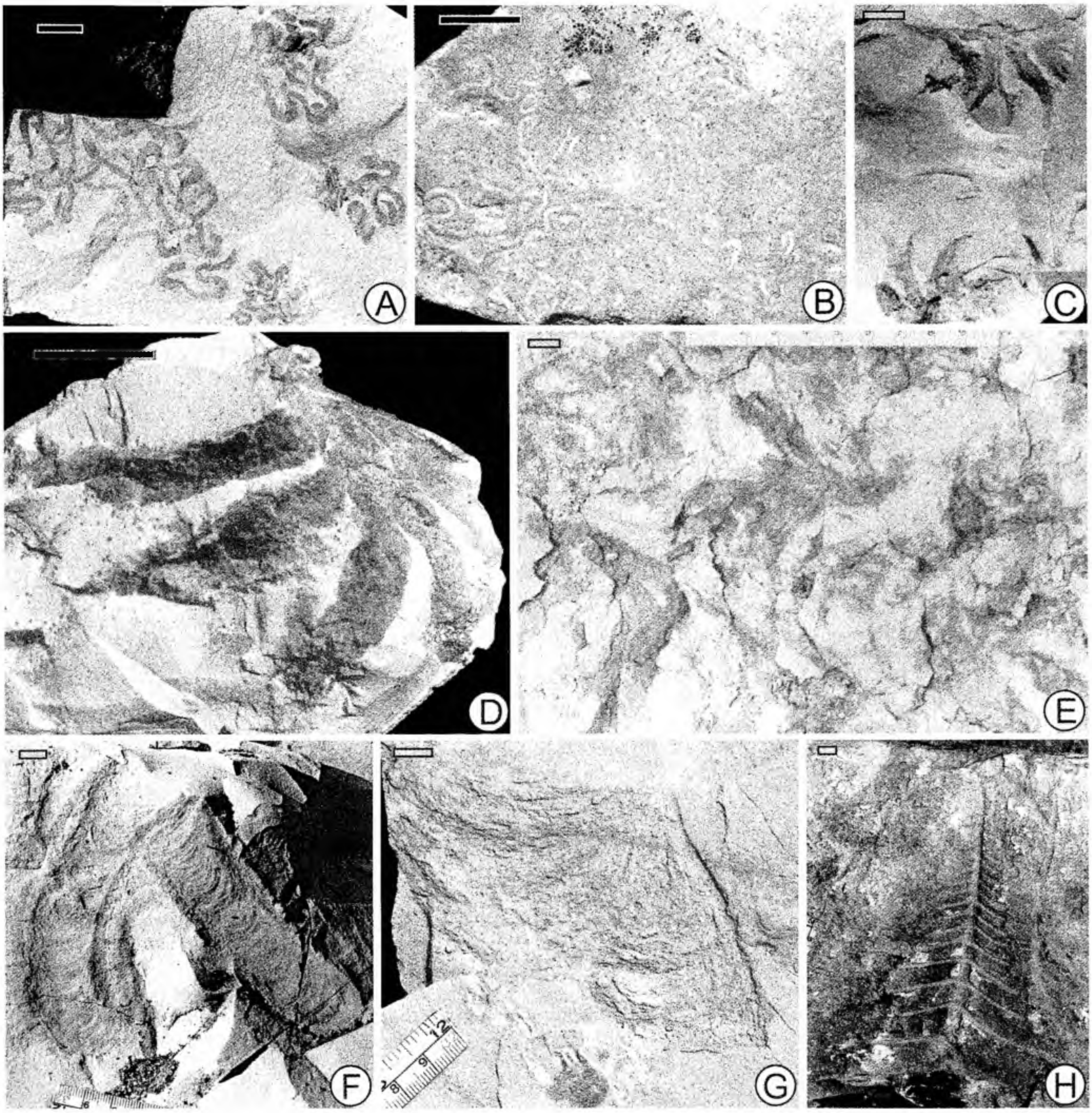


Fig. 11. Spreiten trace fossils. **A** – *Phycosiphon* isp., horizontal parting surface in blackish-grey mud shale, Çağlayan Fm, locality 1. specimen 173P9. **B** – *Phycosiphon incertum*, horizontal parting surface of turbidite marlstone capping, Akveren Fm, locality 5, specimen 173P3. **C, D** – *Phymatoderma* isp. form A, parting surfaces of turbidite marlstone capping, locality 5, specimen 173P5; **E** – *Phymatoderma* isp. form B, upper surface of sandstone turbidite, Kusuri Fm, locality 17; **F** – *Zoophycos* isp., marlstone capping of thick calcarenitic tempestite, Akveren Fm, locality 6; **G** – *Zoophycos* isp., upper surface of calcarenitic tempestite, Kusuri Fm, locality 20; **H** – *Zoophycos* isp., vertical section of turbidite marlstone capping, Akveren Fm, locality 5. The scale bars are 1cm. The locality numbers are as in Fig. 2 and Table 1, and the specimen number refers to collection at the Institute of Geological Science, Jagiellonian University

wider, from 25 to 95 mm, in a downward direction. The upper and middle whorls are symmetrical, whereas the lowest three are asymmetrical. A cross-section of the marginal tunnel is visible in only one of the whorls. Form B is an endichnial planar feature, straight or slightly curved, composed of tongue-like lobes filled with spreite laminae and encircled by a marginal tunnel (Figs 11F, G). The spreites are concordantly arcuate. The lobes are up to 100 mm long and 22–30 mm wide, and the marginal tunnel is 5–7 mm wide. In the example from Kusuri Fm, the lobe is 70 mm wide and its marginal tunnel is 5 mm across.

Remarks: The asymmetry of the lowest whorls in form A is probably due to their lobate shape, whereas the upper symmetric whorls are probably more circular. A similar pattern of a downward increase of whorl diameter and change from circular to lobate shape in *Zoophycos* structure was described by Bromley and Hanken (2003) and Pervesler and Uchman (2004). The lobes in

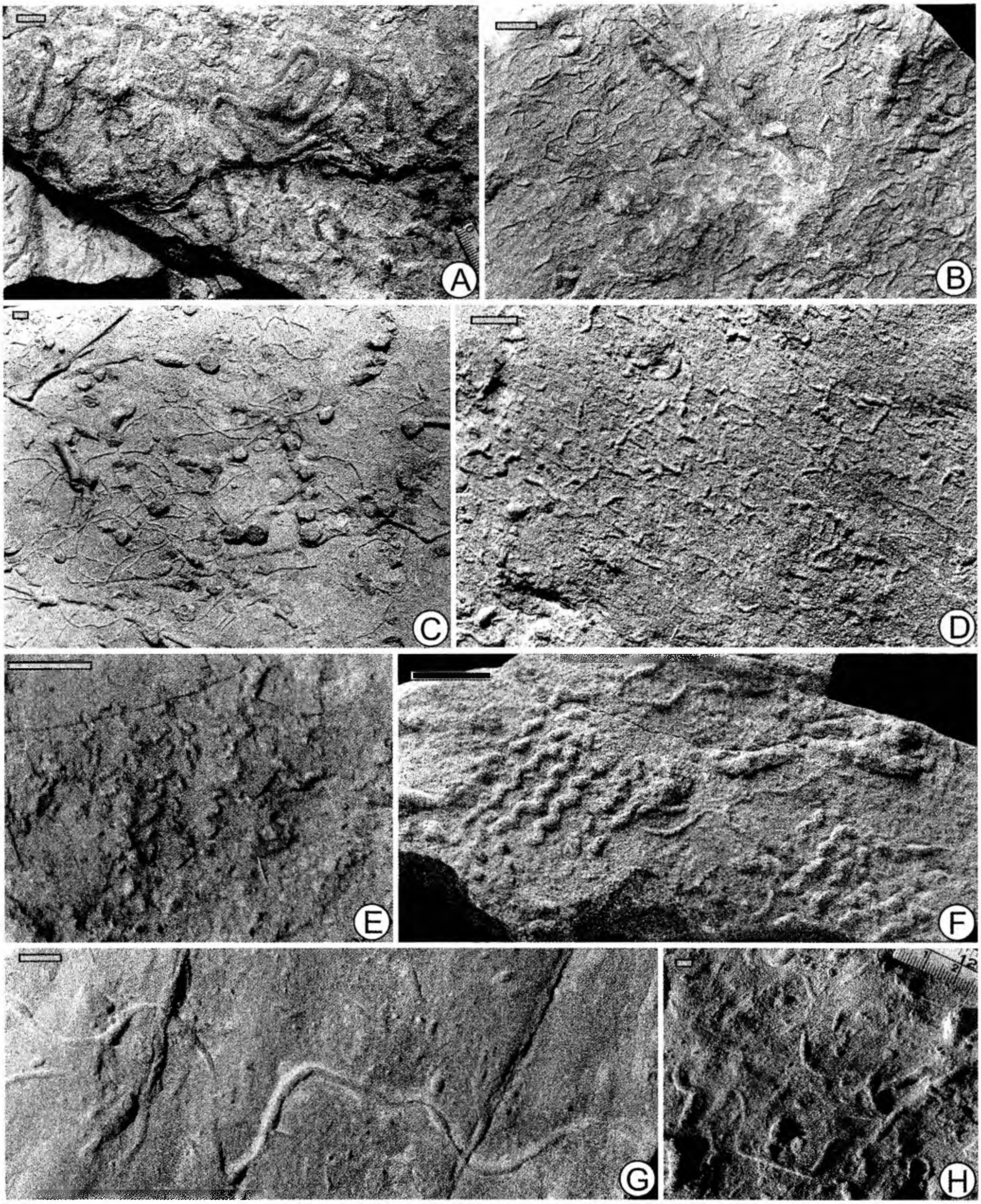


Fig. 12. Winding and meandering trace fossils. **A** – *Cosmorhaphe lobata*, turbiditic marlstone sole, Akveren Fm, locality 5; **B** – ?*Gordia* isp., sandstone turbidite sole, Kusuri Fm, locality 18; **C** – *Gordia* isp. and *Ophiomorpha rudis* (the knobs and cylinders), sandstone turbidite sole, Kusuri Fm, locality 18; **D** – ?*Gordia* isp., sandstone turbidite sole, Kusuri Fm, locality 17; **E** – *Helicolithus sampelayoi*, sandstone turbidite sole, Kusuri Fm, locality 17; **F** – *Helicolithus ramosus*, sandstone turbidite sole, Kusuri Fm, locality 18, specimen 173P22; **G** – *Helminthopsis* isp. form A, calcarenitic turbidite sole, Akveren Fm, locality 7; **H** – *Helminthopsis* isp. form B, calcarenitic turbidite sole, Akveren Fm, locality 7. The scale bars are 1 cm. The locality numbers are as in Fig. 2 and Table 1, and the specimen number refers to collection at the Institute of Geological Science, Jagiellonian University

form B are probably part of a larger structure, incompletely exposed. *Zoophycos* is a complex feeding structure, whose producers may be sipunculoids (Wetzel & Werner, 1981), polychaete annelids and arthropods (Ekdale & Lewis 1991), or enteropneust hemichordates (Kotake, 1992). According to Kotake (1989, 1991a), *Zoophycos* is produced by surficial ingestors of organic detritus. The *Zoophycos* tracemaker is thought to have migrated to deep-water environments in the Jurassic (Bottjer *et al.*, 1988; Olivero, 2003). In late Quaternary deposits, *Zoophycos* occurs at water depths in excess of 1000 m (Löwemark & Schäfer, 2003). Pervesler and Uchman (2004) described *Zoophycos* from Miocene molasse deposits of an upper offshore zone and lower shoreface. Pemberton *et al.* (2001) mentioned the occurrence of this ichnogenus in similar environments in the Cretaceous. These sublittoral environments thus probably demarkate the upper bathymetric limit for this trace fossil.
Occurrence: Akveren Fm, localities 5 and 6; Kusuri Fm, locality 20 (Fig. 2, Table 1).

WINDING AND MEANDERING STRUCTURES

Gordia Emmons 1844
Gordia isp.
Fig. 12C

Description: Hypichnial, winding to looping smooth ridges, 1–1.3 mm wide, preserved in semirelief. Most of the ridge curvatures are gentle, but some are sharp, and the ridges cross one another.
Remarks: The *Gordia* ichnogenus is discussed by Fillion and Pickerill (1990) and Pickerill and Peel (1991).
Occurrence: Kusuri Fm, locality 18 (Fig. 2, Table 1).

?*Gordia* isp.
Figs 12B, D

Description: Hypichnial, hemicylindrical, irregular-short ridges, winding to curved, up to 18 mm long and 1–1.2 mm wide, commonly crossing one another. True branching is not evident, but local tendency for looping is recognizable.
Remarks: Since the looping is uncertain, the trace fossil is included in *Gordia* with reservation.
Occurrence: Kusuri Fm, localities 17 and 18 (Fig. 2, Table 1).

Cosmorhaphe Fuchs 1895
Cosmorhaphe lobata Seilacher 1977
Fig. 12A

Description: A hypichnial semi-cylindrical ridge, 3 mm wide and preserved in semirelief, forming first- and second-order meanders. Only one, incomplete first-order meander is visible, but it is recognizably narrow and deep. At least 12 second-order meanders are visible, 5–7 mm wide and ranging in amplitude from 25 to 38 mm.
Remarks: *Cosmorhaphe lobata* is a typical agrichnial structure known from the Late Cretaceous until the Miocene; for discussion, see Seilacher (1977) and Uchman (1998).
Occurrence: Akveren Fm, locality 5 (Fig. 2, Table 1); collection specimen 173P7.

Helicolithus Azpeitia Moros 1933
Helicolithus sampelayoi (Azpeitia Moros 1933)
Fig. 12E

Description: A hypichnial string, about 1 mm wide, twisted in a corkscrew manner and forming meanders, preserved in semirelief. Up to 16 whorls of twisted string, about 2 mm apart, are recognizable in each meander. The meanders are 3–5 mm wide and have an amplitude of up to 22 mm. The direction of the screw turn reverses at the meander apices.
Remarks: *Helicolithus* is a typical agrichnial structure known from the Late Certaceous until the Oligocene; for discussion, see Seilacher (1977) and Uchman (1998).
Occurrence: Kusuri Fm, locality 13 (Fig. 2, Table 1).

Helicolithus ramosus (Vialov 1971)
Fig. 12F

Description: A hypichnial, horizontal string that forms a stretched helicoidal spiral with tight meanders. In the larger specimen (173P22), the string is 1.2 mm wide and the spiral width is between 1.5 and 2 mm. The meanders are 1–3 mm apart and the spiral whorls are spaced at 3–4 mm. In the two smaller specimens (173P23, 24), the string is 0.6 mm wide and the spiral width is 1 mm wide, with meanders 1–2 mm apart and the spiral whorls spaced at 2 mm.
Remarks: The trace fossil has been discussed by Tunis and Uchman (1996). Spirals of *H. sampelayoi* are generally tighter and their meanders wider.
Occurrence: Kusuri Fm, locality 18 (Fig. 2, Table 1); collection specimens 173P22-24.

Helminthopsis Heer 1877
Helminthopsis isp.
Fig. 12G–H

Description: Two morphotypes of this ichnogenus have been found. Form A is a hypichnial, semicylindrical smooth ridge, about 2–3 mm wide and loosely meandering. The meanders display both sharp and gentle curves, but their incomplete preservation does not allow determination at the species level. In one case (Fig. 12G), there are two apparent branches extending from one point in the ridge, but this feature is considered to be the artifact of a coincidental crossing by another burrow. Form B is similarly a hypichnial, smooth, semi-cylindrical ridge, about 2–3 mm wide and loosely meandering (Fig. 12H).
Remarks: *Helminthopsis* is a eurybathic, facies-crossing trace fossil, common in flysch, and produced probably by polychaetes or priapulids (Książkiewicz, 1977; Fillion & Pickerill, 1990).
Occurrence: Akveren Fm, locality 7 (Fig. 2, Table 1) and coastal outcrop directly west of Türkeli village (locality ca. 15 km west of the Istafan Cape in Fig. 2).

