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ICHNOLOGY OF UPPER CRETACEOUS–LOWER PALAEOGENE DEEP-SEA DEPOSITS IN THE HAYMANA BASIN OF CENTRAL ANATOLIA

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Abstract: Upper Cretaceous to lower Palaeogene carbonate and siliciclastic deposits that crop out widely in the Haymana and Polatlı districts (Ankara Province) of the Haymana Basin (Central Anatolia) are rich in larger benthic foraminifera, various macrofossils and ichnofossils. The ichnofossils of the Haymana and Yeşilyurt formations were studied at five localities. The Upper Cretaceous siliciclastics of the Haymana Formation contain moderately diverse trace fossils, belonging to the deep-sea *Nereites* ichnofacies. The Paleocene siliciclastic and carbonate deposits of the Yeşilyurt Formation comprise similar trace fossils, which do not show significant changes in comparison to the Haymana Formation. This indicates that the K-Pg boundary extinction event did not affect the ichnofauna with any longer consequences.

The Upper Cretaceous coarser, siliciclastic deposits of the Haymana and Beyobası formations are rich in shallow-marine, larger benthic foraminifera, including species of *Orbitoides, Omphalocyclus, Siderolites, Hellenocyclina,* and *Loftusia*, whereas fine siliciclastic deposits contain abundant planktonic, open-marine foraminifera, such as *Globotruncana* and *Heterohelix*. Palaeogene siliciclastic to carbonate deposits of the Kartal, Yeşilyurt and Çaldağ formations are rich in the larger, benthic foraminifera *Nummulites, Discocyclina, Assilina* and *Alveolina*. The larger foraminifers have been redeposited from nearby, shallow-marine parts of the basin.

Key words: Trace fossils, benthic foraminifera, Campanian, Paleocene, Turkey.

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INTRODUCTION

The study area is in the Haymana Basin, southwest of Ankara (Central Anatolia; Fig. 1). Due to the economic and scientific value of the Haymana Basin, previous studies date back to the early and middle 20th century (e.g., Chaput, 1935). Many studies have been conducted on the petroleum geology (e.g., Demirel and Şahbaz, 1994), sedimentology, stratigraphy, structural geology, and the geologic history of the region (e.g., Ünalan *et al*., 1976; Amirov, 2008; Okay and Altıner, 2016). Taxonomic palaeontology studies date back to the 1960s. In the earliest studies, Dizer (1964, 1968) described a few species of the large foraminifers *Alveolina* and *Nummulites*. Later, many studies on microforaminifera, especially on planktonic foraminifera, the biostratigraphy of Upper Cretaceous deposits and the K-Pg boundary (e.g., Toker, 1975; Vardar, 2018), larger benthic foraminifera of the Cretaceous to Palaeogene deposits (Meriç, 1979, 1984; Özcan and Özkan-Altıner, 1997; Sirel, 1998; Dinçer, 2016), deep-sea benthic foraminifera (Tanık, 2017), ostracods (Duru and Gökçen, 1990), and molluscs (Hoşgör, 2012) were presented. Except for only a few macro trace fossils' data and a study of microboring activity in the larger, benthic foraminifera (Görmüş *et al*., 2019), details on trace fossil have not yet been well documented for the Cretaceous-Palaeogene deposits in the Haymana Basin. The purpose of this paper is to describe and interpret the trace fossils of the Cretaceous–Palaeogene deposits of the Haymana and Yeşilyurt formations and provide some data on the foramanifers in them.

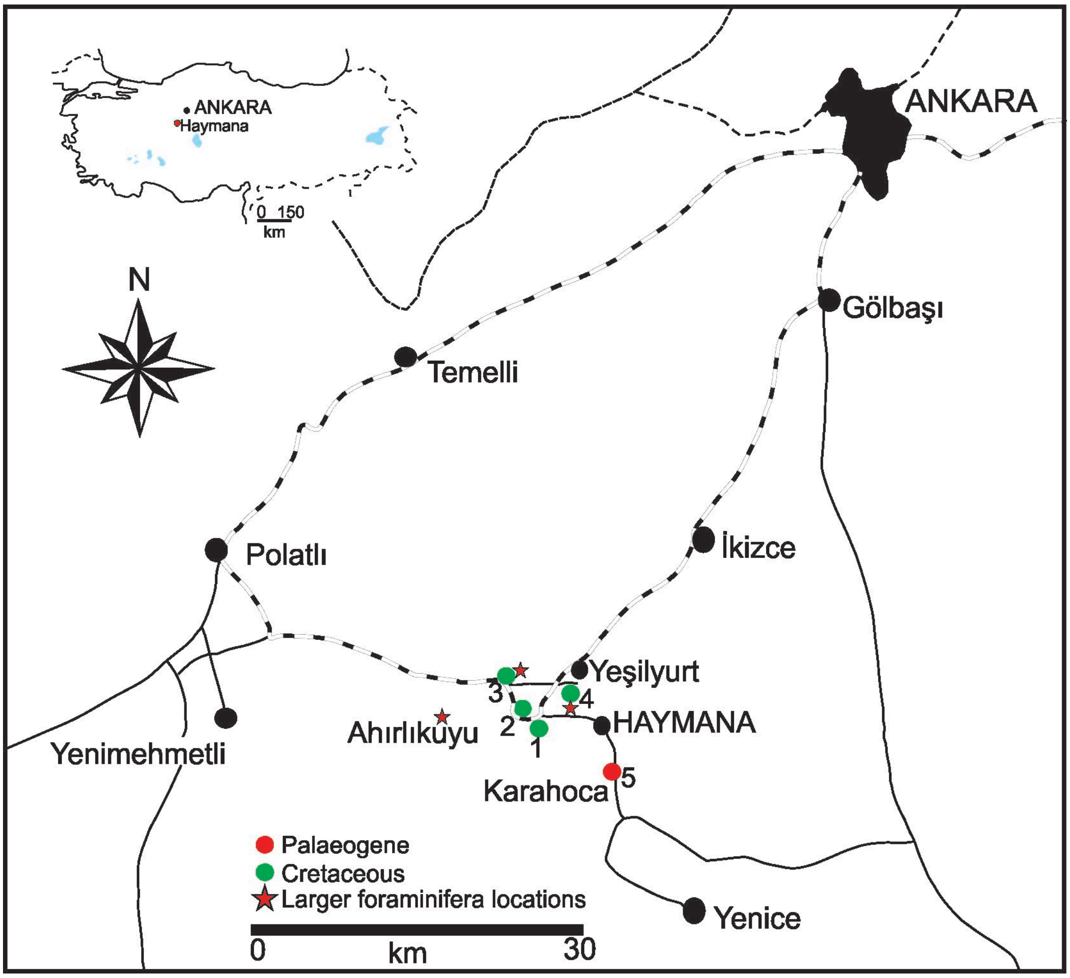

Fig. 1. Location map of the study area.

GEOLOGICAL SETTING

In the Cretaceous–Palaeogene of the Haymana area, the lithostratigraphic units are as follows (from the bottom to the top): the Upper Cretaceous Haymana and Beyobası formations and the Paleocene Kartal, Çaldağ and Yeşilyurt formations (Ünalan *et al*., 1976). The Cretaceous deposits unconformably overlie basement rocks, known as the Dereköy Mélange (Karakaya Complex) and carbonates of the Mollaresul Formation (Ünalan *et al*., 1976; Okay and Altıner, 2016). The Paleocene carbonate deposits of the Çaldağ Formation conformably overlie siliciclastics of the shallow-marine Maastrichtian Beyobası Formation (Sirel, 1998), while the Paleocene rhythmic siliciclastics of the Yeşilyurt Fm cover the Campanian-Maastrichtian fine siliciclastics of the open-marine deposits, belonging to the Haymana Formation (Amirov, 2008; Esmeray, 2008; Esmeray-Senlet *et al*., 2015; Karabeyoğlu, 2017; Tanık, 2017; Vardar, 2018). The total thickness of the Cretaceous and Paleocene units reaches more than 2 km in the region (Okay and Altıner, 2016; Karabeyoğlu, 2017). Deposits of the Maastrichtian Haymana and Beyobası formations and various deposits of the Paleocene Kartal, Çaldağ and Yeşilyurt formations display lateral and vertical facies changes (Ünalan *et al*., 1976). In this study, trace fossil of the Haymana and Yeşilyurt formations are presented, whereas the data on larger benthic foraminifera refer to the Haymana, Beyobası and Çaldağ formations (Figs 2, 3).

MATERIAL AND METHODS

Observations were made at five measured sections, containing Cretaceous to Palaeogene deposits. Sampling for foraminifers was based on changes in the lithology. The identification of trace fossils was made in the field from bedding surfaces, or on parting surfaces and in vertical sections, and from photographs and sketches. Foraminifers from the Haymana Formation were mainly microscopically identified; more than fifty thin sections were prepared at the Ankara University Geological Engineering Department. Single thin sections of *Loftusia* and *Orbitoides* from the weathered sediments (Haymana Fm) in the Ahırlıkuyu area (Fig. 2) and locality 3 were prepared.

THE STUDIED SECTIONS AND THEIR ICHNOLOGICAL FEATURES

Five sections were studied in the area between Haymana (localities 1–4) and Yeşilyurt villages (locality 5), in the Haymana Basin (Figs 1, 2).