Helminthorhaphe Seilacher 1977
Helminthorhaphe flexuosa Uchman 1995
Fig. 13B

Description: Hypichnial, semicylindrical ridge, 2–2.2 mm wide and forming meanders. The meanders are 7–10 mm wide and have an amplitude of 20 to 40 mm. The distance between meander limbs ranges from 2 to 7 mm, and there are no distinct bulges at the meander bends.
Remarks: *Helminthorhaphe* is a graphoglyptid (agrichnial) trace fossil; for discussion, see Seilacher (1977) and Uchman (1995, 1998).
Occurrence: Kusuri Fm, localities 17 and 19 (Fig. 2, Table 1).

Helminthorhaphe japonica (Tanaka 1970)
Fig. 13A

Description: Hypichnial, semicylindrical and slightly winding ridge, about 3 mm wide and forming meanders. The distance between meander limbs ranges from 2 to 10 mm. The meander am-

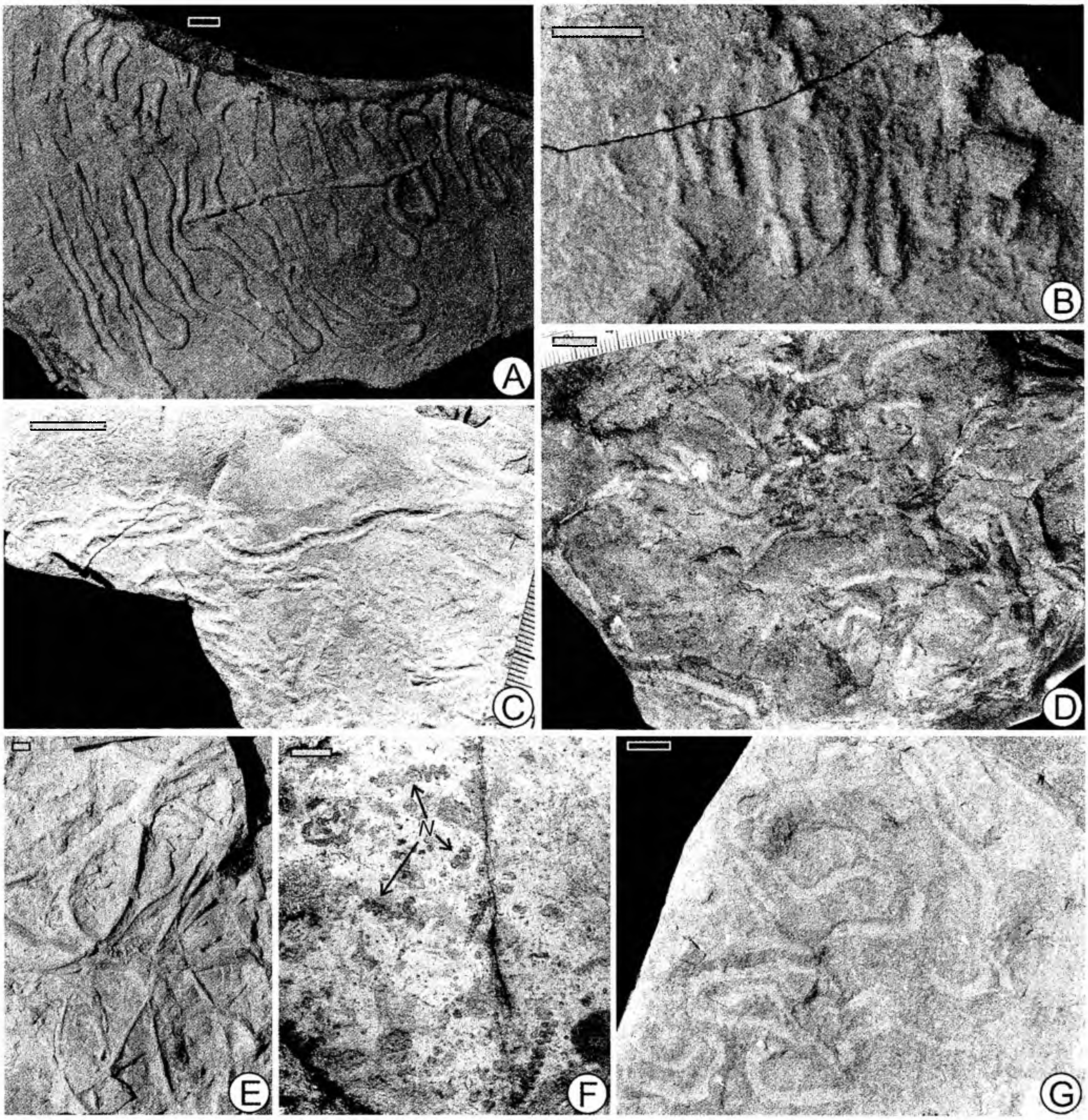


Fig. 13. Other winding and meandering trace fossils. **A** – *Helminthorhaphe japonica*, sandstone turbidite sole, Kusuri Fm, locality 19; **B** – *Helminthorhaphe flexuosa*, sandstone turbidite sole, Kusuri Fm, locality 17; **C** – *Nereites* isp. form B, upper surface of turbidite marlstone capping, Akveren Fm, locality 7; **D** – *Nereites irregularis*, upper surface of sandstone turbidite, Kusuri Fm, locality 20; **E** – *Protovirgularia* isp., lower surface of turbiditic marlstone, Akveren Fm, locality 7; **F** – *Nereites* isp. (*N*) form C, upper surface of silty marlstone turbidite, Atbaşı Fm, locality 9; **G** – *Nereites* isp. form A, upper surface of turbidite mudstone capping, Yemişliçay Fm, locality 2. The scale bars are 1 cm. The locality numbers are as in Fig. 2 and Table 1

plitude increases in one direction from 25 to 60 mm. There are distinct bulges at the meander bends.

Remarks: Same as for *H. flexuosa* above.

Occurrence: Kusuri Fm, locality 19 (Fig. 2, Table 1).

Nereites MacLeay 1839
Nereites irregularis (Schafhäutl 1851)
Fig. 13D

Description: Endichnial, meandering ribbon-like form, preserved in full relief and strongly flattened, composed of a distinct central string and thin, poorly preserved side lobes of reworked sediment. The central string is 2–2.5 mm wide. Its filling is of a lighter colour and finer-grained than the surrounding sediment, and is locally meniscate.

Remarks: *Nereites* is a typical pascichnion produced by an unknown tracemaker (see discussion by Rindsberg, 1994; Uchman, 1995; Mángano *et al.*, 2002; for discussion of the ichnospecies *N. irregularis*, see Uchman, 1995, 1999).

Occurrence: Kusuri Fm, locality 20 (Fig. 2, Table 1).

Nereites isp. form A
Fig. 13G

Description: Horizontal, endichnial, irregularly meandering trace fossil visible on parting surfaces as a central band, 3–4 mm wide, bounded on both sides by indistinct zones 1–2 mm wide. The central band is lighter in colour than the host siltstone and its margins are uneven. Local lobes at the margins suggest meniscate filling. The bounding zones are diffuse, darker than the host rock and absent from some segments of the band.
Remarks: The tripartite structure is typical of *Nereites*, which consists of a central faecal string bounded by zones of reworking (Uchman, 1995).
Occurrence: Yemişliçay Fm, locality 2 (Fig. 2, Table 1).

Nereites isp. form B
Fig. 13C

Description: Horizontal, epichnial, irregularly meandering trace fossil composed of a winding central ridge and two lobate side zones. The central ridge is 2 mm wide and shows meniscate structure. The menisci are spaced at about 1.5 mm. The edges of menisci are locally elevated, whereby the ridge shows constrictions and swellings. The lobate zones are irregularly asymmetrical, and are slightly depressed relative to the surrounding bedding surface. These zones consist of elongate, overlapping lobes, whose axes are concordantly inclined towards the ridge axis. The lobate zone is locally up to 2 mm wide, but absent in other places.
Remarks: Same as for morphotype A above.
Occurrence: Akveren Fm, locality 7 (Fig. 2, Table 1).

Nereites isp. form C
Fig. 13F

Description: Horizontal, dark lobate stripes, with a total width of 3–4 mm, exposed on the bedding surface of a white-weathering marlstone bed. A thin tunnel, about 1 mm wide, is locally visible along the centre of a stripe. The lobes have an apparent zigzag pattern, as they occur alternatingly on both sides of the central tunnel and are separated on either side by gaps of about 0.5 mm. The lobe tips are 2.5–3 mm apart.
Remarks: The structure of a central tunnel and lobes is typical of *Nereites* (Uchman, 1995).
Occurrence: Atbaşı Fm, locality 9 (Fig. 2, Table 1).

Protovirgularia McCoy 1850
Protovirgularia isp.
Fig. 13E

Description: Hypichnial, keel-shaped and gently winding ridges, 3–4 mm wide, some with a longitudinal, thin and commonly discontinuous furrow. The ridges extend in various directions and cross one another.
Remarks: *Protovirgularia* as a molluscan locomotion trace, as proved by neoichnological experiments (Seilacher & Seilacher, 1994); for discussion, see also Uchman (1998) and Mángano *et al.* (2002).
Occurrence: Akveren Fm, locality 7 (Fig. 2, Table 1).

Scolicia de Quatrefages 1849
Scolicia prisca de Quatrefages 1849
Fig. 14A

Description: Epichnial trilobate furrow, 25–30 mm wide, with a semicircular, convex bottom and oblique slopes. It shows densely packed, fine transverse ribs at the bottom and looser, thicker, asymmetrical ribs on the slopes. The convex bottom zone is about 5–10 mm wide, with two parallel strings along its edges. Each string is about 2 mm wide. The furrow passes into a meniscate-filled structure that shows arcuate double menisci in horizontal cross-section (see *Laminites* preservation in Uchman, 1995).
Remarks: *Scolicia* is a pascichnion produced by irregular echinoids (see discussion by Uchman, 1995) and known since the Tithonian (Tchoumatchenco & Uchman, 2001).
Occurrence: Kusuri Fm, localities 13 and 18 (Fig. 2, Table 1).

Scolicia vertebralis Książkiewicz 1977
Figs 14B–E

Description: Epichnial winding structures in the form of bands, furrows or sporadically ridges, 25–50 mm wide. The bands in sandstone are filled with shallow menisci made of muddy sand, interrupted in the axial part by undulation. The filling is locally removed and the trace fossil is visible as a shallow epichnial groove with an axial string and obliquely ribbed slopes. This trace fossil sporadically has the form of low epichnial ridges with an axial narrow furrow dividing the ridge into two lobes. The central part of each lobe shows a narrow delicate ridge that passes locally in a furrow, parallel to the axial furrow.
Remarks: The structure of a ribbed epichnial groove with a single central string on the bottom is typical of *Scolicia vertebralis* Książkiewicz (1977), although this ichnospecies requires a revision.
Occurrence: Kusuri Fm, locality 18 (Fig. 2, Table 1).

Scolicia strozzii (Savi & Meneghini 1850)
Figs 14G, 15A–C

Description: Winding, smooth, bilobate hypichnial ridge, about 20–25 mm wide and up to 5 mm high, divided by a semicircular axial furrow that occupies up to two-thirds of the ridge width. The structure is preserved in semirelief in fine-grained sandstone turbidites. In some cases in the Kusuri Fm, the ridges are 8–15 mm wide and the axial furrow in some of them is less distinct. Some of the ridges form meanders or coiling meanders.
Remarks: This ichnospecies was described in the earlier literature as *Taphrhelminthopsis* Sacco or *Taphrhelminthoida* Książkiewicz, but is considered to be a casted washed-out shallow *Scolicia* burrow (Uchman, 1995).
Occurrence: Akveren Fm, locality 7; Atbaşı Fm, locality 11; Kusuri Fm, localities 13, 18 and 19 (Fig. 2, Table 1).

Scolicia isp.
Fig. 14F

Description: Two morphotypes of unspecified *Scolicia* have been found. Form A is a horizontal, endichnial winding band, 16 mm wide, preserved in full relief on a parting surface and bounded by two strings, each about 2 mm wide, filled with a slightly different sediment (Fig. 14F). Form B a horizontal, hypichnial flat winding ridge, 38 mm wide, with a poorly defined bilobate shape and preserved in full relief.
Remarks: The bilobate or trilobate structure is typical of *Scolicia*. This ichnogenus appeared in Tithonian (Tchoumatchenco & Uchman, 2001), and its occurrence as morphotype A in the Çağlayan Fm is thus one of the earliest.
Occurrence: Form A found in the Çağlayan Fm, locality 1; form B in the Akveren Fm, locality 5 (Fig. 2, Table 1).

Bilobate ridge
Fig. 15D

Description: Hypichnial, winding ridges, about 18 mm wide,

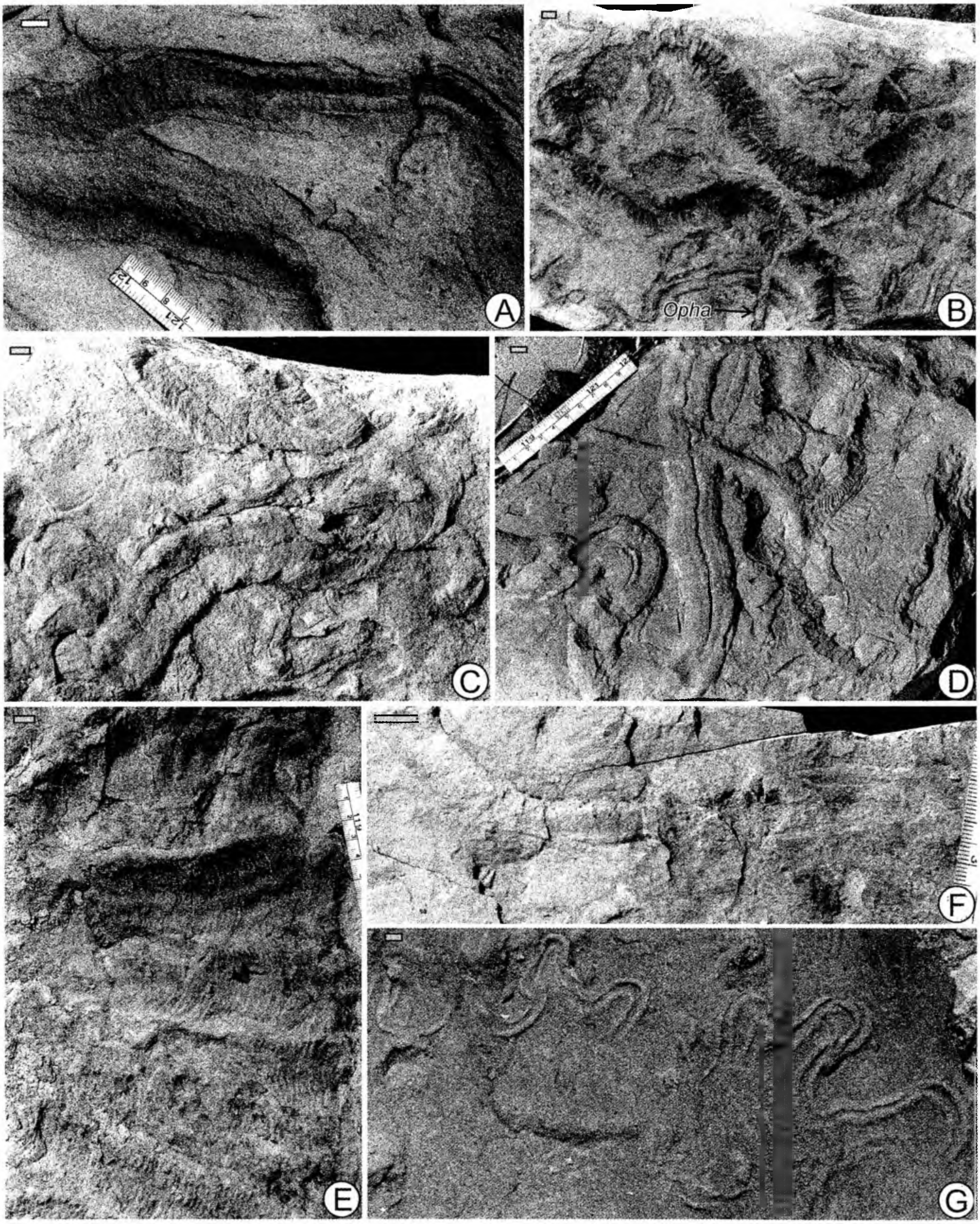


Fig. 14. *Scolicia*. **A** – *Scolicia prisca*, upper surface of sandstone turbidite, Kusuri Fm, locality 18; **B** – *Scolicia vertebralis* and *Ophiomorpha annulata* (*Opha*), upper surface of sandstone turbidite, Kusuri Fm, locality 18; **C**, **D** – *Scolicia vertebralis*, upper surface of sandstone turbidite, Kusuri Fm, locality 18; **E** – *Scolicia vertebralis*, upper surface of sandstone turbidite, Kusuri Fm, locality 18; **F** – *Scolicia* isp., parting surface of blackish-grey mudshale, Çağlayan Fm, locality 1; **G** – *Scolicia strozzii*, sandstone turbidite sole, Kusuri Fm, locality 16. The scale bars are 1 cm. The locality numbers are as in Fig. 2 and Table 1