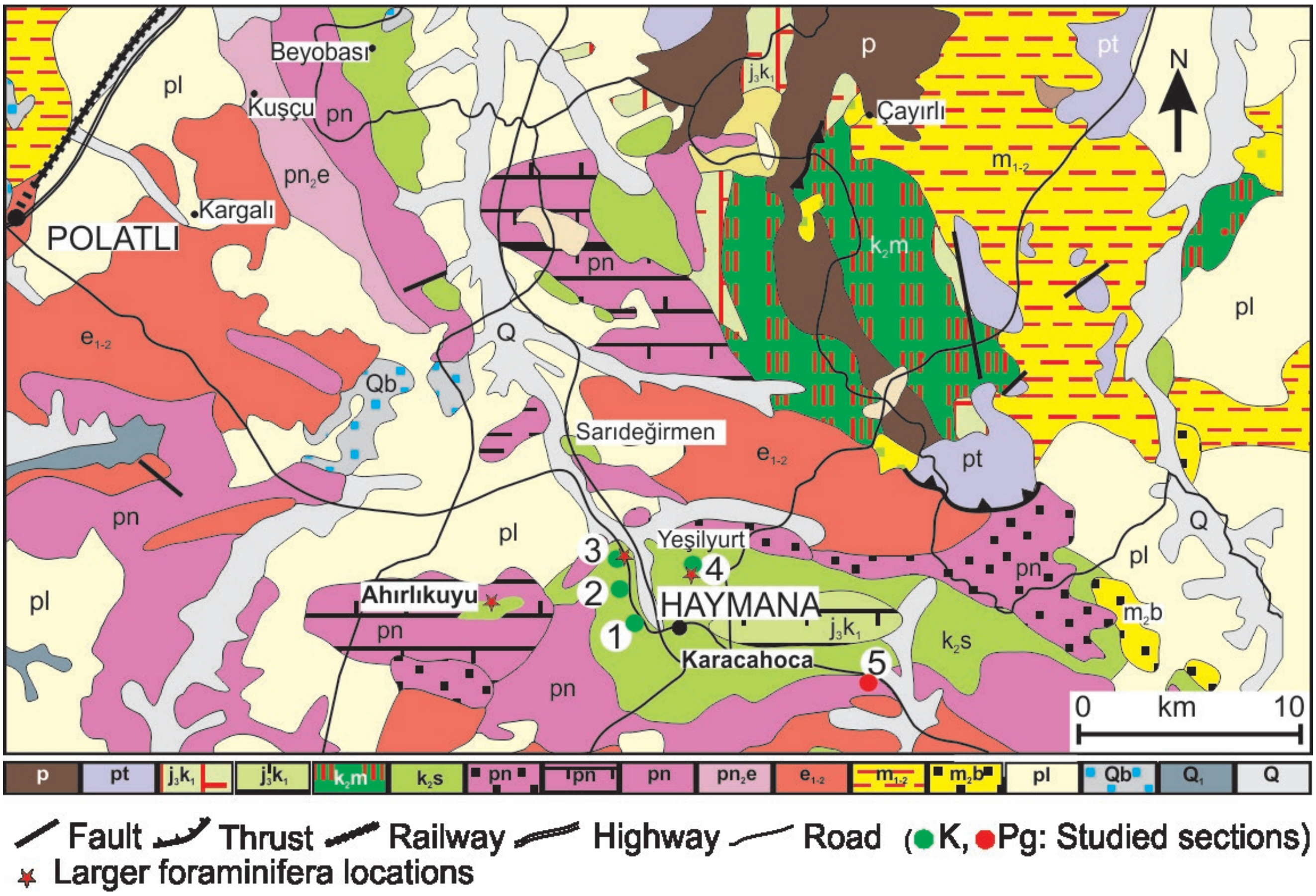

Fig. 2. Geological map of the Haymana district (modified from Atıcı *et al*., 2014). Abbreviations: p – Palaeozoic, pt – Permo-Triassic, j_3k_1 – Jurassic–Cretaceous of the Mollaresul Fm, k_2m – Dereköy Mélange, k_2s – Cretaceous of the Haymana Fm, pn – Paleocene of the Kartal Fm (coarse siliciclastics). pn – Çaldağ Fm (carbonates), pn – Yeşilyurt Fm (siliciclastics), pn_2e – Paleocene-Eocene siliciclastics, $e_{1\text{-}2}$ – Çayraz Fm, $m_{1\text{-}2}$-m_2b – Miocene fine to coarse clastics, pl – Pliocene, Qb – Quaternary basalt, Q1, Q – Quaternary. The numbers in circles refer to the studied localities. The asterisk indicates the larger foraminifera localities.

Locality 1

The measured section, 18 m thick, was examined along the Haymana – Polatlı road (Fig. 1), approximately 1––1.2 km northwest of the centre of Haymana Province (Ankara J28b2-29a1 Quadrangle sheet; GPS coordinates: N39°26′18.52″, E 32°29′0.87″). The section represents the lower part of Unit B (Fig. 3). It is composed of yellow, medium-fine-grained sandstone, greenish-grey siltstones and greenish marl. The sandstones are 3–5 cm thick, mostly yellow but brown at the upper part of the section. The greenish-grey siltstones are parallel-laminated and the marls have a cleavage structure (Fig. 4A–C). Larger benthic foraminifera were not observed. The positions of trace fossils (*Chondrites* isp., *C. intricatus, C. affinis, Nereites* isp., *Phycosiphon incertum*, *Palaeophycus* isp., *Thalassinoides* isp., *Trichnichnus* isp., and ?*T. linearis*) in the section is shown in Figure 5.

Locality 2

The measured section at locality 2 is 9 m thick and was examined on the Haymana – Polatlı road, about 2 km northwest of the Haymana city center, at the Yeşilyurt road junction (Ankara J28b2-29a1 Quadrangle sheet; GPS coordinates: N39°26′46.74″, E32°28′45.10″). It represents a fragment of the middle part of the Haymana Formation (Figs 1, 3; top of the Unit B and the lower part of the Unit C) and starts with with intercalations of greenish-grey marl, siltstones, yellowish fine and coarse sandstones (Fig. 4D–F). The section contains ammonites.

Larger benthic foraminifera were not found in this section. The trace fossils include cf. *Asteriacites* isp., ?*Bergaueria* isp., *Chondrites intricatus*, ?*Cochlichnis* isp., *Helminthopsis* isp., *Helminthorhaphe flexuosa, Ophiomorpha rudis*, *Paleodictyon minimum, P. strozzii*, *Scolicia vertebralis, Thalassinoides* isp., cf. *Thorichnus* isp., and *Zoophycos* isp. (Fig. 6).

Locality 3

The measured section at locality 3 is 20 m thick. It is located approximately 2 km north of the Haymana city center, east of the Haymana-Yeşilyurt road (Ankara J28b2--29a1 Quadrangle sheet; GPS coordinates: N 39°26′55.90″, E32°29′11.43″). It represents the middle part of the Haymana Formation (Figs 1, 3, 7, 8; Unit C) and consists of medium- to coarse-grained siliclastics and carbonates. While greenish-grey marls with sandstones are observed

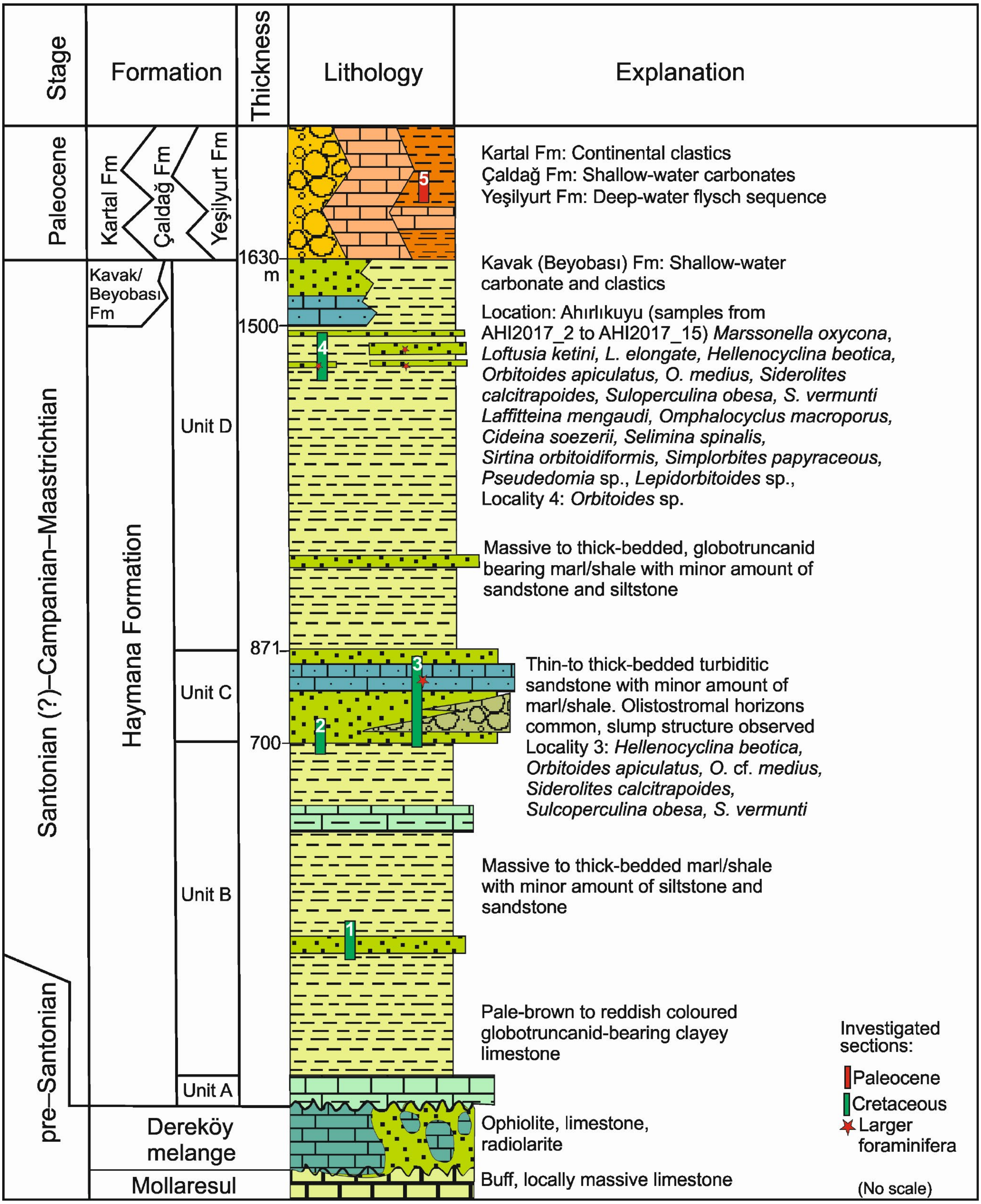

Fig. 3. Generalized measured section of the studied area (modified from Özcan and Özkan-Altıner, 1997; Görmüş *et al*., 2019).

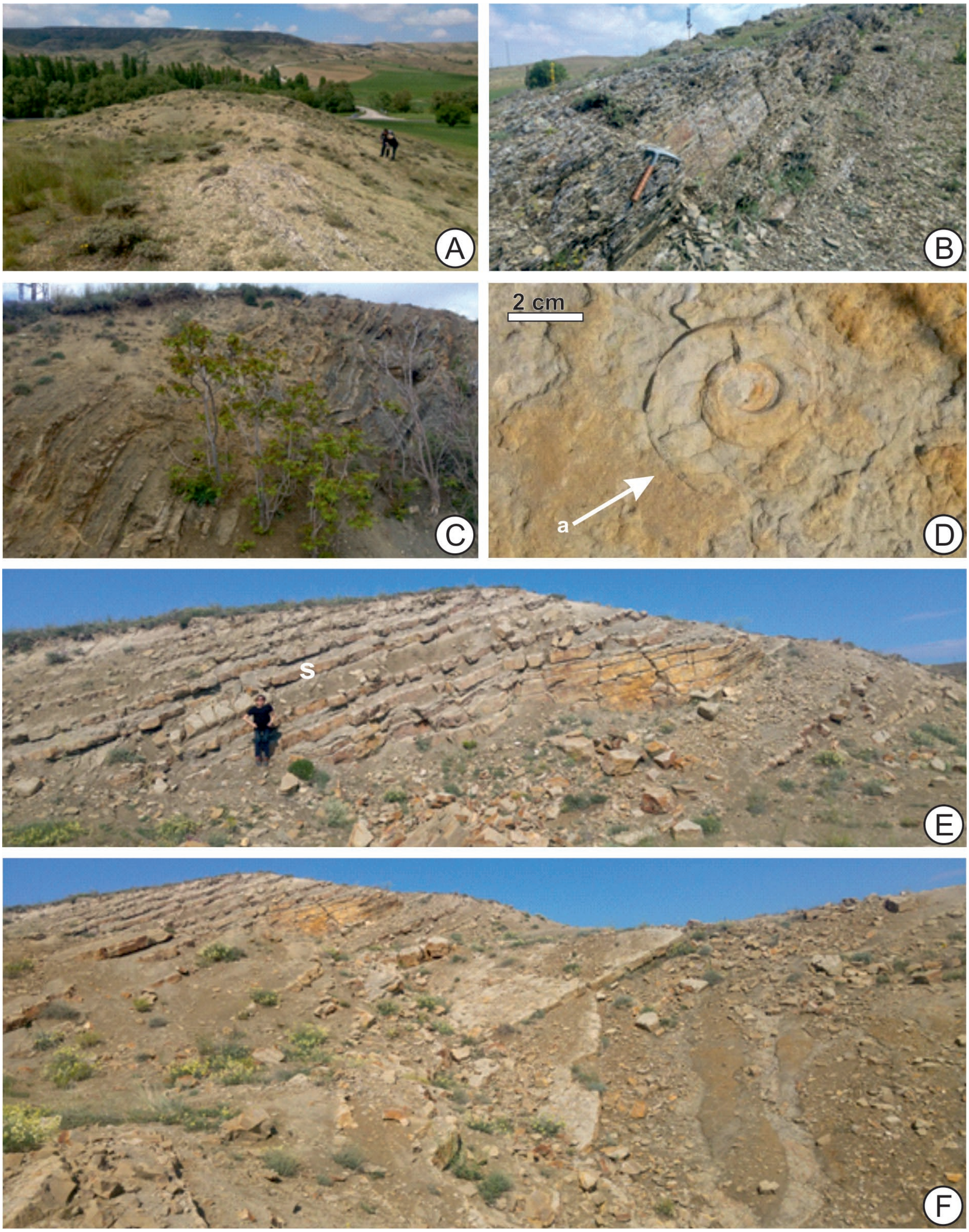

Fig. 4. Outcrops of the lower–middle part of the Haymana Fm. **A.** Locality 1 measured section, northwest of Haymana. **B.** Locality 1 measured section, northeast of Haymana. **C.** Folded sandstone–mudstone deposits of the locality 1. **D.** Ammonite outer mould (a), 2 km of northwest Haymana, Locality 2. **E, F.** Locality 2 section showing of sandstone-mudstone alternations, northeast of Haymana.