markedly elevated above the bedding surface of turbiditic sandstone. The ridges are preserved in semirelief and cross one another. Their cross-section is semicylindrical in some segments, but the ridges are bilobate in other segments, with a narrow, V-shaped axial furrow along at the top of the ridge.
Remarks: The bilobate shape and winding pattern resemble *Scolicia strozzii*, but the latter does not normally show ridges with such steep and locally overhanging slopes. Furthermore, the axial furrow in *S. strozzii* is wider and never V-shaped.
Occurrence: Kusuri Fm, locality 18 (Fig. 2, Table 1).

SPIRAL STRUCTURES

Spirorhaphe Fuchs 1895
Spirorhaphe involuta (De Stefani 1895)
Figs 15E, F

Description: Two preservational varieties of this ichnospecies have been recognized. Form A is a hypichnial, semi-cylindrical undulating ridge, 1.0–1.5 mm wide, forming a spiral that is 40–53 mm wide. At least 7 whorls, spaced at 1–3 mm, are recognizable within the spiral, which also forms a loop in its central part. Form B is an epichnial, undulating semi-cylindrical groove, 2.0 mm wide, forming a spiral that is 65–75 mm wide. There are 10 whorls in the spiral, 1–7 mm apart, and its central part is a loop. Very similar forms, with the same morphometric parameters, are preserved also in convex hypichnial semirelief.
Remarks: *Spirorhaphe* is a typical graphoglyptid agrichnion; for discussion, see Seilacher (1977) and Uchman (1998).
Occurrence: Form A found in Kusuri Fm, localities 15 (specimen 173P15) and 17; form B in Kusuri Fm, locality 17 (Fig. 2, Table 1).

BRANCHED WINDING AND MEANDERING TRACES

Gyrolithes de Saporta 1884
Gyrolithes isp.
Fig. 16A, B

Description: Endichnial cylindrical trace, 3–3.5 mm wide, forming a vertical spiral about 25 mm in diameter. Only three whorls are recognizable, 9–12 mm apart.
Remarks: For discussion of *Gyrolithes*, see Schlirf (2000).
Occurrence: Akveren Fm, locality 5 (Fig. 2, Table 1); collection specimen 173P3.

Acanthorhaphe Książkiewicz 1970
Acanthorhaphe delicatula Książkiewicz 1977
Fig. 17A

Description: Hypichnial semi-cylindrical ridge, about 1.5 mm wide and 15 mm long, forming an arc with short appendages on the convex side. The appendages are up to 2 mm long and 2–3 mm apart.
Remarks: For discussion of *Acanthorhaphe*, see Seilacher (1977) and Uchman (1998).
Occurrence: Akveren Fm, locality 7 (Fig. 2, Table 1).

?*Acanthorhaphe* isp.
Fig. 17B

Description: Hypichnial semicylindrical ridge, about 2 mm wide, forming a meander. One half of the meander displays short, straight appendages on its convex side. The appendages are up to 10 mm in length.
Remarks: It cannot be precluded that this trace fossil is an accidental composite structure.
Occurrence: Kusuri Fm, locality 17 (Fig. 2, Table 1).

Belocosmorhaphe Uchman 1998
Belocosmorhaphe aculeata (Książkiewicz 1977)
Fig. 17D

Description: Hypichnial string, about 2 mm wide, with first- and second-order meanders and with short, knobby lateral appendages. The first-order meanders are 4–8 mm wide and up to 16 mm in amplitude, whereas the second-order meanders are up to 2 mm wide and their amplitude reaches 2 mm.
Remarks: *Belocosmorhaphe* is a new ichnogenus name (Uchman, 1998) for *Helminthoida aculeata* Książkiewicz (1977), and this is its fourth known occurrence.
Occurrence: Kusuri Fm, locality 13 (Fig. 2, Table 1).

Belorhaphe Fuchs 1895
Belorhaphe zickzack (Heer 1877)
Fig. 17C

Description: Hypichnial, "triangular" meanders, 5 mm wide, with an apical angle of 63–77° and amplitude of 5 mm, preserved in semirelief. The meander apices show swellings.
Remarks: For discussion of this ichnospecies, see Uchman (1998).
Occurrence: Kusuri Fm, locality 18 (Fig. 2, Table 1).

Desmograpton Fuchs 1895
Desmograpton dertonensis (Sacco 1888)
Fig. 17E

Description: Hypichnial double rows of string-sized, U- or J-shaped semi-meanders. Their curved segments are inwardly oriented, in alternating position, with two opposing semi-meanders joined by short bars. The semi-meander string is 1.5 mm wide, and the axial elements are elevated. The connecting bars are about 3 mm long, perpendicular to the burrow axis and poorly preserved. The arms of semi-meanders are 2 to 5 string-widths apart.
Remarks: *Desmograpton* is a typical graphoglyptid; for discussion, see Uchman (1995).
Occurrence: Kusuri Fm, locality 13 (Fig. 2, Table 1).

Ubinia Grossgeim 1961
Ubinia wassoevitschi Grossgeim 1961
Fig. 17H

Description: Hypichnial trace fossil composed of an axial hemicylindrical ridge and arcuate simple branches. The branches are paired symmetrically on both sides of the ridge and are partly overlapping at their ends. The diameter of ridge and the branches are about 1.5 mm wide and preserved in semirelief.
Remarks: This is the third known occurrence of this ichnospecies and the second in Cretaceous deposits. *Ubinia* is a very rare graphoglyptid trace fossil and has been discussed by Wetzel and Uchman (1997) and Jensen and Mens (1999). These latter authors erroneously implied that the former authors included *Dendrorhaphe haentzscheli* Seilacher (1977) in this ichnogenus. Jensen and Mens (1999) described *Dendrorhaphe* isp. that probably belongs to *Trichichnus appendicus* Uchman (1999).
Occurrence: Yemişliçay Fm, locality 2 (Fig. 2, Table 1); collection specimen 173P10.

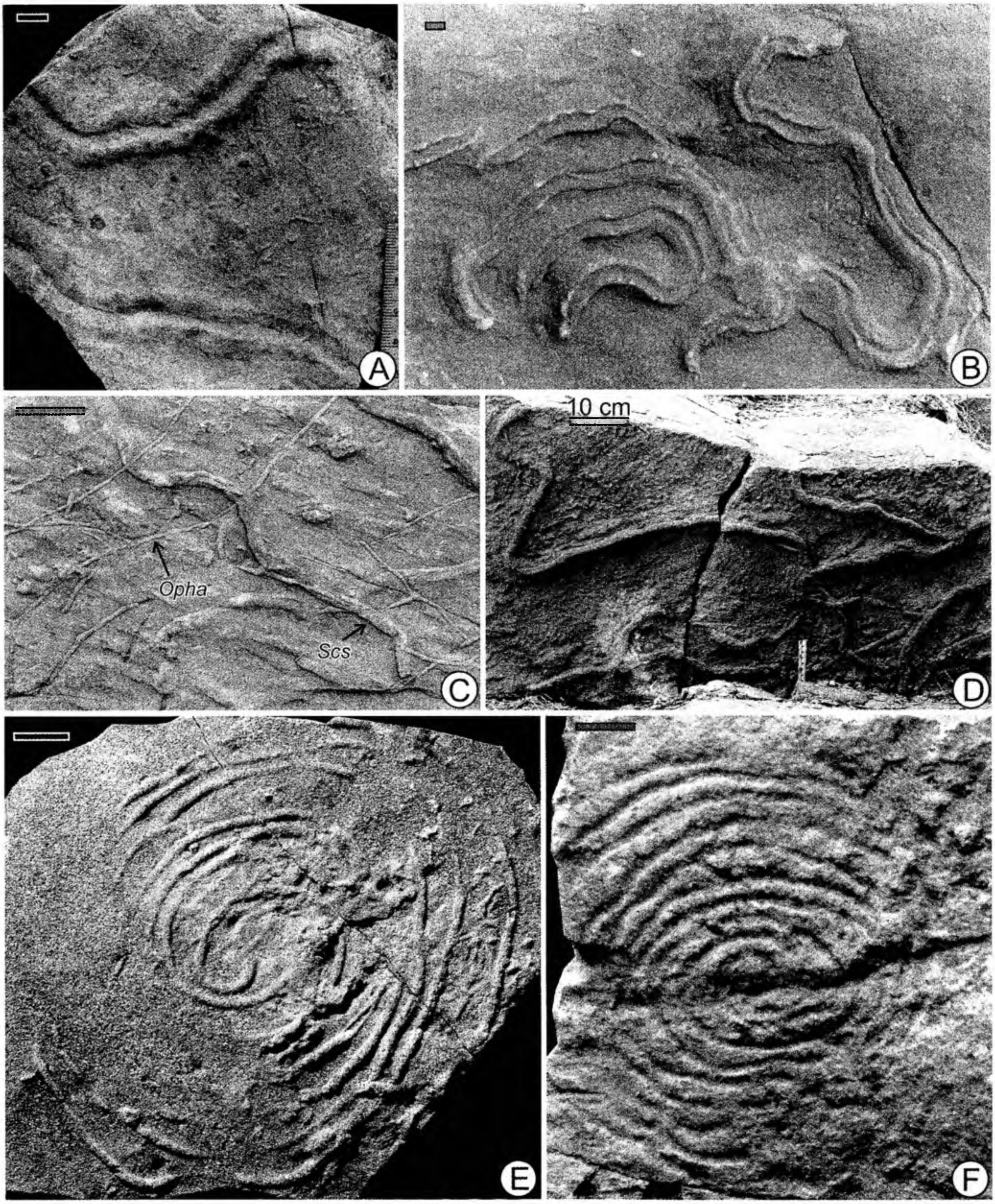


Fig. 15. Winding and spiral trace fossils in the Kusuri Fm **A** – *Scolicia strozzii*, sandstone turbidite sole, locality 12; **B** – *Scolicia strozzii*, sandstone turbidite sole, locality 18; **C** – *Scolicia strozzii* and *Ophiomorpha annulata* (*Opha*), sandstone turbidite sole, locality 18; **D** – bilobate ridge, sandstone turbidite sole, locality 18; **E** – *Spirorhaphe involuta*, sandstone turbidite sole, locality 18; **F** – *Spirorhaphe involuta*, concave form on the upper surface of sandstone turbidite, locality 18. The scale bars are in A–C and E–F 1 cm. The locality numbers are as in Fig. 2 and Table 1

Urohelminthoida Sacco 1888
Urohelminthoida appendiculata (Heer, 1877)
Fig. 17I

Description: Hypichnial, semi-cylindrical meandering ridges, 2 mm wide, not well preserved. The meanders are 5–10 mm wide and more than 60 mm in amplitude, and their axis is curved. Short appendages extend from the meander apices.
Remarks: For discussion of this graphoglyptid ichnospecies, see Uchman (1995).
Occurrence: Akveren Fm, locality 7 (Fig. 2, Table 1).

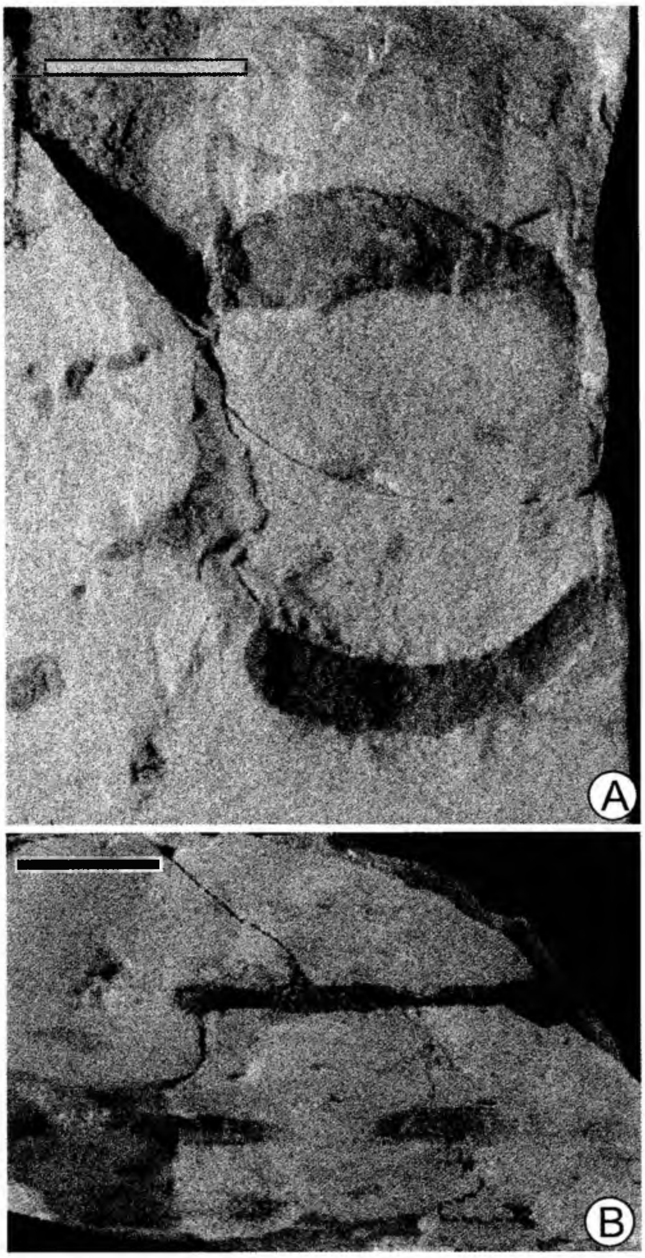


Fig. 16. *Gyrolithes* isp. in a marlstone capping of calcarenitic turbidite, Akveren Fm, locality 5, specimen 173P3. **A** – view from above; **B** – side view. The scale bars are 1 cm. The locality number refers to Fig. 2 and Table 1, and the specimen number refers to collection at the Institute of Geological Science, Jagiellonian University

Protopaleodictyon Książkiewicz 1970
Protopaleodictyon incompositum Książkiewicz 1970
Figs 18F, G

Description: Hypichnial, semicylindrical ridge, 1.5–2 mm wide, irregularly meandering and branched. The branches extend outwards from the meander bends, and some of the branches are long and winding.
Remarks: For discussion of *Protopaleodictyon*, see Uchman (1998).
Occurrence: Kusuri Fm, locality 18 (Fig. 2, Table 1).