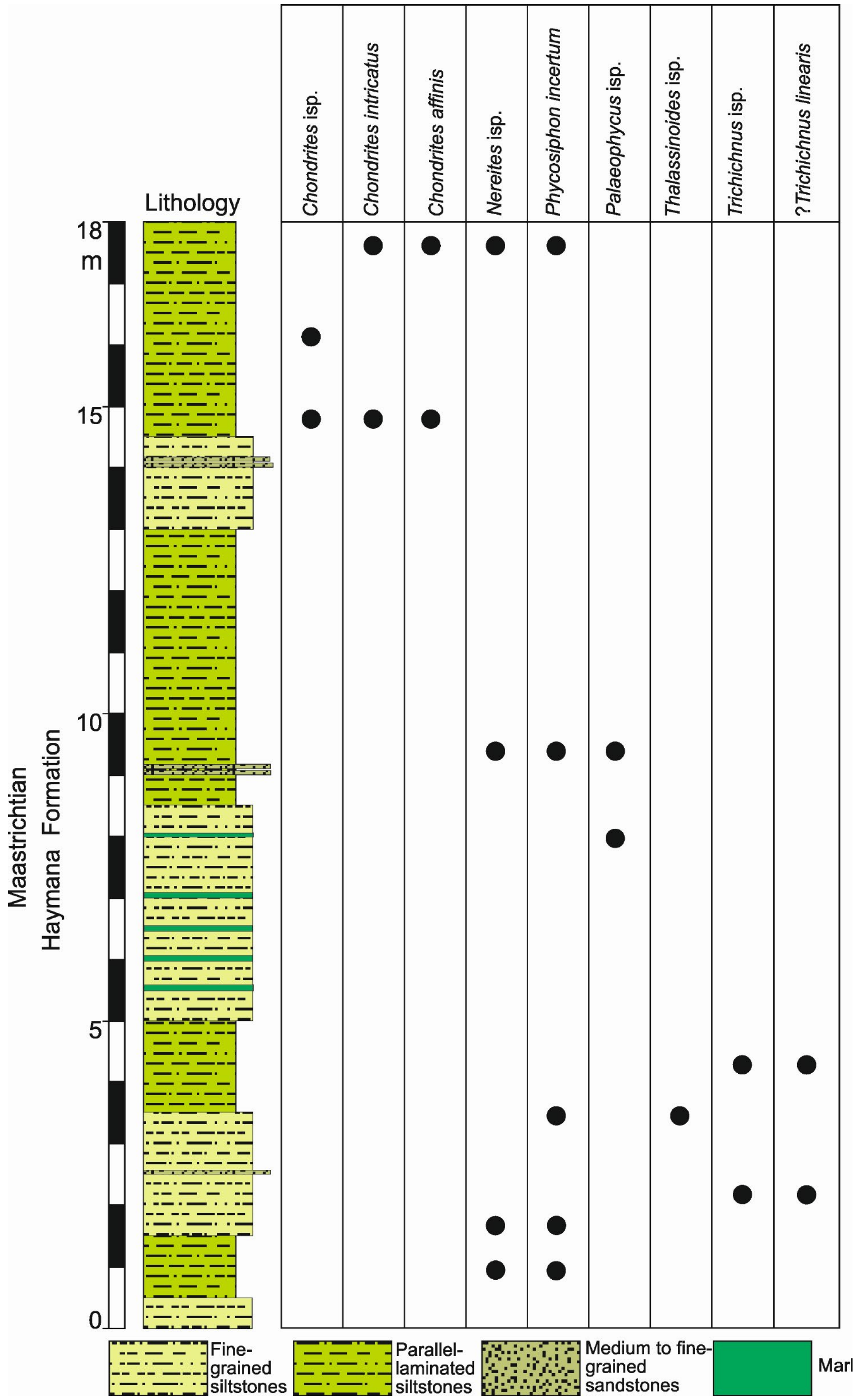

Fig. 5. Measured section of locality 1, Haymana Fm.

at the bottom of the measured section, the upper part of the section continues with similarly coloured laminated sandstones, siltstones and marl beds, containing ammonites. This part of the section also contains conglomerates of ophiolitic origin and coarse-grained sandstones, which are about 8 m thick and interpreted as a channel fill. *Orbitoides* is observed in the sandstones and limestones in the upper part of the section. Besides larger benthic foraminifera (*Hellenocyclina beotica, Orbitoides apiculatus, Orbitoides* cf. *medius, Siderolites calcitrapoides, Suloperculina obesa, S. vermunti*, *Textularia* sp.), algae, bryzoa, coral, rudist and bivalves occur. Trace fossils were observed in greenish gray coloured, fine-medium grained sandstones along the channel-margin deposits (?*Bergaueria* isp., ?*Halopoa* isp., *O. annulata, O. rudis*, *Planolites* isp., *Thalassinoides* isp.).

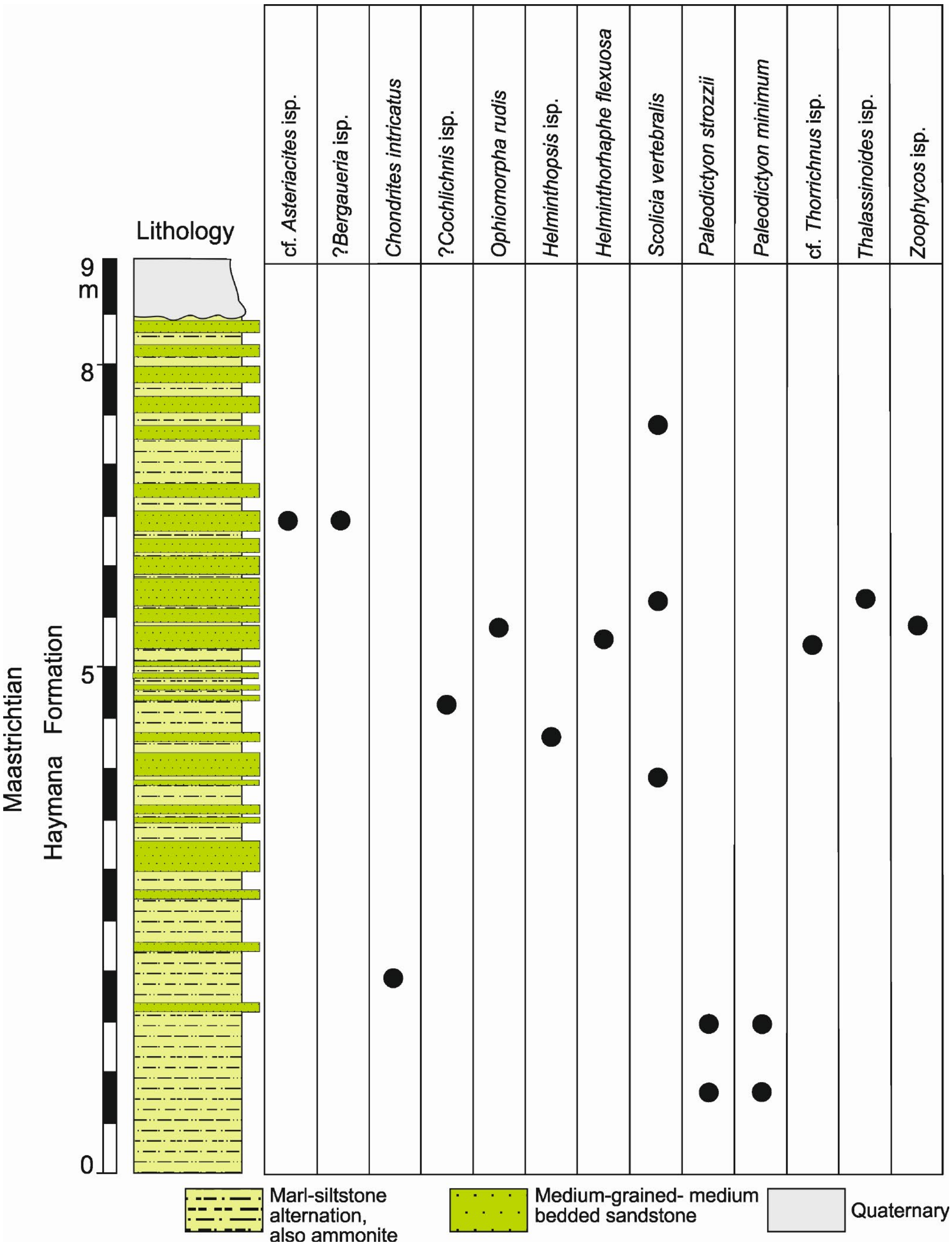

Fig. 6. Measured section of locality 2, Haymana Fm.

Locality 4

The section was measured on the side of the Haymana – Ankara road, approximately 4.5 km northeast of the Haymana city center (Ankara J28b2-29a1 Quadrangle sheet; GPS coordinates: N39°28′13.86″, E32°31′38.05″). It is 17 m thick and contains medium- to coarse-grained siliciclastic channel deposits in the upper part of the Haymana Formation (Figs 1, 3, 9; Unit D). The section starts with yellow, medium-coarse grained, medium--bedded sandstone and siltstone intercalations, containing larger benthic foraminifera. The sandstones are interbedded with conglomerates towards the top. Bed thicknesses range from 20 to 30 cm. Several trace fossils (*Halopoa storeana*, ?*Halopoa* isp., *Planolites* isp., *Scolicia prisca*, *S. strozzii*, *Thalassinoides* isp.) have been identified on the lower bedding surfaces of medium- to coarse-grained sandstones. Grey, fossiliferous- sandy and silty-limestones overlie the fine- to medium-grained sandstones and continues with laminated sandstones up the sections (Fig. 10).

Locality 5

The section of the Yeşilyurt Formation studied is located 2.2 km north of Karacahoca village (Figs 1, 11), approximately 7.5 km southeast of the Haymana city center (Ankara J28b2 Quadrangle sheet; GPS coordinates: N39°25′37.57″; E 32°33′17.11″). The section is 60 m thick and consists of

Fig. 7. Outcrops of the middle part of the Haymana Fm. **A, B.** View of channel deposits, locality 3 (north of Haymana village).

siliciclastics. It starts with polymictic conglomerates with intercalations of coarse-grained sandstone and passes upward into fine- to medium-grained, medium-bedded, yellow, ichnofossiliferous marls. The deposits of the section contain (Fig. 12) ?*Bergaueria* isp., *Chondrites* isp., *C. affinis, C. intricatus,* ?*Desmograpton* isp., ?*Halopoa* isp., *H. storeana, Helminthopsis* isp., *Helminthorhaphe flexuosa, Lockeia* isp., *Megagrapton submontanum, Ophiomorpha annulata, O. rudis, P. arvense, P. latum*, *P. majus, P. minimum, P. strozzii, Paleodictyon* isp., *Planolites* isp., *P. beverleyensis*, *P. montanus*, *Scolicia prisca*, *Scolicia strozzii, Thalassinoides* isp., and *Zoophycos* isp. Larger benthic foraminifers were not found in this measured section.

FORAMINIFERA ASSEMBLAGES

The Maastrichtian and Paleocene deposits of the Haymana Basin are rich in benthic foraminifera (Table 1). Among the trace fossil localities studied, larger benthic foraminifera were recorded in thin sections from the section at locality 3 (Fig. 8) and very rarely from the locality 4 section. Towards the upper part of the locality 3 section, sandy and silty limestones contain abundant larger benthic foraminifera, while the entire succession includes a rich macrobiota, such as algae, bivalves and corals. Larger benthic foraminifera include *Hellenocyclina beotica* Reichel, 1949, *Orbitoides apiculatus* Schlumberger, 1902, *Orbitoides* cf. *medius* (d'Archiac, 1837), *Siderolites calcitrapoides* Lamarck, 1801, *Sulcoperculina obesa* Cizancourt, 1949, *S. vermunti* Thiadens, 1937. These benthic index foraminifera support the Maastrichtian age of the Haymana Formation. They were derived from a shallow palaeoenvironment and were redeposited in sandy and silty limestone turbidites.

The Haymana Formation siliciclastics from the Ahırlıkuyu area contain a rare exposure of the K-Pg boundary interval (Fig. 2). The exposure shows vertical facies changes of the Haymana and Beyobası formations to carbonate-platform limestones of the Çaldağ Formation. In this area, shallow-water siliciclastics of the Haymana Formation contain

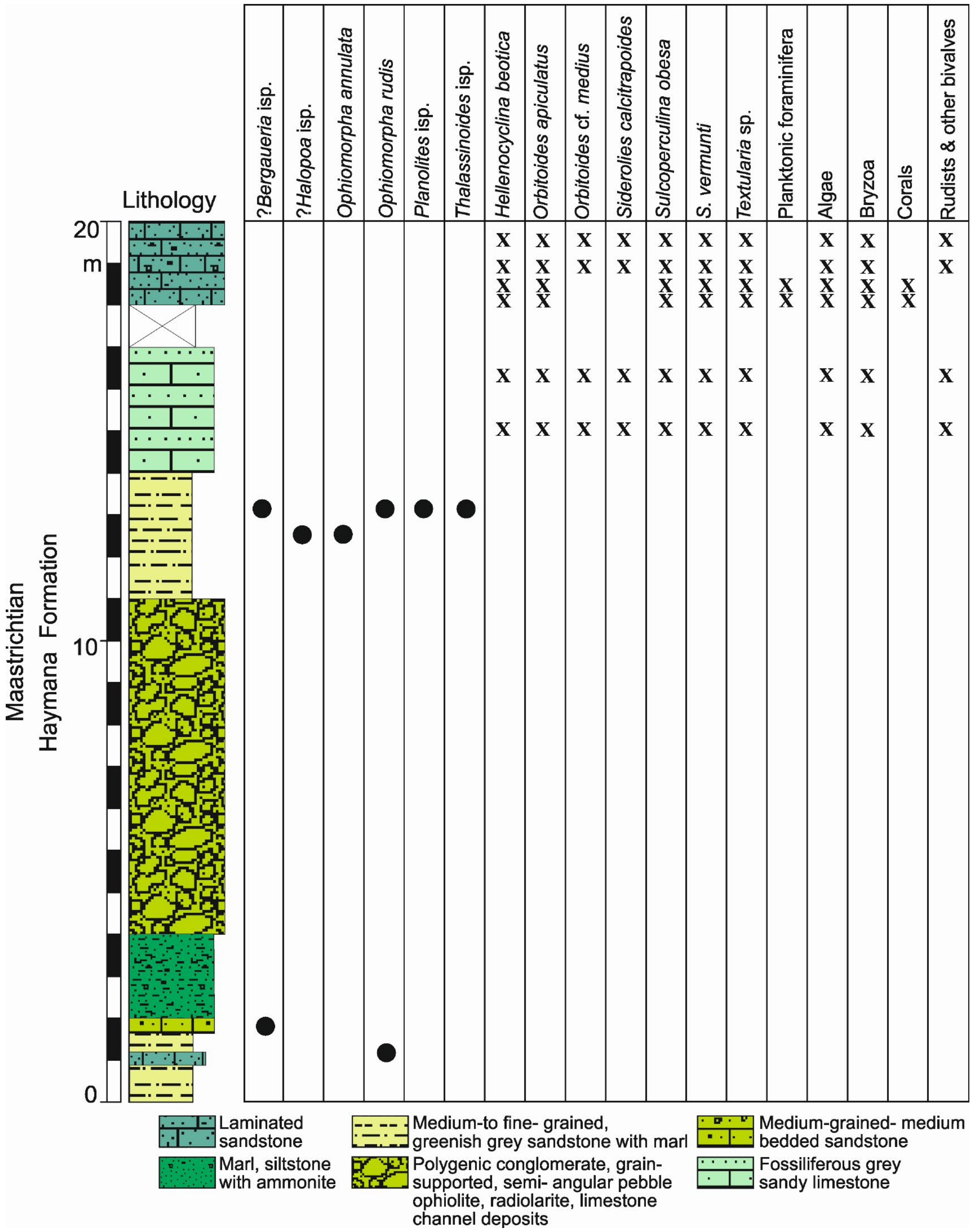

Fig. 8. Measured section of locality 3, Haymana Fm.

abundant, larger benthic foraminifera, while the Palaeogene carbonates contain Danian benthic foraminifera (Sirel, 1998, 2010). The larger benthic foraminifera of the Maastrichtian deposits include *Marssonella oxycona* Reuss, 1860, *Loftusia ketini* Meriç, 1979, *L. elongate* Cox, 1937, *Hellenocyclina beotica* Reichel, 1949, *Orbitoides apiculatus* Schlumberger, 1902, *O. medius* (d'Archiac, 1837), *Siderolites calcitrapoides* Lamarck, 1801, *Suloperculina obesa* Cizancourt, 1949, *S. vermunti* Thiadens, 1937, *Laffitteina mengaudi* (Astre, 1924), *Omphalocyclus macroporus* (Lamarck, 1816), *Cideina soezerii* (Sirel, 1973), *Selimina spinalis* Inan, 1996, *Sirtina orbitoidiformis* Brönnimann and Wirz, 1962, *Simplorbites papyraceous* (Boubée, 1832), *Textularia* sp., *Pseudedomia* sp., *Lepidorbitoides* sp., and representative of Miliolidae, Textulariidae (Figs 13, 14). Sirel (1998, 2010) identified the following Paleocene benthic foraminifera from the Çaldağ Formation in the Ahırlıkuyu area: *Haymanella paleocenica* Sirel, 1999, *H. elongate* Sirel, 2009, *Ankaraella trochoidea* Sirel, 1998, *Kolchidina paleocenica* (Cushman, 1947), *Laffitteina mengaudi* (Astre, 1924), *Kayseriella decostroi* Sirel, 1999, *Planorbulina* sp., *Missisipina binkhorsti* (Reuss, 1862), *Thalmannita madrugaensis* (Cushman and Bermudez 1947), *Akbarina primitive* (Rahaghi, 1983), *Bolkarina aksarayensis* Sirel, 1981,

Table 1

Distribution of benthic foraminifera fauna from the Cretaceous to Paleocene deposits
(*1 – data from Sirel, 2010; *2 – data from Meriç, 1984; *3 – data from Özcan and Özkan-Altıner, 1997).

Benthic foraminifera / Stratigraphy		Textulariids								Miliolids								Rotaliids																			
		Marssonella oxycona	*Loftusia ketini*	*Loftusia elongata*	*Textularia* sp.	*Valvulina* sp.	*Haymanella paleocenica* *1	*H. elongata* *1	*Kolchidina paleocenia* *1	*Ankaraella trochoidea* *1	*Kayseriella decasroi* *1	*Pseudedomia* sp.	*Glomalveolina primaeva* *1	*Pseudolacazina oeztemueri* *1	*P. donatae*	*Scandonea samnitica* *2	Miliolidae	*Orbitoides apiculatus*	*O. gruenbachensis*	*O. megaloformis*	*O. medius*	*Simplorbites papyraceous*	*Lepidorbitoides bisambergensis* *3	*L. campaniensis* *3	*Siderolites calcitrapoides*	*Praesiderolites* sp.	*Cideina soezerii*	*Selimina spinalis*	*Laffiteina mengaudi*	*Sirtina orbitoidiformis*	*Sulcoperculina globosa*	*Suloperculina vermunti*	*Hellenocyclina beotica*	*Pseudocuvillerina sireli* *1	*Missisipina* cf. *binkhorski* *1	*Bolkarina aksarayensis* *1	*Thalmannita madrugaensis* *1
Paleocene	Çaldağ Fm / Yeşilyurt Fm					X	X	X	X	X	X		X	X	X	X	X												X					X	X	X	X
Maastrichtian	Beyobası Fm	X	X	X	X							X					X	X	X	X	X	X	X		X		X	X		X	X	X					
Maastrichtian	Haymana Fm	X	X	X								X					X	X	X	X	X	X	X	X	X	X				X	X	X					

Pseudocuvillierina sireli (Inan, 1988), *Pseudolacazina oeztemueri* Sirel, 1981, *P. donatae* (Drobne, 1974), and *Glomalveolina primaeva* Reichel, 1936. Similar foraminifera have been found in carbonates of the Çaldağ Formation in the Sarıdeğirmen area.

SYSTEMATIC DESCRIPTION OF TRACE FOSSILS

The trace fossils presented are characterized by moderate diversity (21 ichnogenera, 35 ichnospecies). Their systematics is based on the morphological criteria, proposed mainly by Häntzschel (1975), Książkiewicz (1977), Seilacher (1977), Fillion and Pickerill (1990), Crimes and Crossley (1991), and Uchman (1995). They belong to six morphologic groups. The trace fossils are documented in field photographs. Their occurrences in the outcrops are listed in Table 2.

Circular and elliptical structures

The trace fossil cf. *Asteriacites* isp. (Fig. 15A) is a hypichnial, star-shaped mound, ca. 17 mm in diameter. It exhibits short, triangular arms, which are 3.4–4.5 mm long. *Asteriacites* von Schlotheim, 1820 is placed in the circular and elliptical structures by convention (cf. (Riahi *et al*., 2014). It is a resting trace (cubichnion) of asteroids and ophiuroids, which is known mostly from well-oxygenated, shallow-marine (Müller, 1980; Twitchett and Wignal, 1996) and rarely from deep–sea deposits (Mikuláš, 1992; Riahi *et al*., 2014). *Asteriacites* ranges from Cambrian to Holocene (Mikuláš, 1992).

?*Bergaueria* isp. (Fig. 15B, C) is a hypichnial, hemispherical mound, smooth with minor irregularities, circular or oval outline, 4.3–5 mm wide, preserved in sandstone beds.