Zigzag cylinder
Fig. 18B

Description: Hypichnial, cylindrical horizontal ridge, 5 mm wide, preserved in full relief. It shows a zigzag pattern of nearly straight segments, 20–30 mm long, with short protrusions plunging at the apices into the host turbiditic sandstone.
Remarks: This trace-fossil structure resembles *Belorhaphe*, although the latter is known to be much smaller and preserved in semirelief. The linear segments of the zigzag structure are similar to *Ophiomorpha annulata*, which indeed occurs in the same bed, but itself never shows zigzag patterns.
Occurrence: Kusuri Fm, locality 20 (Fig. 2, Table 1); collection specimen 173P18.

Cluster of knobs
Fig. 18A

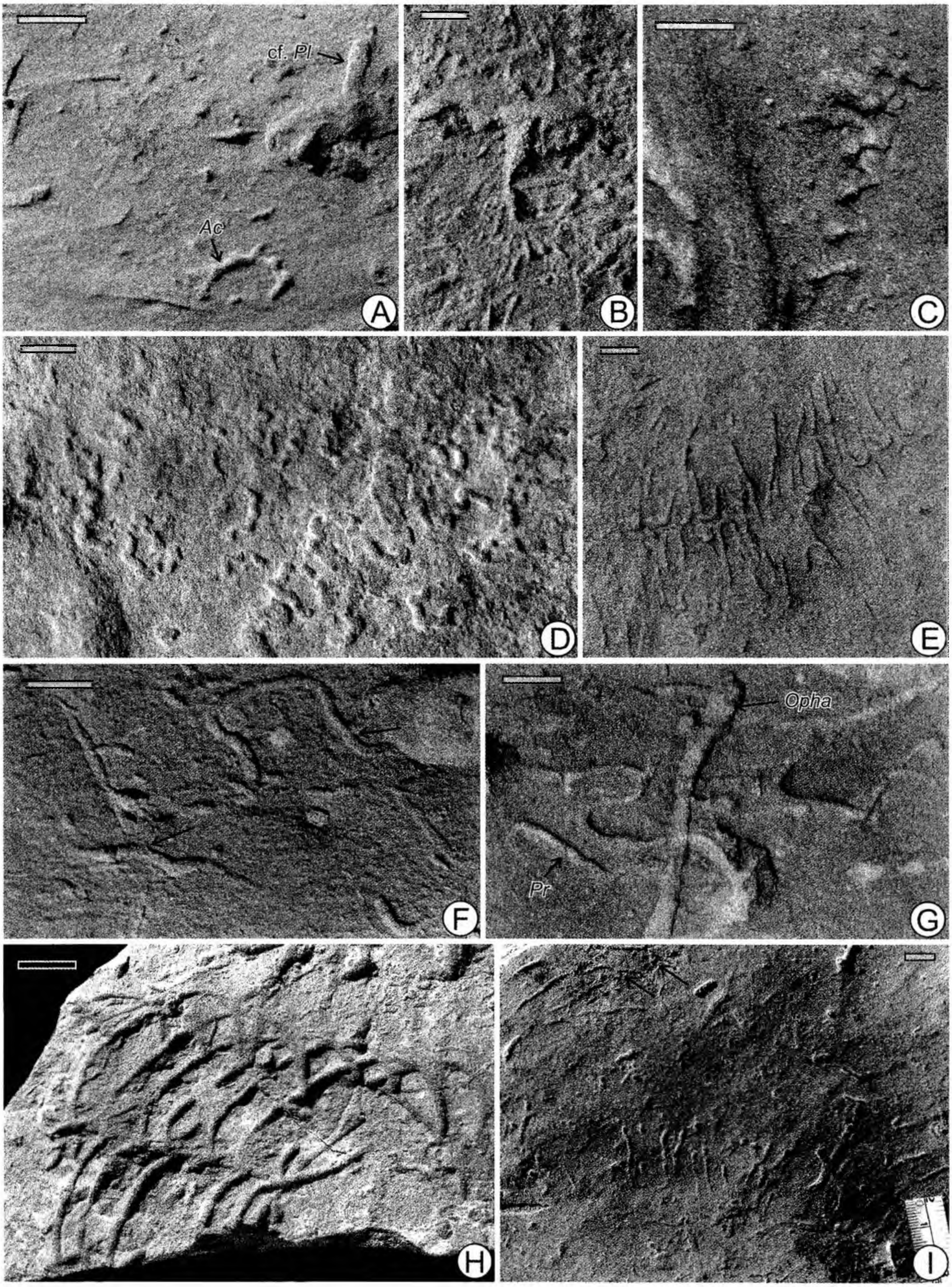
Description: A group of at least 40 hypichnial knobs, 2.0–2.5 mm across and 5–10 mm apart, forming a cluster about 75 mm across. The knobs lack any distinct spatial pattern.
Remarks: The knobs are most likely casts of the vertical shafts of some graphoglyptid burrow system (cf. Seilacher, 1977).
Occurrence: Akveren Fm, locality 5 (Fig. 2, Table 1).

NETWORKS

Megagrapton Książkiewicz 1968
Megagrapton irregulare Książkiewicz 1968
Fig. 18C

Description: Irregular hypichnial network preserved in semirelief

Fig. 17. Winding and meandering trace fossils with branches. **A** – *Acanthorhaphe delicatula* (*Ac*) and cf. *Planolites* isp. (cf. *Pl*), lower surface of turbiditic marlstone, Akveren Fm, locality 7; **B** – ?*Acanthorhaphe* isp., sandstone turbidite sole, Kusuri Fm, locality 17; **C** – *Belorhaphe zickzack*, sandstone turbidite sole, Kusuri Fm, locality 18; **D** – *Belocosmorhaphe aculeata*, sandstone turbidite sole, Kusuri Fm, locality 13; **E** – *Desmograpton dertonensis*, sandstone turbidite sole, Kusuri Fm, locality 13; **F** – *Protopaleodictyon incompositum* (arrows indicate the branching points), sandstone turbidite sole, Kusuri Fm, locality 18; **G** – *Protopaleodictyon incompositum* (Pr) and *Ophiomorpha annulata* (*Opha*), sandstone turbidite sole, Kusuri Fm, locality 18; **H** – *Ubinia wassoevitschi*, sandstone turbidite sole, Yemişliçay Fm, locality 2, specimen 173P10; **I** – *Urohelminthoida appendiculata* (arrows indicate the protruding appendages), calcarenitic turbidite sole, Akveren Fm, locality 7. The scale bars are 1 cm. The locality numbers are as in Fig. 2 and Table 1, and the specimen number refers to collection at the Institute of Geological Science, Jagiellonian University


cf. Pl
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on turbidite sandstone bedding surface. The network consists of meshes bounded by smooth, hemicylindrical ridges, straight to slightly winding and 2.5–5 mm wide. The meshes are commonly elongate, with the longest dimension in the range of 25–105 mm.
Remarks: For discussion of *Megagrapton*, see Uchman (1998).
Occurrence: Akveren Fm, locality 8; Kusuri Fm, locality 15 (Fig. 2, Table 1).

Megagrapton submontanum (Azpeitia Moros 1933)
Figs 18D–F

Description: Two morphotypes of this ichnospecies have been found. Form A consists of hypichnial, semi-cylindrical ridges forming an irregular network (Fig. 18F). The ridges are about 1.5 mm wide and the network meshes have a maximum dimension of 13–17 mm. Form B is similar, but the ridges here are 2–3 mm wide and the only complete mesh found is 16 mm by 30 mm in size (Figs 18D, E).
Remarks: For discussion of this ichnospecies, see Uchman (1998).
Occurrence: Form A found in the Kusuri Fm, locality 17; form B found at localities 18 (specimen 173P20) and 19 (Fig. 2, Table 1).

Megagrapton isp.
Fig. 18G

Description: Two morphotypes of this ichnospecies have been recognized. Form A consists of hypichnial, irregular semi-cylindrical ridges forming an irregular network. The ridges are about 2 mm wide and only two incomplete meshes are preserved, the larger at least 32 mm across. Form B is similar, but the ridges are about 1.3 mm wide. Here, too, only two incomplete meshes are preserved, the larger one at least 70 mm across.
Remarks: Incomplete preservation does not allow more detailed identification.
Occurrence: Akveren Fm, locality 5 (Fig. 2, Table 1).

Paleodictyon Meneghini in Savi & Meneghini 1850
Paleodictyon latum Vialov & Golev 1965
Fig. 18H

Description: Hypichnial hexagonal network, preserved in convex semirelief. The string is 0.6 mm wide and the maximum mesh size is up to 2.0 mm.
Remarks: For discussion of *Paleodictyon*, see Seilacher (1977) and Uchman (1995).
Occurrence: Akveren Fm, locality 5 (Fig. 2, Table 1); collection specimen 173P12.

Paleodictyon strozzii
Meneghini in Savi & Meneghini 1850
Fig. 18I

Description: Hypichnial subhexagonal network, preserved in convex semirelief. The string is less than 1 mm wide and the maximum mesh size ranges from 4 to 5 mm.
Remarks: Same as for *Paleodictyon* above.
Occurrence: Kusuri Fm, localities 15, 17 and 18 (Fig. 2, Table 1); collection specimen 173P21.

Paleodictyon cf. *maximum* (Eichwald 1868)
Fig. 19C

Description: Hypichnial subhexagonal network, preserved in convex-upward semirelief. The string is flat and 2–3 mm wide, and the maximum mesh size ranges from 5 to 7 mm.
Remarks: The flattened strings are probably due to collapse of the burrow system, which would imply that the string width represents the width of the burrow exterior, including both the lumen and lining (for terminology see Bromley, 1996). The string width would thus be greater than in forms preserved by scouring and casting. Accordingly, the actual string dimension here would correspond to *P. maximum* (Eichwald) or *P. miocenicum* Sacco (see Uchman, 1995).
Occurrence: Kusuri Fm, locality 12 (Fig. 2, Table 1).

Paleodictyon delicatulum Uchman 1995
Fig. 19A

Description: Hypichnial hexagonal network, preserved in convex semirelief. The string is 0.6–0.8 mm wide and the maximum mesh size is 7 to 8 mm.
Remarks: For discussion of *Paleodictyon*, see Seilacher (1977) and Uchman (1995).
Occurrence: Yemişliçay Fm, locality 2 (Fig. 2, Table 1); collection specimen 173P14.

Paleodictyon majus Meneghini in Peruzzi 1880
Fig. 19B

Description: Hypichnial subhexagonal network, preserved as convex-upward semirelief. The string is no wider than about 1–1.5 mm and the maximum mesh size ranges from 7 to 12 mm.
Remarks: Same as for *P. delicatulum* above.
Occurrence: Akveren Fm, locality 5, collection specimen 173P13; Kusuri Fm, locality 13 (Fig. 2, Table 1).

Squamodictyon Vialov & Golev 1960
Squamodictyon tectiforme (Sacco 1886)
Fig. 19D

Description: Thin hypichnial ridges forming a regular network of round, scale-like meshes. The meshes are up to 7–8 mm across and the string is less than 1 mm wide.
Remarks: This typical graphoglyptid trace fossil, produced by an unknown farming animal, is known from Cretaceous and Tertiary flysch deposits (Seilacher, 1977), but very rare in the Palaeogene. *Squamodictyon* was regarded as ichnosubgenus of *Paleodictyon* by Seilacher (1977), but others consider it presently as a separate ichnogenus (e.g., Uchman, 1999; Tchoumatchenco & Uchman, 1999).
Occurrence: Kusuri Fm, locality 18 (Fig. 2, Table 1).

STRATIGRAPHIC DISTRIBUTION OF TRACE FOSSILS

The stratigraphic distribution of the trace fossils in the basin-fill sedimentary succession is highly uneven. In the Çağlayan Fm (Barremian–Cenomanian), dominated by black shales, only *Scolicia* isp., *Phycosiphon* isp. and the morphotypes A and B of *Planolites* isp. have been found. Trace fossils here are relatively rare (a few speciemens), occur in horizons and show low diversity. Only *Phycosiphon* is abundant in some horizons.

The volcaniclastic flysch of the Yemişliçay Fm (late Coniacian–early Campanian) contains 8 ichnogenera. Post-depositional forms include *Chondrites targionii, Chondrites intricatus, Trichichnus* isp., morphotype C of *Planolites* isp., cf. *Planolites* isp., *?Arthrophycus* cf. *tenuis*, *Thalassi-*

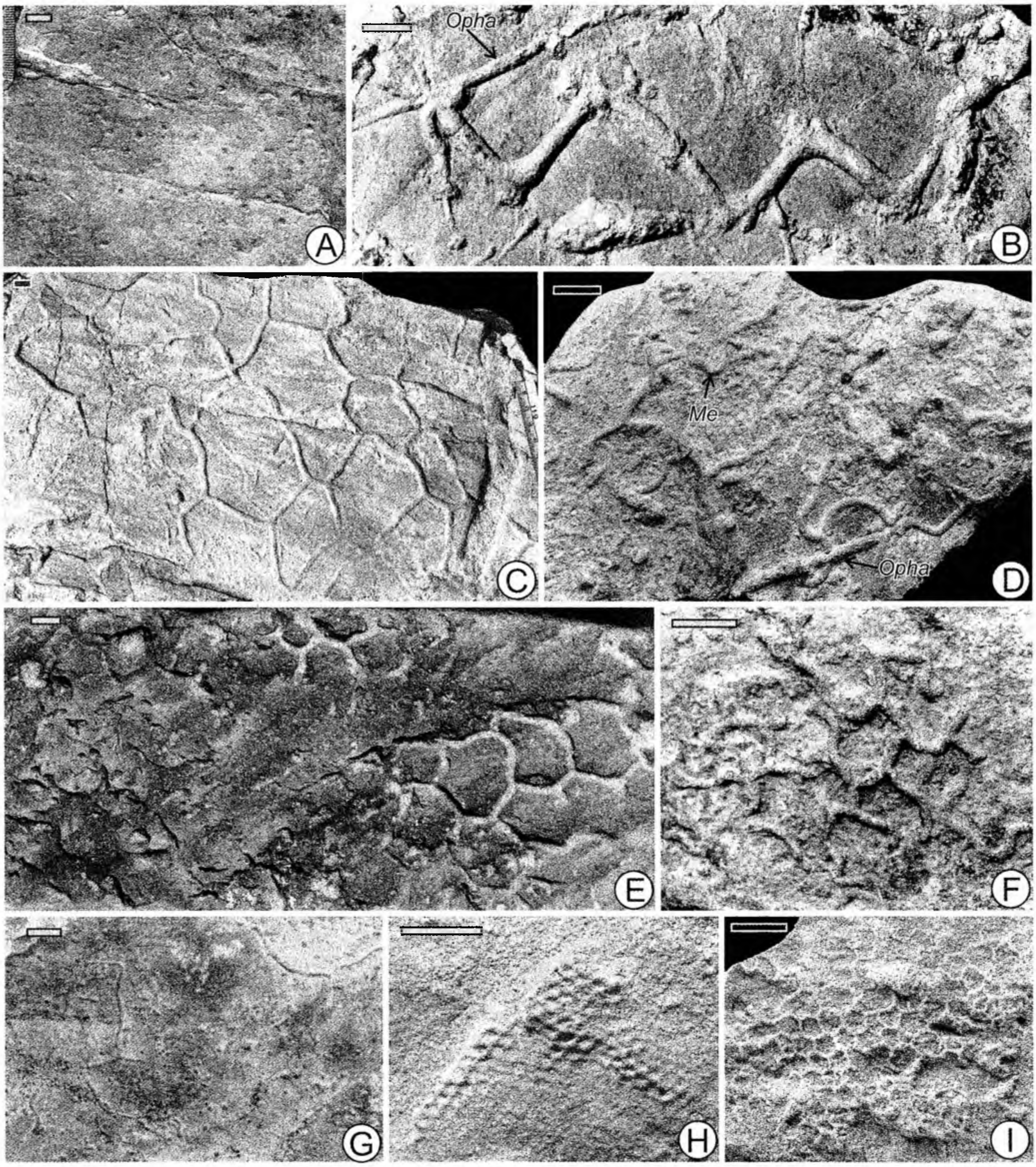

Fig. 18. Miscellaneous and network trace fossils on bed soles. **A** – cluster of knobs, silty turbiditic marlstone, Akveren Fm, locality 7; **B** – zigzag cylinder and *Ophiomorpha annulata* (*Opha*), sandstone turbidite, Kusuri Fm, locality 20; **C** – *Megagrapton irregulare*, silty turbiditic marlstone, Akveren Fm, locality 8; **D** – *Megagrapton submontanum* (*Me*) form B and *Ophiomorpha annulata* (*Opha*), sandstone turbidite, Kusuri Fm, locality 18; **E** – *Megagrapton submontanum* form B, sandstone turbidite, Kusuri Fm, locality 19; **F** – *Megagrapton submontanum* form A, sandstone turbidite, Kusuri Fm, locality 17; **G** – *Megagrapton* isp., sandstone turbidite, Akveren Fm, locality 5; **H** – *Paleodictyon latum*, calcarenitic turbidite, Akveren Fm, locality 5; **I** – *Paleodictyon strozzii*, sandstone turbidite, Kusuri Fm, locality 18, specimen 173P21. The scale bars are 1 cm. The locality numbers are as in Fig. 2 and Table 1, and the specimen number refers to collection at the Institute of Geological Science, Jagiellonian University

noides isp. and *Nereites* isp. form A. Pre-depositional forms include *Ubinia vassoevitschi*, *Paleodictyon majus* and *Paleodictyon delicatulum*. Trace fossils are much more abundant here than in the underlying Çağlayan Fm, but are less diverse than in coeval and lithologically similar flysch successions elsewhere (Uchman, 2004). The pre-depositional forms and *Nereites* are very rare, whereas *Chondrites* and *Planolites* predominate.

No systematic data have been collected from the siliciclastic and increasingly calcareous "normal" flysch of the Gürsökü Fm (late Campanian–Maastrichtian), but observations from locality 3 (Fig. 2) indicate typical *Nereites* ichnofacies. The overlying, calcareous "normal" flysch of the Akveren Fm (late Maastrichtian–early Late Palaeocene) contains a typical *Nereites* ichnofacies, with 30 ichnospecies representing 23 ichnogenera (Table 2). 9 ichnospecies are pre-depositional forms, including 7 ichnospecies of graphoglyptids. *Planolites*, *Chondrites*, *Zoophycos*, *Thalassinoides* and *Scolicia strozzii* are the most common ichnotaxa.

The variegated muddy flysch of the Atbaşı Fm (latest Palaeocene–earliest Eocene) bears a trace fossil assemblage of very low diversity (Table 3). The trace fossils here occur mainly in the subordinate, thin sandstone beds, with *Planolites* and *Scolicia strozzii* being the most common forms. The remaining 3 ichnotaxa (*Ophiomorpha annulata*, ?*Phycodes* isp. and *Nereites* isp. form C) are very rare. They occur in the lowermost part of the formation, which represents the drowning phase of the littoral, foramol-type carbonate platform developed at the top of the Akveren Fm (Leren *et al.*, unpubl. data).

The siliciclastic Kusuri Fm (Early-Middle Eocene) contains the richest assemblage of trace fossils (Table 4). There are 38 ichnospecies, representing 27 ichnogenera. 23 ichnospecies are pre-depositional forms. 20 ichnospecies of 14 ichnogenera represent graphoglyptids. Most of the ichnotaxa occur in the overbank and distal lobe facies comprising thin to medium turbidite beds capped with hemipelagic mudstones. The thick-bedded, channel-fill sandstone turbidites contain only *Ophiomorpha* and *Scolicia*.

DISCUSSION

The trace fossils in the black shales of the Çağlayan Fm are forms produced solely by mobile deposit-feeders (*Scolicia*, *Phycosiphon* and *Planolites*). It was probably the high content of organic matter in the sediment that rendered this mode of feeding most suitable and efficient. Dense occurrences of *Phycosiphon* indicate opportunistic colonization, which is typical of this ichnogenus (Wetzel & Uchman, 2001). The low diversity of trace fossils in the

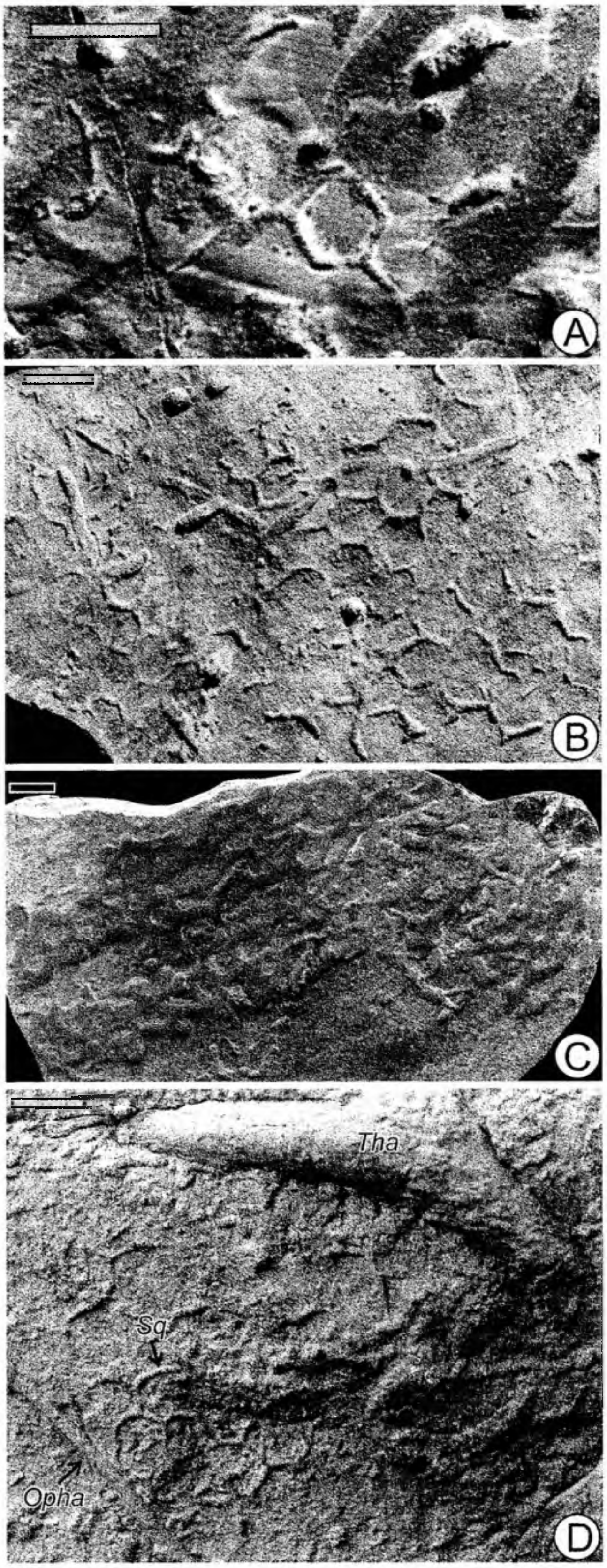

Fig. 19. Network trace fossils on bed soles. **A** – *Paleodictyon delicatulum*, sandstone turbidite, Yemişliçay Fm, locality 2, specimen 173P14; **B** – *Paleodictyon majus*, calcarenitic turbidite, Akveren Fm, locality 5, specimen 173P13; **C** – *Paleodictyon* cf. *maximum*, sandstone turbidite, Kusuri Fm, locality 12; **D** – *Squamodictyon tectiforme* (*Sq*), *Thalassinoides suevicus* form C (*Th*) and *Ophiomorpha annulata* (*Opha*), sandstone turbidite, Kusuri Fm, locality 18. The scale bars are 1 cm. The locality numbers are as in Fig. 2 and Table 1, and the specimen numbers refer to collection at the Institute of Geological Science, Jagiellonian University

Table 2

Trace fossils recognized in the Akveren Fm (locality numbers as in Table 1 and Fig. 2)

Ichnotaxa/localities	4	5	6	7	8
Chondrites intricatus	x	x		x	x
Chondrites targionii	x	x	x		
Halimedites annulata		x			
Halopoa imbricata				x	
Ophiomorpha annulata		x		x	
Ophiomorpha ?nodosa			x		
Planolites isp.		x	x	x	x
Trichichnus linearis		x		x	
Pilichnus dichotomus		x			
Thalassinoides suevicus		x		x	
Thalassinoides ispp.	x	x			x
Lophoctenium minimum				x	
cf. *Phycodes* isp.		x			
Phycosiphon incertum		x		x	
Phymatoderma isp.		x			
Zoophycos isp.	x	x	x		x
Gyrolithes isp.		x			
Helminthopsis isp.				x	
Nereites isp. form B				x	
Protovirgularia isp.				x	
Scolicia strozzii	x	x		x	
cluster of knobs		x			
Acanthorhaphe delicatula				x	
Cosmorhaphe lobata		x			
Urohelminthoida appendiculata				x	
Megagrapton submontanum				x	
Megagrapton irregulare	x				x
Megagrapton isp.		x			
Paleodictyon latum		x			
Paleodictyon majus		x			

Çağlayan Fm can be attributed to a highly eutrophic environment with numerous anoxic events, and to the limited preservation potential of traces, due to the low frequency of taphonomically beneficial turbidity currents. The general diversity of deep-sea trace fossils at the time of sedimentation of the Çağlayan Fm was very low, which is related mainly to the Early Cretaceous anoxic events (Uchman, 2004). The anoxic events in the present case are indicated

Table 3

Trace fossils recognized in the Atbaşı Fm (locality numbers as in Table 1 and Fig. 2)

Ichnotaxa/localities	9	10	11
Planolotes isp.		x	x
Ophiomorpha annulata	x		
?Phycodes isp.	x		
Nereites isp. form C	x		
Scolicia strozzii		x	x

by black shale horizons that are devoid of trace fossils and exibit well preserved primary lamination.

The occurrence of *Scolicia* in the Çağlayan Fm (Fig. 14F) deserves special attention, because this is the fourth known pre-Albian occurrence of this ichnogenus. The present occurrence adds to the documention of the early invasion of irregular echinoids into the deep sea, which commenced in Tithonian time (Tchoumatchnco & Uchman, 2001). Furthermore, it documents the early adaptation of irregular echinoids to burrowing in organic-rich muddy sediments.

The Yemişliçay Fm contains a typical deep-marine *Nereites* ichnofacies, including pascichnia (e.g., *Nereites* and *Planolites*), chemichnia (e.g., *Chondrites*) and agrichnia (e.g., *Ubinia* and *Paleodictyon*). Pre-depositional (all agrichnia) and post-depositional (most of pascichnia and fodinichnia) assemblages are readily distinguishable here. The low diversity of trace fossils (8 ichnogenera recognized) is intriguing, because coeval "normal" flysch in other basins commonly bears some 20–25 ichnogenera (Uchman, 2004). Further sampling in other outcrops may be needed to solve this puzzling issue, although the outcrop sections studied are of good quality and span a stratigraphic thickness of about 200 m. The reduced diversity may have been due to the high supply of volcaniclastic sediment, which may have been less hospitable to infauna. Volcaniclastic grains are chiefly glass sherds, with sharp edges and smooth surfaces, and may thus be unsuitable for the development of a bacterial film that is crucial to the infaunal food chain. Furthermore, the impact of active volcanism on the hydrochemical conditions within the basin may have played a significant role, with poisonous substances being released by volcanic eruptions and their products. An increased concentration of such substances in the near-bottom and pore waters could have been lethal to infauna.

The Gürsökü Fm contains the deep-water *Nereites* ichnofacies, which is only preliminarily recognized. The overlying calcareous Akveren Fm contains a moderately diverse trace-fossil assemblage typical of *Nereites* ichnofacies, except for the uppermost 50 m of the formation, where the appearance of tempestites heralded the first major episode of basin shallowing. The *Nereites* ichnofacies in this formation is represented by pascichnia (e.g., *Planolites*, *Halopoa*, *Scolicia*, *Nereites*), fodinichnia (*Zoophycos*, *Phycosiphon*, *Lophoctenium*), chemichnia (*Chondrites*) and ag-

Table 4

Trace fossils recognized in the Kusuri Fm (locality numbers as in Table 1 and Fig. 2)

Ichnotaxa/localities	12	13	14	15	16	17	18	19	20	21
Alcyonidiopsis isp.									x	
Chondrites intricatus	x	x		x		x	x		x	x
Chondrites targionii	x									
Halopoa isp.				x		x				
Planolites isp.	x	x		x		x				
Ophiomorpha rudis		x	x		x	x	x	x		x
Ophiomorpha annulata	x	x	x	x	x	x	x	x	x	x
Thalassinoides suevicus		x								
Phycosiphon incertum									x	
Phymatoderma isp.						x				
Zoophycos isp.									x	
Lorenzinia ?*apenninica*							x			
Lorenzinia isp.							x			
cf. *Cosmorhaphe* isp.	x									
Gordia isp.		x	x			x	x			
?*Gordia* isp.						x	x			
Helminthopsis isp.				x						
Helminthorhaphe flexuosa						x		x		
Helminthorhaphe japonica								x		
Nereites irregularis								x	x	
Scolicia vertebralis				x			x			
Scolicia prisca		x		x			x			
Scolicia strozzii	x	x	x		x	x	x	x		
Spirorhaphe involuta		x	x	x		x	x			
?*Acanthorhaphe* isp.						x				
Belocosmorhaphe aculeata		x								
Belorhaphe zickzack							x			
Desmograpton dertonensis		x		x						
Helicolithus sampelayoi		x	x	x			x	x		
Helicolithus ramosus										
Protopaleodictyon incompositum							x			
Megagrapton submontanum		x	x	x		x	x	x		x
Megagrapton irregulare				x						
Paleodictyon strozzii		x		x		x	x	x		
Paleodictyon cf. *maximum*	x									
Paleodictyon majus		x				x				x
Squamodictyon tectiforme							x			
Zigzag cylinder									x	
Bilobate ridge							x			

richnia (*Cosmorhaphe*, *Paleodictyon*, *Megagrapton*, *Acanthorhaphe*). *Thalassinoides* is quite common, whereas *Ophiomorpha annulata* is relatively rare. The latter two represent open burrows of larger crustaceans. The trace fossils indicate great behavioural diversity related to a sequential colonization of turbiditic substrate, from vagile infauna (the tracemakers of *Phycosiphon* and *Nereites*) to stationary chemichnia (*Chondrites*, *Pilichnus*, *Trichichnus*), and to colonization of the turbidite-capping, "background" hemipelagic mud (graphoglyptids). This common sequence of trace fossils, typical of flysch deposits, reflects the decline in nutrient and oxygen after a turbidity-current event (Wetzel & Uchman, 2001). All beds are biotuturbated, which indicates a generally well oxygenated seafloor.