Bergaueria Prantl, 1945 is a dwelling or resting trace of sea anemones (Pemberton *et al*., 1988; Pickerill, 1989; Pacześna, 2010). It is common in the softground siliciclastic deposits of beaches, tidal flats and shallow-marine to deep-sea settings (Knaust, 2017). *Bergaueria* ranges from the Ediacaran to Recent (Mángano and Buatois, 2016; Knaust, 2017).

Lockeia isp. (Fig. 15D) is a hypichnial, amygdaloidal mound, distinctly curved trace fossil, 3.5 mm wide and 6.4 mm long. *Lockeia* James, 1879 is a cubichnion (resting), produced mainly by bivalves (Seilacher and Seilacher, 1994) in various environments, but mostly in shallow-marine settings. It ranges from Ediacaran to Pleistocene (Fillion and Pickerill, 1990).

Simple and branched structures

Chondrites affinis (Sternberg, 1833) (Fig. 15E) is a system of tunnels, showing four or five branches, extending sideways, which are almost straight or distinctly curved, 8 mm wide. Up to three orders of branches are present. This ichnospecies was previously synonymised with *C. targionii* (Brongniart, 1828). After an analysis of the

Table 2

Distribution of trace fossils in the sections studied.

Stratigraphy		cf. *Asteriacites* isp.	?*Bergaueria* isp.	*Lockeia* isp.	*Chondrites affinis*	*Chondrites intricatus*	*Chondrites* isp.	*Halopoa storeana*	?*Halopoa* isp.	*Ophiomorpha annulata*	*Ophiomorpha rudis*	*Palaeophycus* isp.	*Planolites beverleyensis*	*Planolites montanus*	*Planolites* isp.	*Thalassinoides* isp.	cf. *Thorichnus* isp.	?*Trichichnus linearis*	*Trichichnus* isp.	*Phycosiphon incertum*	*Zoophycos* isp.	?*Cochlichnis* isp.	*Helminthopsis* isp.	*Helminthorhaphe flexuosa*	*Nereites* isp.	*Scolicia prisca*	*Scolicia strozzii*	*Scolicia vertebralis*	?*Desmograpton* isp.	*Megagrapton submontanum*	*Paleodictyon* isp.	*Paleodictyon arvanse*	*Paleodictyon latum*	*Paleodictyon majus*	*Paleodictyon minimum*	*Paleodictyon strozzii*
Paleocene	Yeşilyurt Fm, Locality 5		X	X	X	X	X	X	X	X	X		X	X	X	X					X		X	X		X	X		X	X	X	X	X	X	X	X
Upper Cretaceous	Haymana Fm, Locality 4							X	X						X	X										X	X									
Upper Cretaceous	Haymana Fm, Locality 3		X						X	X	X				X	X																				
Upper Cretaceous	Haymana Fm, Locality 2	X	X			X					X					X	X				X	X						X							X	X
Upper Cretaceous	Haymana Fm, Locality 1				X	X	X					X				X		X	X	X					X											

well-preserved specimens from the Saraceno Fm (?Upper Cretaceous; Eocene–Miocene) in the southern Italy, it is considered to be a separate ichnospecies, recommended for further use (Uchman *et al*., 2012). *Chondrites* Sternberg, 1833 has been interpreted as the chemichnion of an unknown deposit feeder (Bromley, 1996). *C. affinis* occurs in Upper Cretaceous to Neogene offshore, deep-sea sediments (Uchman *et al*., 2012).

Chondrites intricatus (Brongniart, 1823) (Figs 15F, 19E) is a branching burrow system, composed of straight, unlined segments. The branches have acute angles, usually 25°–35°. The second-order branches predominate and the third-order branches are rare. The main (master) branches are 0.5–1 mm wide and 15 mm long; second-order branches are 0.3–0.4 mm wide and between 4.2–5.4 mm long. *C. intricatus* is a common trace fossil in deep-sea sediments (Uchman, 1995, 1998). It is distinguished by its straight and fine branches and acute angle of branching (Fu, 1991; Uchman, 1999). *Chondrites* is interpreted as a chemichnion (Bromley, 1996), produced by unknown organisms (Seilacher, 1990; Fu, 1991). It occurs from the Tommotian (Crimes, 1987) to the Holocene (Wetzel and Werner, 1981).

Chondrites isp. (Fig. 15G) is as root-like, branching tunnel systems. The tunnels branch at angles of 45°–90° and are 0. 5–1.0 mm wide.

Halopoa storeana Uchman, 2001 (Fig. 15H, I) is a simple, cylindrical, hypichnial ridge, 4 mm wide, preserved in full relief and covered with wrinkles. The wrinkles are commonly 11 mm long, 3–4 mm wide. *H. storeana* differs from *H. imbricata* in the orientation of the surficial wrinkles. The wrinkles of *H. imbricata* are parallel to subparallel to the trace axis, whereas the wrinkles on *H. storeana* have a plaited pattern (Uchman, 2001). *Halopoa* Torell, 1870, including *H. storeana* is a pascichnion burrow (Uchman, 1998) and found in sandstone turbidites of deep-marine flysch deposits (Uchman, 1998). Its stratigraphic range includes the Paleocene (Książkiewicz, 1977) and lower Oligocene of the Polish Carpathians (Uchman, 1998).

?*Halopoa* isp. (Fig. 15J) is a hypichnial, horizontal, straight to gently curved, cylindrical burrow, covered with oblique, irregular ridges or wrinkles. The ridges are 7–8 mm wide. *Halopoa* is usually horizontal, relatively long and unbranched, with continuous furrows and wrinkles. However, the ichnotaxa in question exhibits some, if not all the features of *Halopoa* − with very few wrinkles – therefore, it should be accompanied by question marks.

Ophiomorpha annulata (Książkiewicz, 1977) (Fig. 16A, B) occurs as a hypichnial, rarely branched, tubular cylinders with or without a wall, 3–4 mm in diameter. It is preserved in full relief along the bedding planes of sandstone beds. This ichnospecies is generally interpreted as a dwelling and feeding structure, produced probably by deeply burrowing crustaceans (Uchman, 2004). *Ophiomorpha* is very common in Mesozoic and Cenozoic deposits in shallow- and marginal marine environments, although some species have been recorded in deeper-marine settings (Frey *et al.,* 1978).

Ophiomorpha rudis (Książkiewicz, 1977) (Fig. 16C–F) is a horizontal, vertical, or oblique, sparsly branched, sand-filled cylindrical tunnel, 8–20 mm in diameter, with or without a wall. *O. rudis* generally is interpreted as a dwelling–feeding structure, produced by crustaceans searching for food in sediments rich in plant detritus (Uchman, 2009; Demircan and Uchman, 2017). It is characteristic of deep-sea, sandy deposits (Uchman, 2009). *Ophiomorpha rudis* is known from the Tithonian to the Miocene (Tchoumatchenco and Uchman, 2001).

Planolites beverleyensis (Billings, 1862) (Fig. 16G–I) is a cylindrical, horizontal to oblique, smooth structure without a wall, 5–8 mm in diameter. It has the same filling as the surrounding rock. *P. beverleyensis* is interpreted as a feeding structure of vermiform animals (Howard and Frey, 1984). *Planolites* Nicholson, 1873 occurs in several facies

Fig. 9. Views of locality 4, Haymana Fm. **A**. Carbonates in the lower part. **B.** Limestones and conglomerates in the middle part. **C.** Limestones in the upper part.

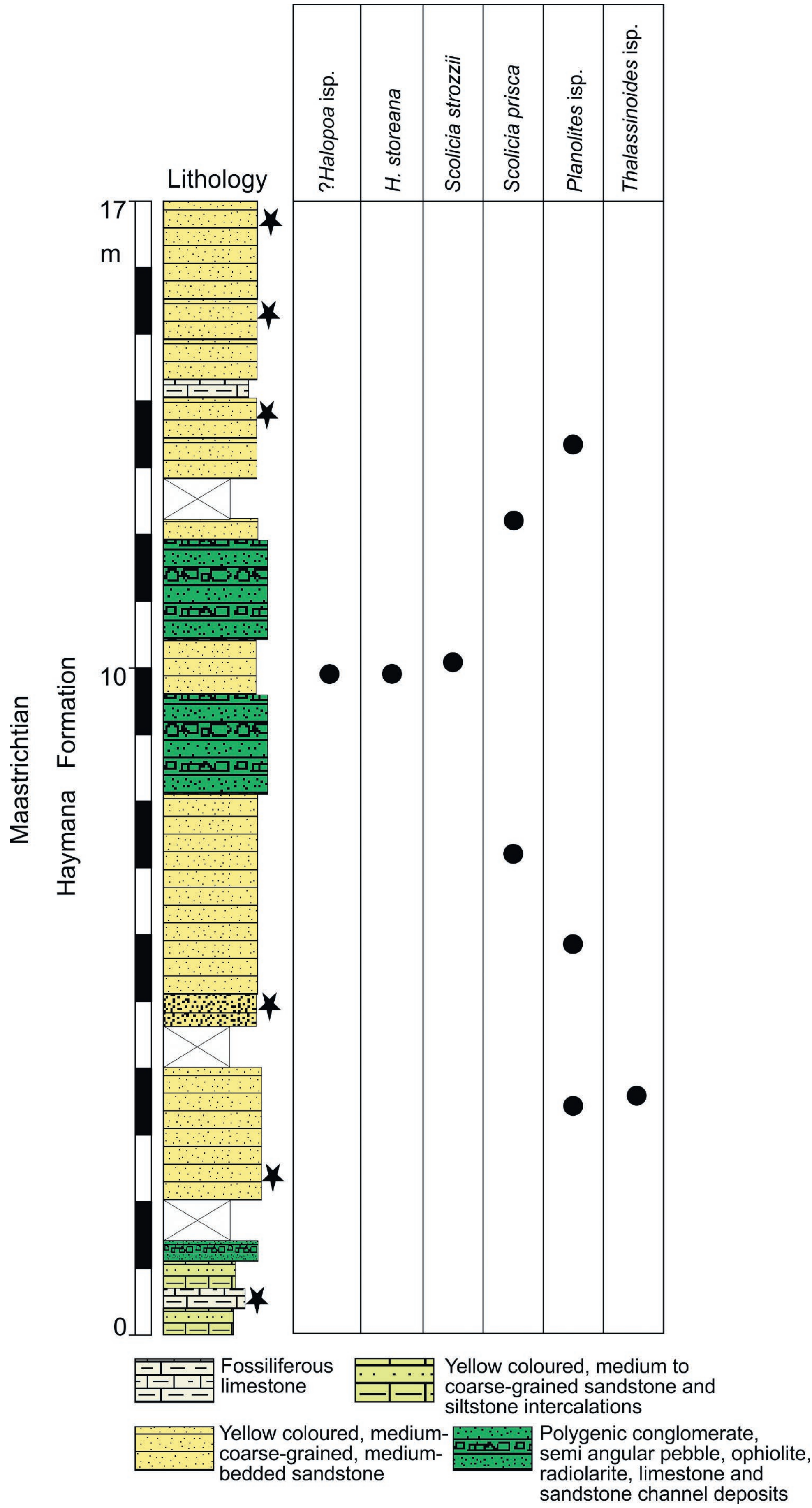

Fig. 10. Measured section of locality 4, Haymana Fm.