The trace-fossil assemblages in carbonate flysch deposits are generally less diverse than in their siliciclastic equivalents. This difference may be due to the lower effective weight of the light and porous carbonate grains, which could render the lower parts of turbidites relatively rich in sand fraction and could also reduce the capability of turbidity currents to exert the delicate scouring and casting action that is necessary for the preservation of many burrows (Uchman, 1999).

The tempestitic uppermost part of the Akveren Fm contains *Ophiomorpha annulata*, *Zoophycos*, *Chondrites*, *Planolites* and *Helminthopsis* isp. form B., whereas the associated shoreface calcarenites sporadically show large and small *Ophiomorpha ?nodosa* (locality 6 and coastal outcrop 15 km west of the Istafan Cape, Fig. 2). This trace-fossil assemblage is not typical of any particular ichnofacies. The domichnial deep burrow *Ophiomorpha ?nodosa* is typical of the high-energy nearshore *Skolithos* ichnofacies, as well as the *Cruziana* ichnofacies in the bathymetric range of tempestitic sedimentation (e.g., Pemberton *et al.*, 2001). *Ophiomorpha annulata* is typical of flysch deposits (e.g., Uchman, 2001), whereas *Zoophycos* and *Chondrites* are characteristic of low-energy environments dominated by mud and silt, typically not shallower than the offshore zone. However, *Zoophycos* have also been reported from shoreface deposits of Cretaceous and Miocene age, by Pemberton *et al.* (2001) and Pervesler and Uchman (2004), respectively. The trace-fossil assemblage as a whole does not contain any ichnotaxa typical of the *Cruziana* ichnofacies and, instead, appears to be a mixture of the *Zoophycos* and *Skolithos* ichnofacies. The associated benthic forams confirm a neritic environment, generally no deeper than 200 m and mainly shallower than 100 m (Leren, 2003). Interestingly, the directly underlying turbiditic part of the succession at localities 7 and 8 (Fig. 2) still bears trace fossils typical of the *Nereites* ichnofacies, including agrichnial graphoglyptids, although the associated benthic forams indicate an "outer-shelf-to-slope", deep neritic environment (E. Sirel, pers. commun. 2002). These seemingly odd relationships make for an important case, where the bathymetric upper limit for the *Nereites* ichnofacies in a shallowing-upward succession can be recognized. In the light of the present evidence, this limit would correspond to a sub-neritic water depth apparently no greater than 200–300 m. This particular issue deserves separate consideration and will be discussed in a subsequent paper.

The Atbaşı Fm contains winding and meandering pascichnia (*Scolicia strozzii*, *Nereites*), simple pascichnia (*Planolites*), domichnia (*Ophiomorpha annulata*) and fodinichnia (*?Phycodes*). The winding and meandering pascichnia are typical of the *Nereites* ichnofacies, but no other morphological group typical of this ichnofacies, particularly graphoglyptids, have been found. Therefore, the trace fossil assemblage can be regarded as an impoverished *Nereites* ichnofacies. The red and green colours of the Atbaşı Fm is characteristic of the so-called "deep-sea red beds", and analogous deposits of the same age in the Carpathians are known to show signatures of oligotrophy (Leszczyński & Uchman, 1993). The same factor may have influenced the benthic fauna community of the Atbaşı Fm, as the sediment-starved Sinop-Boyabat Basin (Leren *et al.*, unpubl. data) is likely to have suffered also a shortage of nutrient supply. Furthermore, the predominance of hemipelagic sedimentation and scarcity of turbidity currents may have drastically decreased the preservation potential of trace fossils.

The Kusuri Fm contains a highly diverse trace-fossil assemblage of the *Nereites* ichnofacies, except for the topmost part (localities 19–21, Fig. 2), where tempestites and littoral bioclastic limestone indicate a second episode of major shallowing, which culminated in the tectonic inversion of the basin. The high diversity (27 ichnogenera) and high relative abundance (about 52%) of graphoglyptids is typical of Eocene flysch deposits in many basins, because a worldwide oligotrophy at this time promoted behavioural specialization and the agrichnial tracemakers of graphoglyptids appear to have been very successful (Uchman, 2004).

The trace-fossil assemblage of the Kusuri Fm shows some variation with respect to turbidite facies. The mudstone-rich lowermost part of the formation, containing only thin turbidites (locality 12, Fig. 2 and Table 1), differs from the remaining part by relatively abundant *Chondrites* and rare *Ophiomorpha*. This fact can be attributed to the muddy substrate, which would favour *Chondrites* and disfavour *Ophiomorpha*. The highest diversity of trace fossils is observed in the distal lobe deposits and overbank facies, where graphoglyptids are most common. The corresponding trace-fossil assemblage can be ascribed to the *Paleodictyon* ichnosubfacies of the *Nereites* ichnofacies, which is typical of flysch facies composed of thin to medium turbidite beds (Seilacher, 1974). The thick sandstone turbidites of palaeochannels and proximal lobes show a lower trace-fossil diversity, with *Ophiomorpha annulata* and *Ophiomorpha rudis* as the most common ichnospecies. They commonly penetrated through thick sand beds and formed galleries along the bedding planes or at the top surfaces of underlying beds. *O. annulata* can be seen to have penetrated sand beds up to 120 cm thick, and *O. rudis* probably even thicker beds. *Scolicia strozzii* is also relatively abundant here, but other trace fossils are rare. This trace-fossil assemblage is typical of the *Ophiomorpha rudis* subichnofacies, which is characteristic of similar turbiditic facies in flysch successions of Cretaceous, Palaeogene and Neogene age (Uchman, 2001).

Ophiomorpha rudis indicates acitivity of crustaceans, which apparently penetrated the sandy substrate in search for deeply buried plant detritus. Plant material is an important nutrient, with the cellulose broken down by microbial maturation in anoxic burial zone. The siliciclastic turbiditic system of the Kusuri Fm was fed by a large fluvio-deltaic system (Janbu *et al.*, unpubl. data), which supplied also abundant plant detritus to the basin. This depositional setting contrasts with that of the Akveren Fm, where the turbidity currents were derived by storms from an extensive carbonate ramp and carried little or no plant detritus. The difference in sediment source and feeder system is reflected by the scarcity of *Ophiomorpha* in the Akveren Fm.

The uppermost part of the Kusuri Fm, overlain by a littoral limestone unit, consists of predominantly calcareous turbidites that, up-section, gradually give way to tempestites. The tempestite-bearing part of the succession, about 50 m thick (locality 20, Fig. 2 and Table 1), shows *Ophiomorpha annulata*, *Chondrites intricatus* and *Zoophycos* isp., which commonly penetrated sand beds 20–100 cm thick. No trace fossils typical of the *Cruziana* ichnofacies have been found in these deposits, although the tempestites and associated benthic forms indicate neritic water depths (E. Sirel, pers. commun. 2002). The shallowest known occurrence of *Zoophycos* is its sporadic presence in middle shoreface deposits (Pemberton *et al.*, 2001; Pervesler & Uchman, 2004), but *Ophiomorpha annulata* is typical of flysch deposits.

The underlying turbiditic deposits at locality 21 (Fig. 2 and Table 1), stratigraphically no more than 30 m below the tempestitic deposits contain *Nereites irregularis*, *Alcyonidiopsis* isp., *Chondrites intricatus*, *Ch. targionii*, *Phycosiphon incertum* and the enigmatic, cylindrical zigzag trace fossil. *Chondrites* and *Phycosiphon* are common in fine-grained deep-marine and neritic offshore deposits, but *N. irregularis* is typical of flysch and, to the best of our knowledge, has never been reported from shelf-type neritic facies. In the context of the sedimentary facies succession, this trace-fossil assemblage could be ascribed to the *Nereites* ichnosubfacies of the *Nereites* ichnofacies, which is typical of shaley "distal" flysch in many basins (Seilacher, 1974).

The turbiditic deposits in the abandoned quarry at locality 19 (Fig. 2 and Table 1), stratigraphically about 40 m below the tempestite-bearing topmost succession, contain *Ophiomorpha rudis*, *O. annulata*, *Scolicia strozzii*, *Nereites irregularis, Helminthorhaphe flexuosa, H. japonica, Helicolithus sampelayoi, Megagrapton submontanum* and *Paleodictyon strozzii*. High contribution of graphoglyptids, represented by the last 5 ichnotaxa, points to a typical *Nereites* ichnofacies (*Paleodictyon* ichnosubfacies).

Taken together, the evidence from both the Akveren Fm and the Kusuri Fm indicates that the *Nereites* ichnofacies may not be limited to great bathyal depths, but can occur also in subneritic environments, possibly no deeper than 200–300 m, when forced into such an environment by rapid shallowing of the basin. A similar case may be the occurrence of *Nereites* ichnofacies in tempestite-bearing, deep intra-shelfal troughs reported from the Late Cretaceous shelf of Tanzania (Gierlowski-Kordesch & Ernst, 1987; Ernst & Zander, 1993). However, it is an open question as to whether these cases should be regarded as some odd exceptions or an indication of a wider rule.

Another intriguing fact is the lack trace fossils typical of the *Cruziana* ichnofacies in the tempestitic, uppermost neritic part of both the Akveren Fm and the Kusuri Fm, which contrasts with the ichnological evidence reported, for example, from the Cretaceous of the North American Seaway (Pemberton *et al.*, 2001). Perhaps, a clue to this puzzle is the presence or absence of well-established shelf habitats next to the deep-water basin. The intracratonic North American Seaway was characterized by wide and stable shelf zones, with only far-away connections to deep oceanic basins. In the active-margin tectonic setting of the Sinop-Boyabat Basin, the shelf zone was narrow, unstable and periodically non-existant, whereas the deep-water basin itself was directly connected to the Tethys Ocean. It is possible that the tracemakers at the transition from turbiditic to tempestitic sedimentation in the uppermost parts of the Akveren and Kusuri formations were the deep-water survivors captured in a rapidly shallowing, "remnant" marine basin. Some of these benthic animals apparently persisted in the emerging neritic environment, where the intermittent incursions of sand from storm-generated geostrophic currents resembled closely turbiditic sedimentation. No expansion of *Cruziana* and *Skolithos* ichnofacies occurred, because there was no pre-existing, well-established population of these tracemakers. Only the topmost shoreface sandstones in the Akveren Fm show sparse evidence of *Ophiomorpha ?nodosa*, a typical shallow-marine trace fossil.

CONCLUSIONS

1. The Çağlayan Fm (Barremian–Cenomanian) contains low-diverse trace fossils produced by mobile deposit-feeders (*Scolicia*, *Phycosiphon*, *Planolites*) in a muddy, poorly oxygenated deep-water environment influenced by anoxic episodes.

2. *Scolicia* in the Çağlayan Fm is the fourth known pre-Albian occurrence of this ichnogenus, adding to the evidence of an early encroachment of irregular echinoids into deep-sea environment and documenting their early adaptation to burrowing in organic-rich muddy deposits.

3. The Yemişliçay Fm (late Coniacian–early Campanian) contains a low-diverse *Nereites* ichnofacies. The low diversity in a "normal" flysch is thaught to be related to strong volcanism, which yielded sediment unsuitable for bacterial coating and poisened the seafloor environment.

4. The Akveren Fm (late Maastrichtian–Late Palaeocene) contains a moderately diverse *Nereites* ichnofacies, except for the uppermost part of this calcareous flysch succession, where tempestites and littoral bioclastic limestones mark major shallowing of the basin and where an odd mixture of *Zoophycos* and *Skolithos* ichnofacies occurs, instead of a neritic *Cruziana* ichnofacies.

5. The Atbaşı Fm (latest Palaeocene–earliest Eocene) records a dramatic rise of relative sea level and contains an impoverished *Nereites* ichnofacies, which is attributed to oligotrophy and reduced preservation potential in a sand-starved environment.

6. The Kusuri Fm (Early–Middle Eocene) bears a high-diverse *Nereites* ichnofacies, which persists almost to

the top of this siliciclastic flysch succession, where tempestites and bioclastic littoral limestones indicate another major shallowing of the basin.

7. The turbiditic palaeochannels and proximal lobe facies of the Kusuri Fm show lower trace-fossil diversity, but abundant *Ophiomorpha rudis, O. annulata* and common *Scolicia strozzii*. This assemblage is typical of the *Ophiomorpha rudis* subichnofacies of the *Nereites* ichnofacies, which characterizes similar flysch deposits in the Cretaceous to Neogene basins.

8. The abundance of *Ophiomorpha* in the Kusuri Fm and its scarcity in the Akveren Fm is attributed to the difference in sediment source (siliciclastic *versus* carbonate) and availability of plant detritus. The source of the Kusuri turbiditic system was a large fluvial delta, which provided also abundant plant detritus, whereas the Akveren system originated from an extensive carbonate platform, poor in plant material.

9. The trace-fossil evidence from the shallowing-upward Akveren and Kusuri formations indicates that the upper bathymetric limit for the occurrence of the *Nereites* ichnofacies may be a subneritic environment no deeper than 200–300 m. The shallow occurrence of the *Nereites* ichnofacies and the lack of typical *Cruziana* ichnofacies in the overlying neritic deposits may reflect the survival of deep-water ichnofauna in a rapidly shallowing basin that lacked well-developed shelfal habitats.

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REFERENCES

Aktaş, G. & Robertson, A. H. F., 1990. Tectonic evolution of the Tethys suture zone in SE Turkey: evidence from the petrology and geochemistry of Late Cretaceous and Middle Eocene extrusives. In: Malpas, J., Moores, E. M., Panayiotou, A. & Xenophontos, C. (eds), *Ophiolites – Oceanic Crustal Analogues. Proceeding of the International Symposium Troodos 1987.* Cyprus Geological Survey, Nicosia, pp. 311–328.

Akýncý, Ö., 1984. The Eastern Pontide volcano-sedimentary belt and associated massive sulphide deposits. In: Dixon, J. E. & Robertson, A. H. F. (eds), The geological evolution of the Eastern Mediterranean. *The Geological Society of London, Special Publication*, 17: 415–428.

Andrew, T. & Robertson, A. H. F., 2002. The Beytehir-Hoyran-Hadým nappes: genesis and emplacement of Mesozoic marginal and oceanic units of the northern Neotethys in southern Turkey. *Journal of the Geological Society of London*, 159: 529–543.

Aydın, M., Demir, O., Özçelik, Y., Terzioğlu, N. & Satýr, M., 1995a. A geological revision of Inebolu, Devrekani, Ağlý and Küre areas: new observations on Paleotethys-Neotethys sedimentary successions. In: Erler, A., Tuncay, E., Bingöl, E. & Örçen, S. (eds), *Geology of the Black Sea Region.* General Directorate of Mineral Research and Exploration (MTA), Ankara, pp. 33–38.

Aydın, M., Demir, O., Serdar, H. S., Özaydin, S. & Harput, B., 1995b. Tectono-sedimentary evolution and hydrocarbon potential of the Sinop-Boyabat Basin, North Türkiye. In: Erler, A., Tuncay, E., Bingöl, E. & Örçen, S. (eds), *Geology of the Black Sea Region.* General Directorate of Mineral Research and Exploration (MTA), Ankara, pp. 254–263.