Fig. 11. Views of locality 5, Yeşilyurt Fm. **A.** Conglomerates in the lower part (western part). **B.** Deposits dominated by sandstones (southern side).

in their different palaeoenvironments, so their usefulness as palaeoenvironmental indicators is limited (Pemberton and Frey, 1982). This taxon is known from the Proterozoic to the Holocene (Häntzschel, 1975; McCann and Pickerill, 1988; Mángano and Buatois, 2016).

Planolites montanus Richter, 1937 (Fig. 16H) is a elatively small, straight to slightly curved, and horizontal to slightly inclined burrow, which is 2–3 mm wide. *P. montanus* differs from *P. beverleyensis* in that it is usually round and shorter (Demircan and Uchman, 2016). It is a widespread trace fossil in different marine and non-marine environments (Pemberton and Frey, 1982).

Planolites isp. (Fig. 16I) is a horizontal to subhorizontal, unbranched, straight to slightly curved, cylinders burrow, which is 3–4 mm wide.

Thalassinoides isp. (Figs 17A–C, 19E) is straight or slightly winding, horizontal burrows, which is 6–22 mm wide, showing Y–or T–shaped branches. *Thalassinoides*,

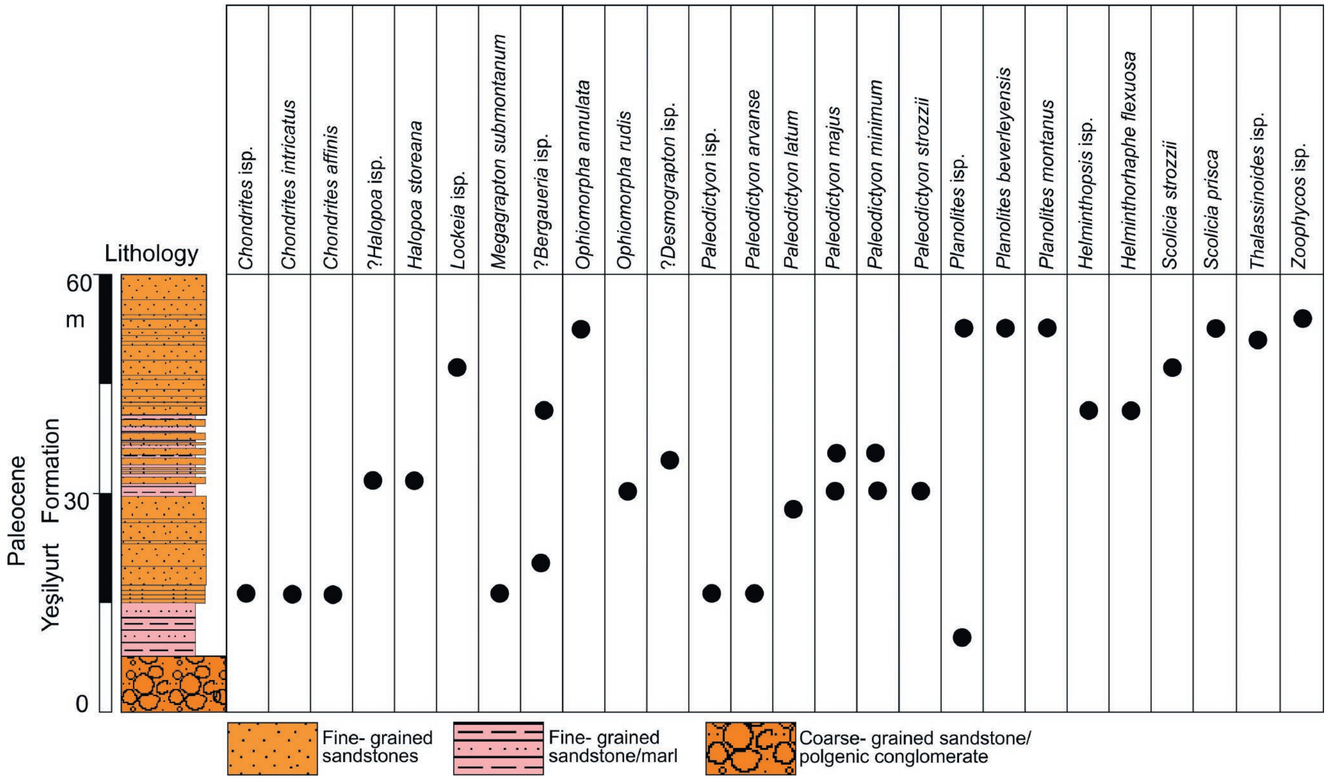

Fig. 12. Measured section of the Yeşilyurt Fm.

with its distinctive Y– or T– shaped branches, has been reported from deep-sea deposits (Kern and Warme, 1974; Uchman, 1995), since the Mesozoic (Bottjer *et al*., 1987). It is also abundant in shallow-marine deposits. *Thalassinoides* Ehrenberg, 1944 mainly was produced by dwelling and/or feeding activity of crustaceans, shrimps and ghost shrimps, whereas it also was formed by shrimps, comparable to recent callianassids, in Mesozoic-Cenozoic sediments (Frey *et al*., 1978).

cf. *Thorichnus* isp. (Fig. 17D, E) is a system of unlined burrows, preserved in positive hyporelief, consisting generally of the master burrow and laterally branches, which are 2–3 mm wide and up to 80 mm long. They form a dendritic or antler-like pattern. The branches are usually more abundant on one side. Originally, *Thorichnus* Pokorný, Krmíček and Sudo, 2017 was identified in subaquatic, lacustrine upper Miocene deposits in southeastern Iceland. Its characteristics indicate the dominance of a deposit-feeding ethology, less frequently the occurrence of surface grazing traces (pascichnia) and permanent dwelling structures (domichnia).

?*Trichichnus linearis* Frey, 1970 (Fig. 17F, H) is a vertical to oblique, unbranched, hair-like, very thin, cylindrical trace fossil, which is less than 1 mm in diameter. Its fill is usually pyritized. The most particular feature of *Trichichnus* is pyritization, which is not found in other trace fossils. *Trichichnus* Frey, 1970 is interpreted as a chemichnion structure (Uchman, 1999). It is produced by modern, large, sulphur bacteria, which live in the transition from anoxic to dysoxic sediments (Kędzierski *et al*., 2015). *Trichichnus* is known from the marine, fine-grained deposits of different depths (Frey, 1970; Wetzel, 1983). It ranges from the Cambrian (Stachacz, 2012) to the Holocene (Wetzel, 1983).

Trichichnus isp. (Fig. 17G) is a cylindrical, straight or slightly winding structure, filled with pyrite or iron oxides, variably oriented and less than 1 mm in diameter. *Trichichnus* is observed winding ferruginous cylinder, which probably was produced by sulfur bacteria in the transition between anoxic-dysoxic sediments (Kędzierski *et al*., 2015).

Palaeophycus isp. (Fig. 17I) is a horizontal, straight, cylindrical burrow with a wall, approximately 2 mm in diameter. The filling is different than the surrounding sediment. *Palaeophycus* Hall, 1847 differs from the morphologically similar *Planolites* in the presence of a wall (Pemberton and Frey, 1982). It is interpreted as a facies-crossing ichnogenus, produced by predaceous vermiform or suspension- and deposit-feeding (Schlirf, 2003) organisms. It ranges from the Ediacaran to Recent (Pemberton and Frey, 1982).

Spreite structures

Phycosiphon incertum Fischer-Ooster, 1858 (Figs 17J, 18A, G, H) occurs as endichnial, horizontal lobes, encircled by a meandering, marginal tunnel. The lobes are 0.8–1 mm wide and up to 7 mm long. The marginal tunnel is about 1 mm wide. The tracemaker was an opportunistic, highly selective deposit-feeder (fodinichnion) and generally colonized sediments enriched in organic matter (Wetzel, 2010), probably a vermiform organism (Bednarz and McIlroy, 2009), but it remains unrecognized (Wetzel and Bromley, 1994; Wetzel and Uchman, 2001; Wetzel, 2008, 2010). *P. incertum* occurs from the Palaeozoic to the Holocene in deposits, ranging from continental shelves to submarine fans (Seilacher, 1978; Fu, 1991; Goldring *et al*., 1991; Savrda *et al.,* 2001; Naruse and Nifuku, 2008).

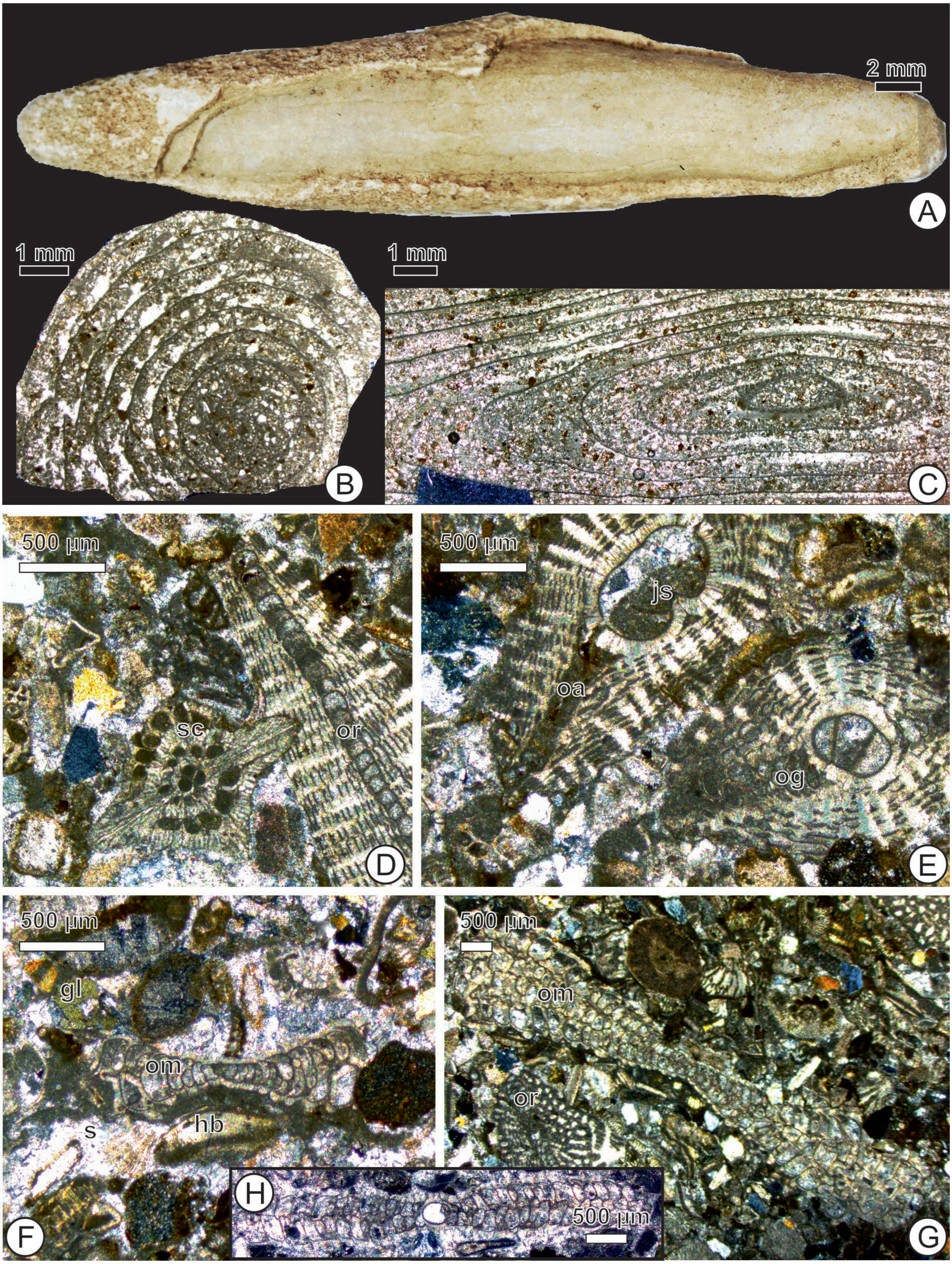

Fig. 13. Larger foraminifera views from the Haymana Formation (Maastrichtian) at Ahırlıkuyu. **A–C.** *Loftusia ketini*, A – external view, B – equatorial section, AHI2017_13, C – tangential section, AHI2017_9. **D.** *Siderolites calcitrapoides* (sc) and *Orbitoides* sp. (or), AHI2017_2. **E.** *Orbitoides apiculatus* (oa) and *O. gruenbachensis* (og), geopetal structure (js), AHI2017_2. **F.** *Omphalocyclus* sp. (om), *Hellenocyclina beotica* (hb), glouconite (gl), sparite, AHI2017_3. **G. H.** *Omphalocyclus macroporus* (om), *Orbitoides* sp. (or), 6. AHI2017_3; 7. AHI2017_15.