Aydın, M., Tahintürk, Ö., Serdar, H. S., Özçelik, Y., Akarsu, I., Üngör, A., Çokuğraş, R. & Kasar, S., 1986. Geology of the region between Ballıdağ-Çangaldağı (Kastamonu). (In Turkish, English abstract) *Türkiye Jeoloji Kurumu Bülteni*, 29, 1–16.

Azpeitia Moros, F., 1933. Datos para el estudio paleontólogico del Flysch de la Costa Cantábrica y de algunos otros puntos de España. *Boletín del Instituto Geologico y Minero de España*, 53: 1–65.

Barka, A., Sütçü, Y.F., Gedik, A., Tekin, T.F., Arel, E., Özdemir, M. & Erkal, T., 1985. *Final Report on the Geological Investigation for the Sinop Nuclear Power Plant.* Report No. 7963, General Directorate of Mineral Research and Exploration (MTA), Ankara. [No pagination].

Bottjer, D. J., Droser, M. L. & Jablonski, D., 1988. Palaeoenvironmental trends in the history of trace fossils. *Nature*, 333: 252–255.

Bromley, R. G., 1996. *Trace Fossils. Biology, Taphonomy and Applications.* 2nd Edition, Chapman and Hall, London, 361 pp.

Bromley, R. G. & Hanken, N.-M., 2003. Structure and function of large, lobed *Zoophycos*, Pliocene of Rhodes, Greece. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 192: 79–100.

Brongniart, A. T., 1823. Observations sur les Fucoids. *Société d'Historie Naturelle de Paris, Mémoire*, 1: 301–320.

Brongniart, A. T., 1828. *Histoire des végétaux fossiles ou recherches botaniques et géologiques sur les végétaux renfermés dans les diverses couches du globe, volume 1.* G. Dufour & E. d'Ocagne, Paris, 136 pp.

Brongniart, A. T., 1849. Tableau des generes de végétaux fossiles considérés sous le point de vue de leur classification botanique et de leur distribution géologique. *Dictionnaire Universel Histoire Naturelle* (Paris), 13: 1–27, 152–176.

Chamberlain, C. K., 1977. Ordovician and Devonian trace fossils from Nevada. *Nevada Bureau of Mines and Geology, Bulletin*, 90: 1–24.

Cloetingh, S., Spadini, G., Van Wees, J. D. & Beekman, F., 2003. Thermo-mechanical modelling of Black Sea Basin (de)formation. *Sedimentary Geology*, 156: 169–184.

Collins, A. C. & Robertson, A. H. F., 1998. Processes of Late Cretaceous to Late Miocene episodic thrust sheet translation in the Lycian Taurides, SW Turkey. *Journal of the Geological Society of London*, 155: 759–772.

Collins, A. C. & Robertson, A. H. F., 2000. Evolution of the Lycian allochthon, western Turkey, as a north-facing late Palaeozoic to Mesozoic rift and passive continental margin. *Geological Journal*, 34: 107–138.

Crimes, P. T. & Fedonkin, M. A., 1994. Evolution and dispersal of deepsea traces. *Palaios*, 9: 74–83.

DeCelles, P. G. & Giles, K. A., 1996. Foreland basin systems. *Basin Research*, 8: 105–123.

Dilek, Y. & Moores, E. M., 1990. Regional tectonics of the eastern Mediterranean ophiolites. In: Malpas, J., Moores, E. M., Panayiotou, A. & Xenophontos, C. (eds), *Ophiolites – Oceanic*

Crustal Analogues. Proceeding of the International Symposium Troodos 1987. Cyprus Geological Survey, Nicosia, pp. 295–309.

Dilek, Y. & Rowland, J. C., 1993. Evolution of a conjugate passive margin pair in Mesozoic southern Turkey. *Tectonics*, 12: 954–970.

Dżułyński, S. & Walton, E. K., 1965. *Sedimentary Features of Flysch and Greywackes. Developments in Sedimentology*, 7, 274 pp. Elsevier, Amsterdam.

Eğin, D., Hirst, D. M. & Phillips, R., 1979. The petrology and geochemistry of volcanic rocks from the northern Hartit River area, Pontide volcanic province, northeastern Turkey. *Journal of Volcanology and Geothermal Research*, 6: 105–123.

Ehrenberg, K., 1944. Ergänzende Bemerkungen zu den seinerzeit aus dem Miozäan von Burgschleinitz beschrieben Gangkernen und Bauten dekapoder Krebse. *Paläontologische Zeitschrift*, 23: 354–359.

Eichwald, E., 1860–1868. *Lethaea Rossica ou paléontologie de la Russie. Décrite et Figurée, Volume 1* (1860), *Atlas* (1868). E. Schweizerbart, Stuttgart, 1657 pp.

Ekdale, A. A., 1992. Mudraking and mudslinging: the joys of deposit-feeding. In: Maples, C. G. & West, R. R. (eds), *Trace Fossils*. Short Course in Paleontology, 5. The Paleontological Society, Cincinnati, pp.145–171.

Ekdale, A. A. & Lewis, D. W., 1991. The New Zealand *Zoophycos* revisited. *Ichnos*, 1: 183–194.

Emmons, E., 1844. *The Taconic System Based on Observations in New York, Massachusetts, Maine, Vermont, and Rhode Island.* Caroll and Cook, Albany, 63 pp.

Ernst, G. & Zander, J., 1993. Stratigraphy, facies development, and trace fossils of the Upper Cretaceous of Southern Tanzania (Kilwa District). In: Abbate, E., Sagri, M. & Sassi, F. P. (eds), *Geology and Mineral Resources of Somalia and Surrounding Regions*. Istituto Agronomico per l'Oltremare, Florence, pp. 259–278.

Fillion, D. & Pickerill, R. K., 1990. Ichnology of the Upper Cambrian? to Lower Ordovician Bell Island and Wabana groups of eastern Newfoundland, Canada. *Palaeontographica Canadiana*, 7: 1–119.

Fischer-Ooster, C., 1858. *Die fossilen Fucoiden der Schweizer Alpen, nebst Erörterungen über deren geologisches Alter*. Huber, Bern, 72 pp.

Frey, R. W., 1970. Trace fossils of Fort Hays Limestone Member of Niobrara Chalk (Upper Cretaceous), West-Central Kansas. *The University of Kansas Paleontological Contributions*, 53: 1–41.

Frey, R. W., Curran, A. H. & Pemberton, G. S., 1984. Tracemaking activities of crabs and their environmental significance: the ichnogenus *Psilonichnus*. *Journal of Paleontology*, 58: 511–528.

Frey, R. W., Howard, J. D. & Pryor, W. A., 1978. *Ophiomorpha*: its morphologic, taxonomic, and environmental significance. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 23: 199–223.

Fu, S., 1991. Funktion, Verhalten und Einteilung fucoider und lophoctenoider Lebensspuren. *Courier Forschungs. Institut Senckenberg*, 135: 1–79.

Fuchs, T., 1895. Studien über Fucoiden und Hieroglyphen. *Denkschriften der kaiserlichen Akademie der Wissenschaften in Wien, mathematisch-naturwissenschaftliche Klasse*, 62: 369–448.

Gabelli, L. De, 1900. Sopra un' interesssante impronta medusoidae. *Il Pensiero Aristotelico della Scienza Moderna*, 1(2): 74–78.

Gedik, A., Ercan, T. & Korkmaz, S., 1984. Orta Karadeniz (Samsun-Sinop) havzasının jeolojisi ve volkanik kayaçlarin petrolojisi. (In Turkish). *Bulletin of the Institute of Mineral Research and Exploration of Turkey*, 99/100: 33–50.

Gedik, A. & Korkmaz, S., 1984. Geology of the Sinop basin and petroleum possibilities. (In Turkish, English abstract). *Jeoloji Mühendisliği*, 19: 53–79.

Gierlowski-Kordesh, E. & Ernst, G., 1987. A flysch trace fossil assemblage from the Upper Cretaceous shelf of Tanzania. In: Mathesis, G. & Schandelmeier, H. (eds), *Current Research in African Earth Sciences*. Balkema, Rotterdam, pp. 217–221.

Göncüoğlu, M. C., Turhan, N., Şentürk, K., Özcan, A., Uysal, Ş. & Yalınız, M. K., 2000. A geotraverse across northwestern Turkey: tectonic units of the Central Sakarya region and their tectonic evolution. In: Bozkurt, E., Winchester, J. A. & Piper, J. D. A. (eds), Tectonics and Magmatism in Turkey and the Surrounding Areas. *The Geological Society of London, Special Publication*, 173: 139–161.

Görür, N., 1988. Timing of opening of the Black Sea basin. *Tectonophysics*. 147: 247–262.

Görür, N., Çağatay, N., Sakýnç, M., Akkök, R., Tchapalyga, A. & Natalin, B., 2000. Neogene Paratethyan succession in Turkey and its implications for the palaeogeography of the Eastern Paratethys. In: Bozkurt, E., Winchester, J. A. & Piper, J. D. A. (eds), Tectonics and magmatism in Turkey and the surrounding areas. *The Geological Society of London, Special Publication*, 173: 251–269.

Görür, N., Oktay, F. Y., Seymen, I. & Şengör, A. M. C., 1984. Palaeotectonic evolution of the Tuszölü basin complex, Central Turkey: sedimentary record of a Neotethyan closure. In: Dixon, J. E. & Robertson, A. H. F. (eds), The Geological Evolution of the Eastern Mediterranean. *The Geological Society of London, Special Publication*, 17: 467–482.

Görür, N. & Tüysüz, O., 1997. Petroleum geology of the southern continental margin of the Black Sea. In: Robinson, A. G. (ed.), Regional and petroleum geology of the Black Sea and surrounding regions. *American Association of Petroleum Geology, Memoir*, 68: 241–254.

Görür, N. & Tüysüz, O., 2001. Cretaceous to Miocene palaeogeographic evolution of Turkey: implications for hydrocarbon potential. *Journal of Petroleum Geology*, 24: 119–146.

Grossgeim, V. A. 1961. Niekatoriye noviye gieroglifi iz nizhniemielovikh otl'ozeniy severo-zapodnokho Kavkaza. (In Russian). *Trudy Krasnodarskoho Filal'a Vsesoyuznoho Neftegazovoho Nauchno-Issedovatielskoho Instituta*, 6: 202–206.

Gürer, Ö. F. & Aldanmaz, E. 2002. Origin of the Upper Cretaceous–Tertiary sedimentary basins within the Tauride-Anatolide platform in Turkey. *Geological Magazine*, 139: 191–197.

Hall, J., 1852. *Paleontology of New York. Volume 2*. C. Van Benthuysen, Albany, 362 pp.

Haq, B. U., Hardenbol, J. & Vail, P. R., 1988. Mesozoic and Cenozoic chronostratigraphy and eustatic cycles. In: Wilgus, C. K., Hastings, B. S., Posamentier, H. W., Van Wagoner, J. C., Ross, C. A. & Kendall, C.G. S.C. (eds), Sea-level changes – an integrated approach. *Society of Economic Paleontologists and Mineralogists, Special Publication*, 42: 71–108.

Hayward, A. B., 1984. Sedimentation and basin formation related to ophiolite nappe emplacement, Miocene, SW Turkey. *Sedimentary Geology*, 40: 105–129.

Heer, O., 1877. *Flora Fossilis Helvetiae. Vorweltliche Flora der Schweiz*. J. Wurster & Co., Zürich, 182 pp.

Janbu, N. E., Leren, B. L. S., Kırman, E. & Nemec, W., 2003. The Late Cretaceous–Eocene turbiditic sedimentation in the Sinop Basin, north-central Turkey: response to tectonic changes in basin morphology. In: *Abstracts AAPG-SEPM Annual Con-*

vention, Part A. American Association of Petroleum Geologists, Salt Lake City, p. 84.

Jensen, S. & Mens, K., 1999. A Lower Cambrian shallow-water occurrence of the branched 'deep-water' type trace fossil *Dendrorhaphe* from the Lontova Formation, eastern Latvia. *Paläontologisches Zeitschrift*, 73: 187–193.

Kaymakcı, N., Duermeijer, C. E., Langereis, C., White, S. H. & Van Dijk, P. M., 2003. Palaeomagnetic evolution of the Çankırı Basin (central Anatolia, Turkey): implications for oroclinal bending due to indentation. *Geological Magazine*, 140: 343–355.

Keighley, D. G. & Pickerill, R. K., 1995. The ichnotaxa *Palaeophycus* and *Planolites*: historical perspectives and recommendations. *Ichnos* 3: 301–309.

Ketin, I. & Gümüt, Ö., 1963. Sinop-Ayancık arasindaki, III. Bölgeye dahil sahalarýn jeolojisi hakkında rapor; 2. Kısım, Jura ve Kretase formasyonlarýnýn etüdü. *Turkish Petroleum Company Report*, 288: 1–118.

Kotake, N. 1989. Paleoecology of the *Zoophycos* producers. *Lethaia*, 22: 327–341

Kotake, N., 1991a. Non-selective surface deposit feeding by the *Zoophycos* producers. *Lethaia*, 24: 379–385.

Kotake, N., 1991b. Packing process for filling material in *Chondrites*. *Ichnos*, 1: 277–285.

Kotake, N., 1992. Deep-sea echiurans: possible producers of *Zoophycos*. *Lethaia*, 25: 311–316.

Książkiewicz, M., 1968. On some problematic organic traces from the Flysch of the Polish Carpathians. Part 3. (In Polish, English summary). *Rocznik Polskiego Towarzystwa Geologicznego*, 38: 3–17.

Książkiewicz, M., 1970. Observations on the ichnofauna of the Polish Carpathians. In: Crimes, T. P. & Harper, C. (eds), *Trace Fossils. Geological Journal, Special Issue*, 3: 283–322.

Książkiewicz, M., 1977. Trace fossils in the Flysch of the Polish Carpathians. *Palaeontologia Polonica*, 36: 1–208.

Lees, A. & Buller, A. T., 1972. Modern temperate-water and warm-water shelf carbonate sediments contrasted. *Marine Geology*, 13: 67–73.

Leren, B. L. S., 2003. *Late Cretaceous to Early Eocene Sedimentation in the Sinop-Boyabat Basin, North-Central Turkey: Facies Analysis of Turbiditic to Shallow-Marine Deposits*. Unpubl. Candidatum Scientiarum Thesis, University of Bergen, 140 pp.

Leszczyński, S. & Uchman, A., 1993. Biogenic structures of organic-poor sediments: examples from the Paleogene variegated shales, Polish Outer Carpathians. *Ichnos*, 2: 267–275.

Lorenz von Liburnau, J. R., 1902. Ergänzung zur Beschriebung der fossilen *Halimeda fuggeri*. *Sitzungsberichte der kaiserlich-königlichen Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Klasse*, 111: 685–712.

Löwemark, L. & Schäfer, P., 2003. Ethological implications from a detailed X-ray radiograph and ^{14}C study of the modern deep-sea *Zoophycos*. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 192: 101–121.

Lundgren, B., 1891. Studier öfver fossilförande lösa block (In Swedish). *Geologiska Föreningen i Stockholm Förhandlinger*, 13: 111–121.

MacLeay, W. S., 1839. Note on the Annelida. In: Murchison, R. I. (ed.), *The Silurian System. Part II: Organic Remains*. Murray, London, pp. 699–701.

Mángano, G. M., Buatois, L., West, R. R. & Maples, C. G., 2002. Ichnology of a Pennsylvanian equatorial tidal flat – the Stull Shale Member at Waverly, eastern Kansas. *Kansas Geological Survey, Bulletin*, 245: 1–133.

Massalongo, A., 1855. *Zoophycos. Novum Genus Plantorum Fossilium*. Antonelli, Verona, 52 pp.