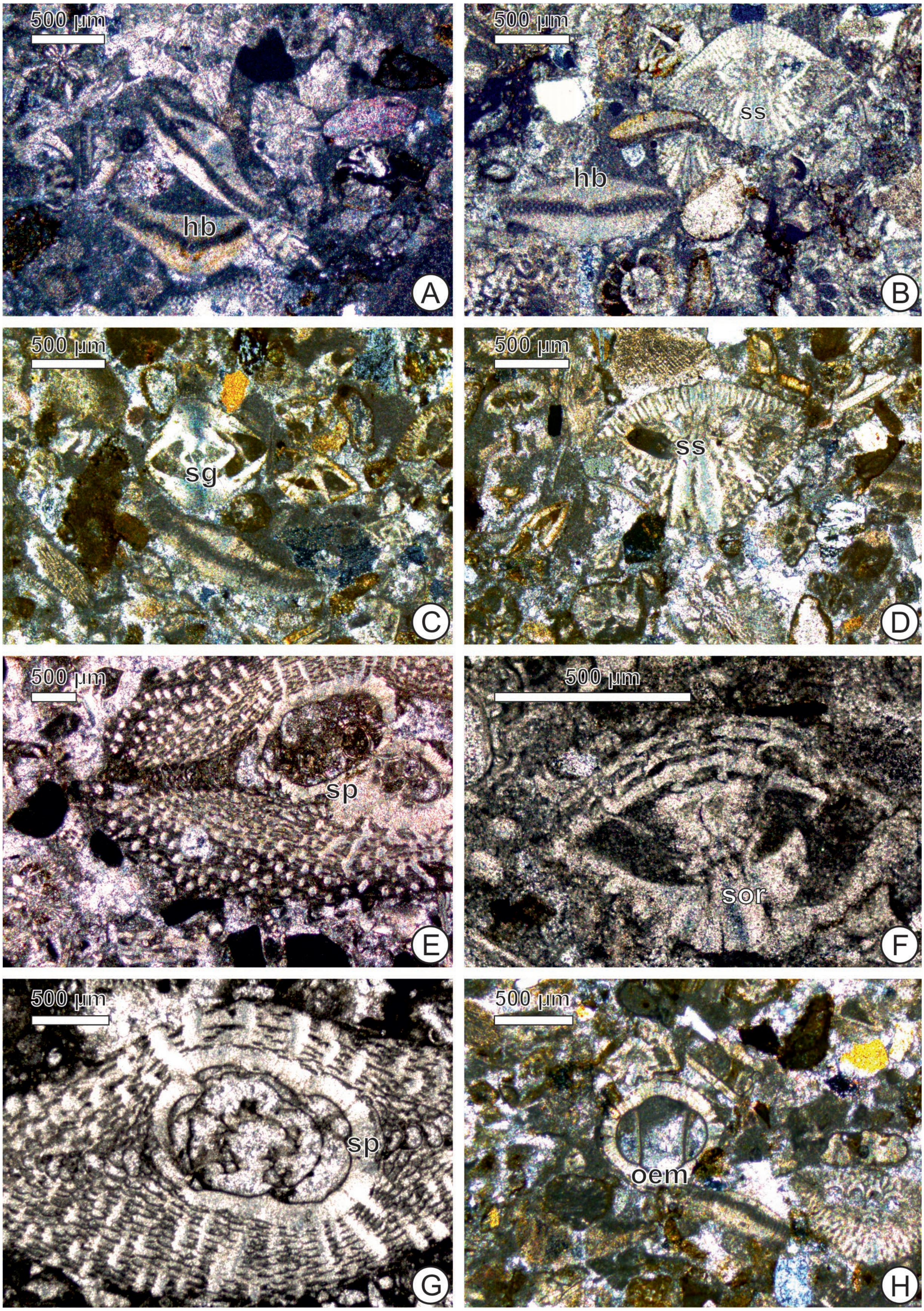

Fig. 14. Selected larger benthic foraminifera in thin sections from the Haymana Formation (Maastrichtian) at Ahırlıkuyu. **A.** *Hellenocyclina beotica* (hb), AHI2017_14. **B.** *Cideina soezerii* (cs), *Hellenocyclina beotica* (hb), AHI2017_14. **C.** *Sulcoperculina globosa* (sg), AHI2017_2. **D.** *Selimina spinalis (ss)*, AHI2017_2. **E.** *Simplorbites papyraceous* (sp), reproduction view, AHI2017_13. **F.** *Sirtina orbitoidiformis* (sor), AHI2017_12. **G.** *Simplorbites papyraceous* (sp), AHI2017_13. **H.** *Orbitoides* embryo within sandy limestones, *Hellenocyclina beotica* (hb), *Sulcoperculina vermunti* (sw), *Cideina soezerii* (cs), AHI2017_2.

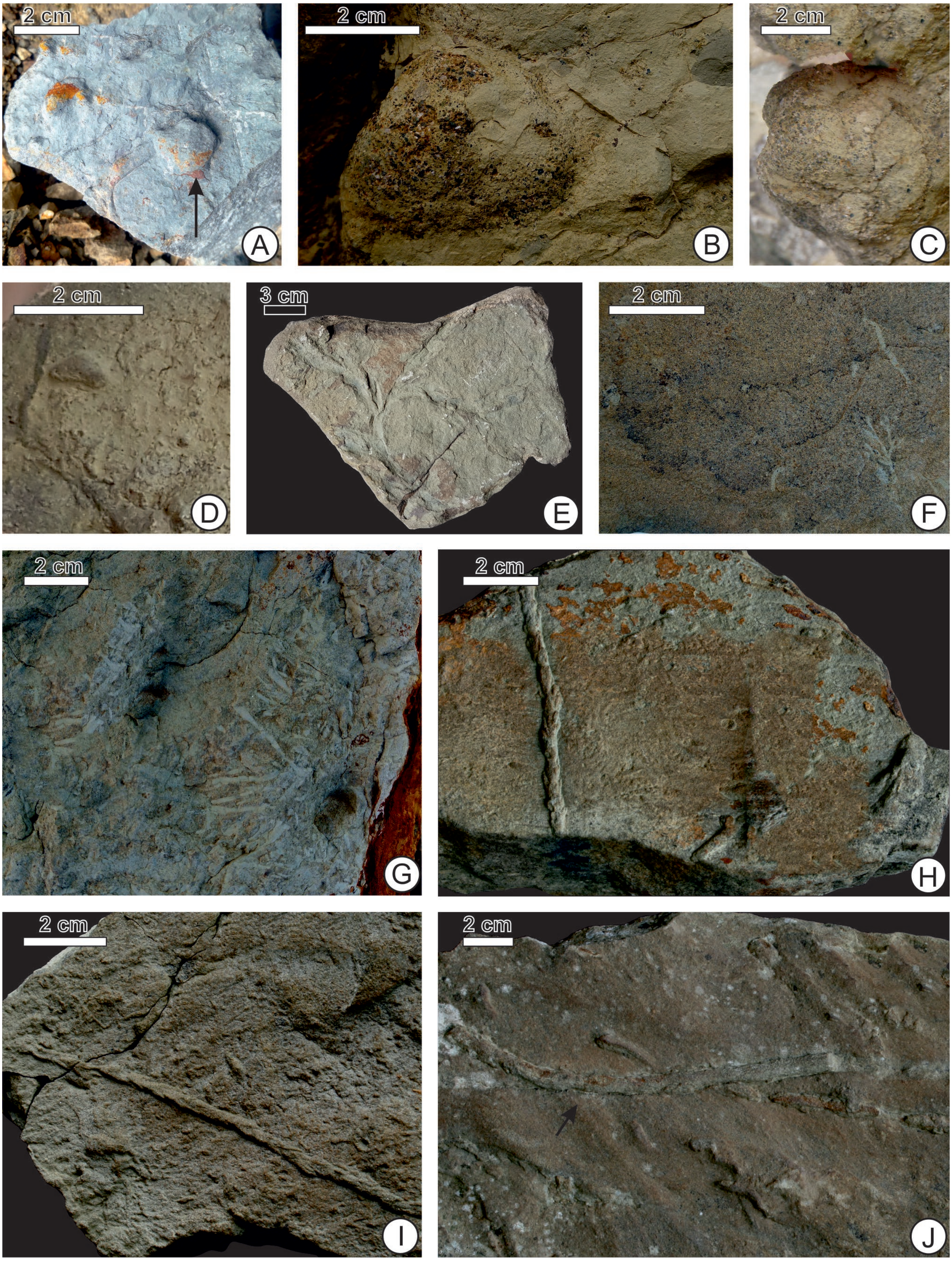

Fig. 15. Field photographs of trace fossils from the Haymana Fm (A–C, E–G, I, J) and Yeşilyurt Fm (D, H). **A.** cf. *Asteriacites* isp., locality 2. **B**, **C.** ?*Bergaueria* isp., locality 2. **D** *Lockeia* isp., locality 5. **E.** *Chondrites affinis*, locality 1. **F.** *Chondrites intricatus*, locality 1. **G.** *Chondrites* isp., locality 1. **H.** *Halopoa storeana*, locality 5. **I.** *Halopoa storeana,* locality 4. **J.** ?*Halopoa* isp., locality 3.