Massalongo, A., 1856. *Studi Paleontologici*. Antonelli, Verona, 53 pp.

McCann, T., 1990. Distribution of Ordovician–Silurian ichnofossil assemblages in Wales – implications for Phanerozoic ichnofaunas. *Lethaia*, 23: 243–255.

McCoy, F., 1850. On some genera and species of Silurian Radiata in the collection of the University of Cambridge. *Annals and Magazine of Natural History, Series 2*, 6: 270–290.

Michard, A., Whitechurch, H., Ricou, L. E., Montigny, R. & Yazgan, E., 1984. Tauric subduction (Malatya-Elazığ provinces) and its bearing on tectonics of the Tethyan realm in Turkey. In: Dixon, J. E. & Robertson, A. H. F. (eds), The Geological Evolution of the Eastern Mediterranean. *The Geologica Society of London, Special Publication*, 17: 361–373.

Meredith, D. J. & Egan, S. S., 2002. The geological and geodynamic evolution of the eastern Black Sea basin: insights from 2-D and 3-D tectonic modelling. *Tectonophysics*, 350: 157–179.

Nicholson, H. A., 1873. Contributions to the study of the errant annelids of the older Palaeozoic rock. *Proceedings of the Royal Society of London*, 21: 288–290. [Published also in *Geologial Magazine*, 10: 309–310.]

Nikishin, A. M., Korotaev, M. V., Ershov, A. V. & Brunet, M.-F., 2003. The Black Sea basin: tectonic history and Neogene–Quaternary rapid subsidence modelling. *Sedimentary Geology*, 156: 149–168.

Okay, A. I., 1989. Tectonic units and sutures in the Pontides, northern Turkey. In: Şengör, A. M. C. (ed.), *Tectonic Evolution of the Tethyan Region*. Kluver, Dordrecht, pp. 109–115.

Okay, A. I . & Şahintürk, Ö., 1997. Geology of the Eastern Pontides. In: Robinson, A. G. (ed.), Regional and Petroleum Geology of the Black Sea and Surrounding Regions. *American Association of Petroleum Geologists, Memoir*, 68: 29–311.

Okay, A. I., Şengör, A. M. I. & Görür, N., 1994. Kinematic history of the opening of the Black Sea and its effect on the surrounding regions. *Geology*, 22: 267–270.

Okay, A. I., Tansel, İ. & Tüysüz, O., 2001. Obduction, subduction and collision as reflected in the Upper Cretaceous–Lower Eocene sedimentary record of western Turkey. *Geological Magazine*, 138: 117–142.

Okay, A. I. & Tüysüz, O., 1999. Tethyan sutures of northern Turkey. In: Durand, B., Jolivet, L., Horvàth, F. & Séranne, M. (eds), The Mediterranean Basins: Tertiary Extension within the Alpine Orogen. *The Geological Society of London, Special Publication*, 156: 475–515.

Olivero, D., 2003. Early Jurassic to Late Cretaceous evolution of *Zoophycos* in French Subalpine Basin (southeast France). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 192: 59–78.

Osgood, R. G., 1970. Trace fossils of the Cincinnati area. *Palaeontographica Americana*, 6: 193–235.

Peccerillo, A. & Taylor, S. R., 1975. Geochemistry of Upper Cretaceous volcanic rocks from the Pontide chain, northern Turkey. *Bulletin of Volcanology*, 39: 1–13.

Pemberton, G. S. & Frey, R. W., 1982. Trace fossil nomenclature and the *Planolites-Palaeophycus* dilemma. *Journal of Paleontology*, 56: 843–881.

Pemberton, S. G., Spila, M., Pulham, A. J., Saunders, T., MacEachern, J. A., Robbins, D. & Sinclair, I. K., 2001. Ichnology and sedimentology of shallow to marginal marine systems: Ben Nevis and Avalon reservoirs, Jeanne D'Arc Basin. *Geological Association of Canada, Short Course Notes*, 15: 1–343.

Peruzzi, D. G., 1880. Osservazioni sui generi *Paleodictyon* e *Pa-*

leomeandron dei terreni cretacei ed eocenici dell'Appennino sett. e centrale. *Atti della Società Toscana di Scenze Naturali Residente in Pisa, Memorie*, 5: 3–8.

Pervesler, P. & Uchman, A., 2004. Ichnofossils from the type area of the Grund Formation (Miocene, Lower Badenian) in northern Lower Austria (Molasse Basin). *Geologica Carpathica*, 55: 103–110.

Pickerill, R. K. & Peel, J. S., 1990. Trace fossils from the Lower Cambrian Bastion Formation of North-East Greenland. *Grønlands Geologiske Undersøgelse, Rapport*, 147: 5–43.

Quatrefages, M. A. de, 1849. Note sur la *Scolicia prisca* (A. de Q.) annélide fossile de la Craie. *Annales des Sciences Naturelles, 3 Série, Zoologie*, 12: 265–266.

Rangin, C., Bader, A. G., Pascal, G., Ecevitoğlu, B. & Görür, N., 2002. Deep structure of the Mid-Black Sea High (offshore Turkey) imaged by multi-channel seismic survey (BLACKSIS cruise). *Marine Geology*, 182: 265–278.

Richter, R., 1850. An der Thüringischen Grauwacke. *Zeitschrift der Deutschen Geologischen Gesellschaft*, 2: 198–206.

Rieth, A., 1932. Neue Funde spongeliomorpher Fucoiden aus dem Jura Schwabens. *Geologische und Paläontologische Abhandlungen, Neue Folge*, 19: 257–294.

Rindsberg, A. K., 1994. Ichnology of the Upper Mississippian Hartselle Sandstone of Alabama, with notes on other Carboniferous formations. *Geological Survey of Alabama, Bulletin*, 158: 1–107.

Rindsberg, A. K. & Martin, A. J., 2003. *Arthrophycus* in the Silurian of Alabama (USA) and the problem of compound trace fossils. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 192: 187–219.

Robinson, A. G., Banks, C. J., Rutherford, M. M. & Hirst, J. P. P., 1995. Stratigraphic and structural development of the Eastern Pontides, Turkey. *Journal of the Geological Society of London*, 152: 861–872.

Robinson, A., Rudat, J. H., Banks, C. J. & Wiles, R. L. F., 1996. Petroleum geology of the Black Sea. *Marine and Petroleum Geology*, 13: 195–223.

Sacco, F., 1886. Impronte organiche dei terreni terziari del Piemonte. *Atti della Reale Accademie delle Scienze di Torino*, 21: 297–348.

Sacco, F., 1888. Note di Paleoicnologia Italiana. *Atti della Società Italiana di Scienze Naturali*, 31: 151–192.

Sanver, M. & Ponat, E., 1981. Kırşehir ve dolaylarina iliskin paleomagnetik bulgular: Kırşehir Masifinin rotasyonu (In Turkish). *Istanbul Yerbilimleri*, 2: 2–8.

Saporta, G., de, 1884. *Les Organismes Problématiques des Anciennes Mers*. Masson, Paris, 102 pp.

Savi, P. & Meneghini, G. G., 1850. Osservazioni stratigrafische e paleontologische concernati la geologia della Toscana e dei paesi limitrofi. Appendix. In: Murchison, R. I., *Memoria sulla struttura geologica delle Alpi, degli Apennini e dei Carpazi*. Stemparia Granucale, Firenze, pp. 246–528.

Schafhäutl, K. E., 1851. *Geognostische Untersuchungen des südbayerischen Alpengebirges*. Literarisch-artistische Anstalt, München, 208 pp.

Schlirf, M., 2000. Upper Jurassic trace fossils from the Boulonnais (northern France). *Geologica et Palaeontologica*, 34: 145–213.

Seilacher, A., 1974. Flysch trace fossils: evolution of behavioural diversity in the deep-sea. *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte*, 1974: 233–245.

Seilacher, A., 1977. Pattern analysis of *Paleodictyon* and related trace fossils. In: Crimes, T. P. & Harper, J. C. (eds), *Trace Fossils 2. Geological Journal, Special Issue*, 9: 289–334.

Seilacher, A., 1978. Evolution of trace fossil communities in the deep sea. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, 157, 251–255.

Seilacher, A., 1990. Aberration in bivalve evolution related to photo- and chemosymbiosis. *Historical Biology*, 3: 289–311.

Seilacher, A. & Seilacher, E., 1994. Bivalvian trace fossils: a lesson from actuopaleontology. *Courier Forschung Institut Senckenberg*, 169: 5–15.

Şengör, A. M. C., 1984. The Cimmeride orogenic system and the tectonics of Eurasia. *The Geological Society of America, Special Paper*, 195: 1–82.

Şengör, A. M. C., 1987. Tectonics of the Tethysides: orogenic collage development in a collisional setting. *Annual Review of Earth and Planetary Sciences*, 15: 213–244.

Stanley, D. C. A. & Pickerill, R. K., 1993. *Fustiglyphus annulatus* from the Ordovician of Ontario, Canada, with a systemathic review of the ichnogenera *Fustiglyphus* Vialov 1971 and *Rhabdoglyphus* Vassoievich 1951. *Ichnos*, 3: 57–67.

Stefani, C. De, 1895. Apercu géologique et description paléontologique de l'Ile de Karpathos. In: Stefani, C. De, Forsyth Major, C. J. &. Barbey, W. (eds), *Karpathos. Etude Géologique, Paléontologique et Botanique*. Bridel, Lousanne, pp. 1–28.

Sternberg, G. K., 1833. *Versuch einer geognostisch-botanischen Darstellung der Flora der Vorvwelt. IV Heft.* C. E. Brenck, Regensburg, 48 pp.

Sunal, G. & Tüysüz, O., 2002. Palaeostress analysis of Tertiary post-collisional structures in the Western Pontides, northern Turkey. *Geological Magazine*, 139: 343–359.

Tanaka, K., 1970. Sedimentation of the Cretaceous flysch sequence in the Ikushumbetsu area, Hokkaido, Japan. *Geological Survey of Japan, Report*, 236: 1–102.

Tchoumatchenco, P. & Uchman, A., 1999. Lower and Middle Jurassic flysch trace fossils from the eastern Stara Planina Mountains, Bulgaria: A contribution to the evolution of Mesozoic ichnodiversity. *Jahrbuch für Geologie und Paläontologie, Abhandlungen*, 213: 169–199.

Tchoumatchenco, P. & Uchman, A., 2001. The oldest deep-sea *Ophiomorpha* and *Scolicia* and associated trace fossils from the Upper Jurassic–Lower Cretaceous deep-water turbidite deposits of SW Bulgaria. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 169: 85–99.

Torell, O. M., 1870. Petrifacta Suecana Formationis Cambricae. *Lunds Universitet Årsskrift*, 6: 1–14.

Tunis, G. & Uchman, A. 1992. Trace fossils in the "Flysch del Grivò" (Lower Tertiary) in the Julian Prealps, NE Italy: Preliminary observations. *Gortania*, 14: 71–104.

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

Tüysüz, O., 1990. Tectonic evolution of a part of the Tethyside orogenic collage: the Kargı Massif, northern Turkey. *Tectonics*, 9: 141–160.

Tüysüz, O., 1993. A geo-traverse from the Black Sea to the central Anatolia: tectonic evolution of northern Neo-Tethys. (In Turkish, English abstract). *Turkish Association of Petroleum Geologists Bulletin*, 5: 1–33.

Tüysüz, O., 1999. Geology of the Cretaceous sedimentary basins of the Western Pontides. *Geological Journal*, 34: 75–93.

Tüysüz, O., Dellaloğlu, A. A. & Terzioğlu, N., 1995. A magmatic belt within the Neo-Tethyan suture zone and its role in the tectonic evolution of northern Turkey. *Tectonophysics*, 243: 173–191.

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.

Uchman, A., 1998. Taxonomy and ethology of flysch trace fossils: A revision of the Marian Książkiewicz collection and studies of complementary material. *Annales Societatis Geologorum Poloniae*, 68: 105–218.

Uchman, A., 1999. Ichnology of the Rhenodanubian Flysch (Lower Cretaceous–Eocene) in Austria and Germany. *Beringeria*, 25: 65–171.

Uchman, A., 2001. Eocene flysch trace fossils from the Hecho Group of the Pyrenees, northern Spain. *Beringeria*, 28: 3–41.

Uchman, A., 2003. Trends in diversity, frequency and complexity of graphoglyptid trace fossils: evolutionary and palaeoenvironmental aspects. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 192: 123–142.

Uchman, A., 2004. Phanerozoic history of deep-sea trace fossils. In: McIlroy, D. (ed.), Application of Ichnology to Palaeoenvironmental and Stratigraphic Analysis. *The Geological Society of London Special Publication*, 228: 125–139.

Uchman, A. & Demírcan, H., 1999. A *Zoophycos* group trace fossil from Miocene flysch in southern Turkey: Evidence for a U-shaped causative burrow. *Ichnos*, 6: 251–259.

Ustaömer, T. & Robertson, A. H. F., 1997. Tectonic-sedimentary evolution of the North Tethyan margin in the Central Pontides of Northern Turkey. In: Robinson, A. G. (ed.), Regional and Petroleum Geology of the Black Sea and Surrounding Regions. *American Assocociation of Petroleum Geologists, Memoir*, 68: 255–290.

Vassoevich, N. B., 1932. Some data allowing us to distinguish the overturned position of flysch sedimentary formations from normal ones. (In Russian, English summary). *Trudy Akademi Nauk SSSR, Geolgicheskiy Institut*, 2: 47–64.

Vialov, O. S., 1971. The rare Mesozoic problematica from Pamir and Caucasus. (In Russian, English summary). *Paleontologicheskiy Sbornik*, 7: 85–93

Vialov, O. S. & Golev, B. T., 1960. K sistematike *Paleodictyon*. (In Russian). *Doklady Akademii Nauk SSSR*, 134: 175–178.

Vialov, O. S. & Golev, B. T., 1965. O drobnom podrazdieleni gruppy Paleodictyonidae. (In Russian). *Byulletin Moskovskovo Obsh- chestva Ispityvania Prirody, Otdiel Gieologii*, 40: 93–114.

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

Wetzel, A. & Uchman, A., 1997. Ichnology of deep-sea fan overbank deposits of the Ganei Slates (Eocene, Switzerland) – a classical flysch trace fossil locality studied first by Oswald Heer. *Ichnos*, 5: 139–162.

Wetzel, A. & Uchman, A., 2001. Sequential colonization of muddy turbidites: examples from Eocene Beloveža Formation, Carpathians, Poland. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 168: 171–186.

Wetzel, A. & Werner, F., 1981. Morphology and ecological significance of *Zoophycos* in deep-sea sediments off NW Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 32: 185–212.

Yılmaz, Y., 1993. New evidence and model on the evolution of the southeast Anatolian orogen. *Bulletin of the Geological Society of America*, 105: 251–271.

Yılmaz, Y., Tüysüz, O., Yiğitbat, E., Genç, T. C. & Tengör, A. M. C., 1997. Geology and tectonic evolution of the Pontides. In: Robinson, A.G. (ed.), Regional and Petroleum Geology of the Black Sea and Surrounding Regions. *American Association of Petroleum Geologists, Memoir*, 68: 183–226.

Yılmaz, Y., Yiğitbat, E. & Genç, Ş. C., 1993. Ophiolitic and metamorphic assemblages of southeast Anatolia and their significance in the geological evolution of the orogenic belt. *Tectonics*, 12: 1280–1297.

Ziegler, P. A., 1990. *Geological Atlas of Western and Central Europe*. 2nd Edition, Shell Internationale Petroleum Maatschappij B.V., The Hague, 239 pp.