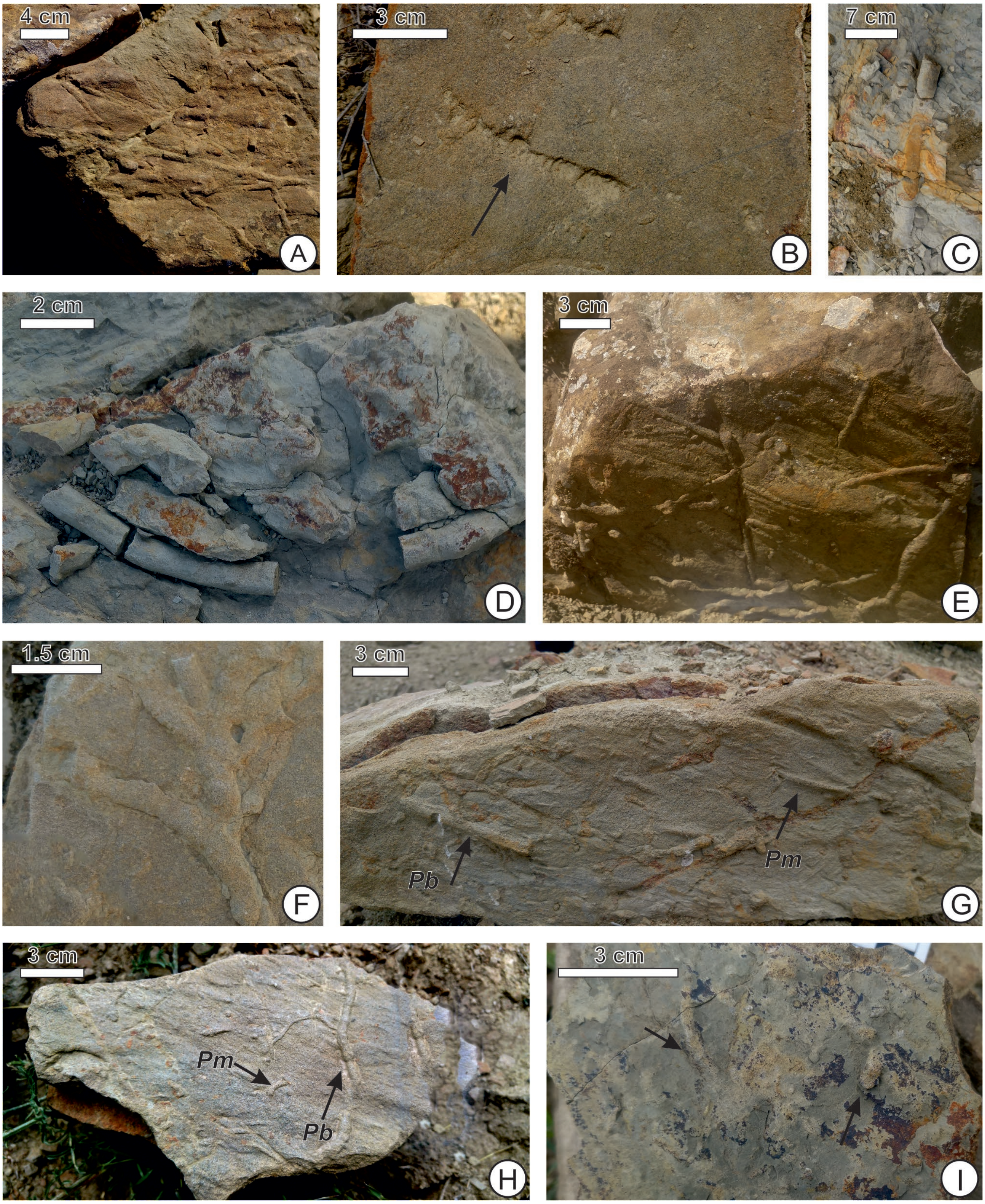

Fig. 16. Field photographs of other trace fossils from the Haymana Fm (A–F) and Yeşilyurt Fm (G–I). **A, B.** *Ophiomorpha annulata*, locality 3. **C–F.** *Ophiomorpha rudis*, locality 2. **G–I.** *Planolites beverleyensis* (Pb), *Planolites montanus* (Pm), locality 5. **H.** *Planolites montanus* (Pm), locality 5. **I.** *Planolites* isp., locality 5.

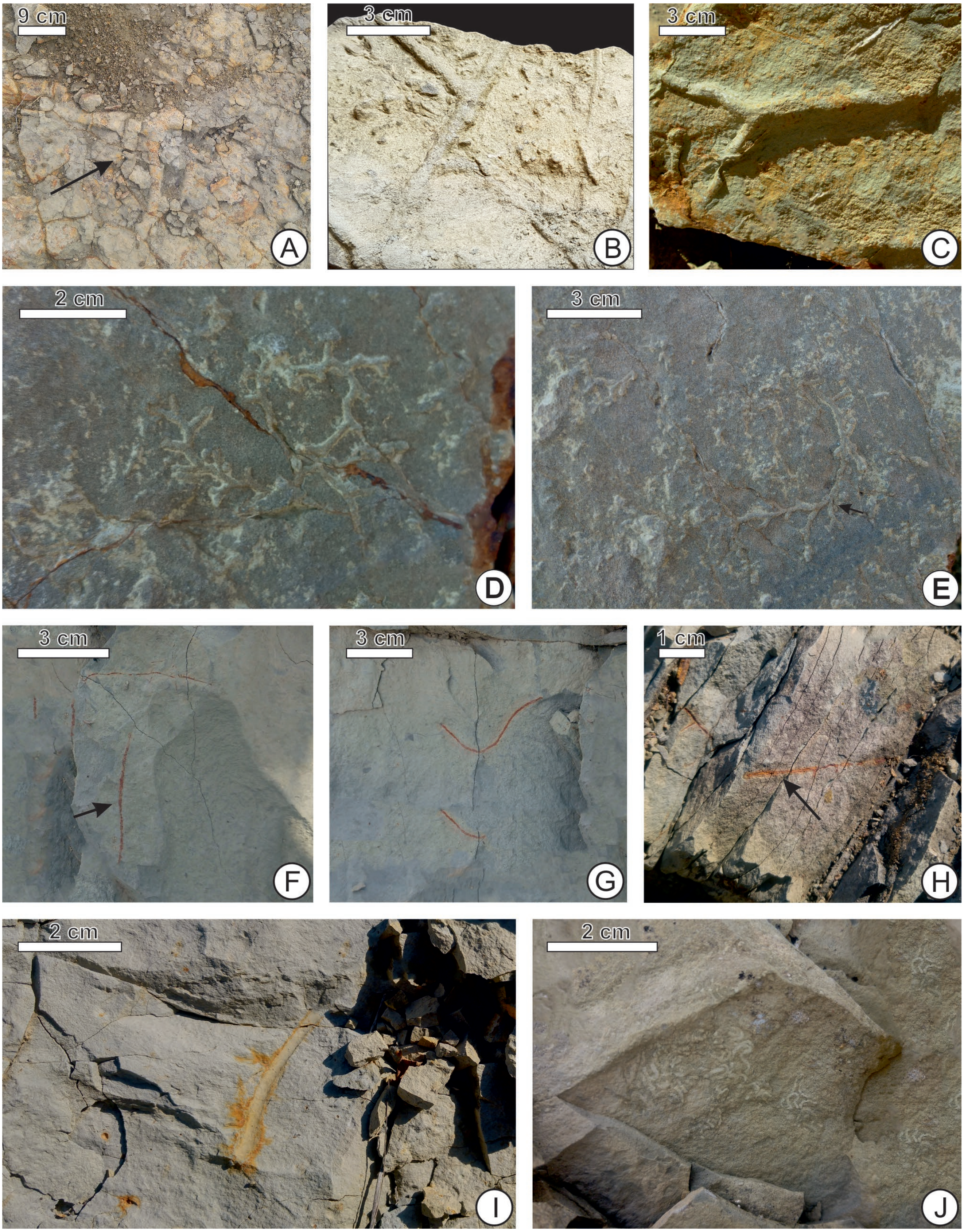

Fig. 17. Other trace fossils (field photographs) from the Haymana Fm from localities 3 (A–C) and 1 (D–J). **A–C.** *Thalassinoides* isp. **D, E.** cf. *Thorichnus* isp. **F**, **H.** *Trichichnus* cf. *linearis*. **G.** *Trichichnus* isp. **I.** *Palaeophycus* isp. **J.** *Phycosiphon incertum*.

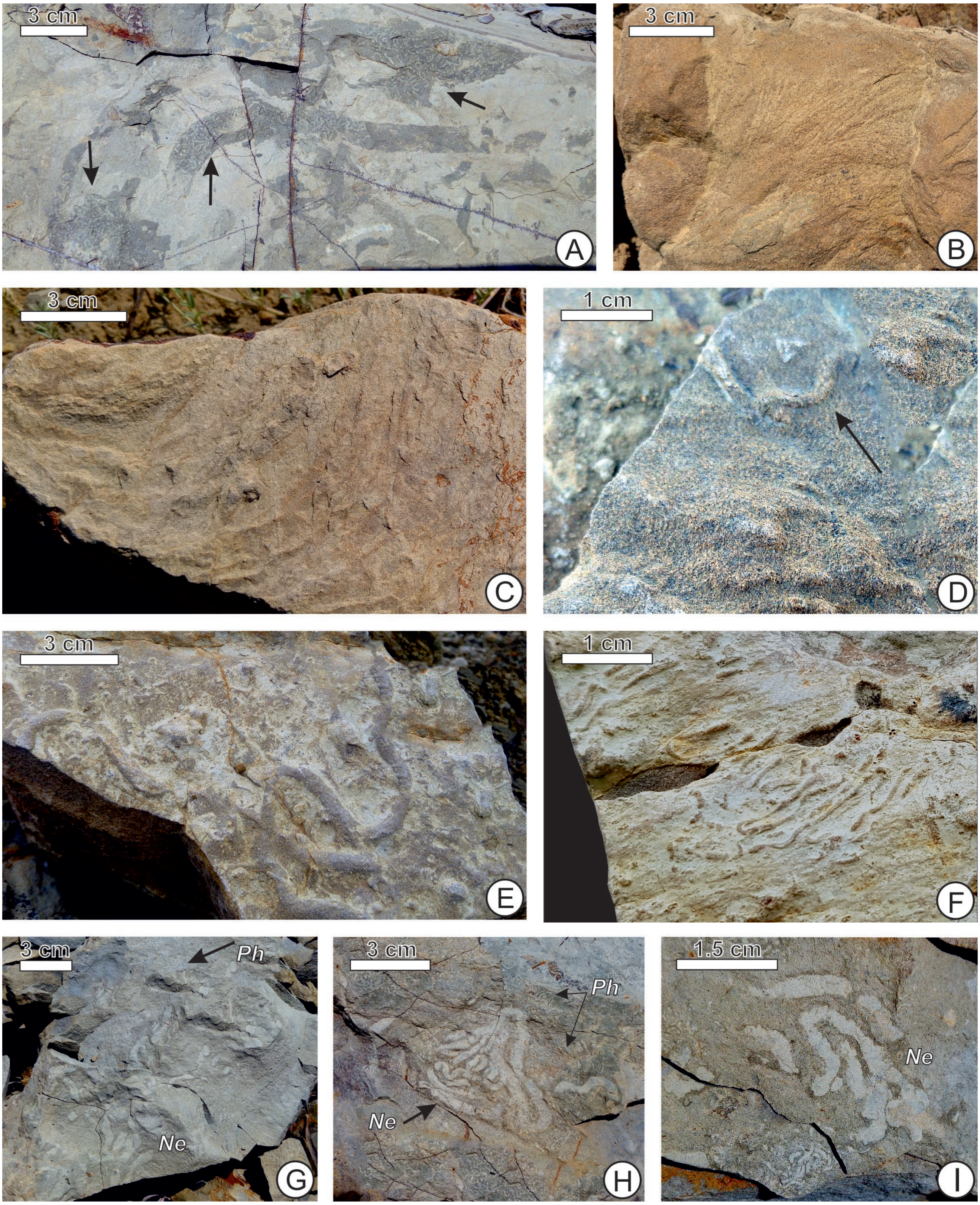

Fig. 18. Field photographs of trace fossils identified in the Haymana Fm (A, B, D–I) and the Yeşilyurt Fm (C). **A.** *Phycosiphon incertum* (black arrows), locality 1. **B.** *Zoophycos* isp., locality 2. **C.** *Zoophycos* isp., locality 5. **D.** ?*Cochlichnis* isp. (black arrows), locality 2. **E.** *Helminthopsis* isp., locality 2. **F.** *Helminthorhaphe flexuosa*, locality 2. **G–I**. *Nereites* isp., locality 1.

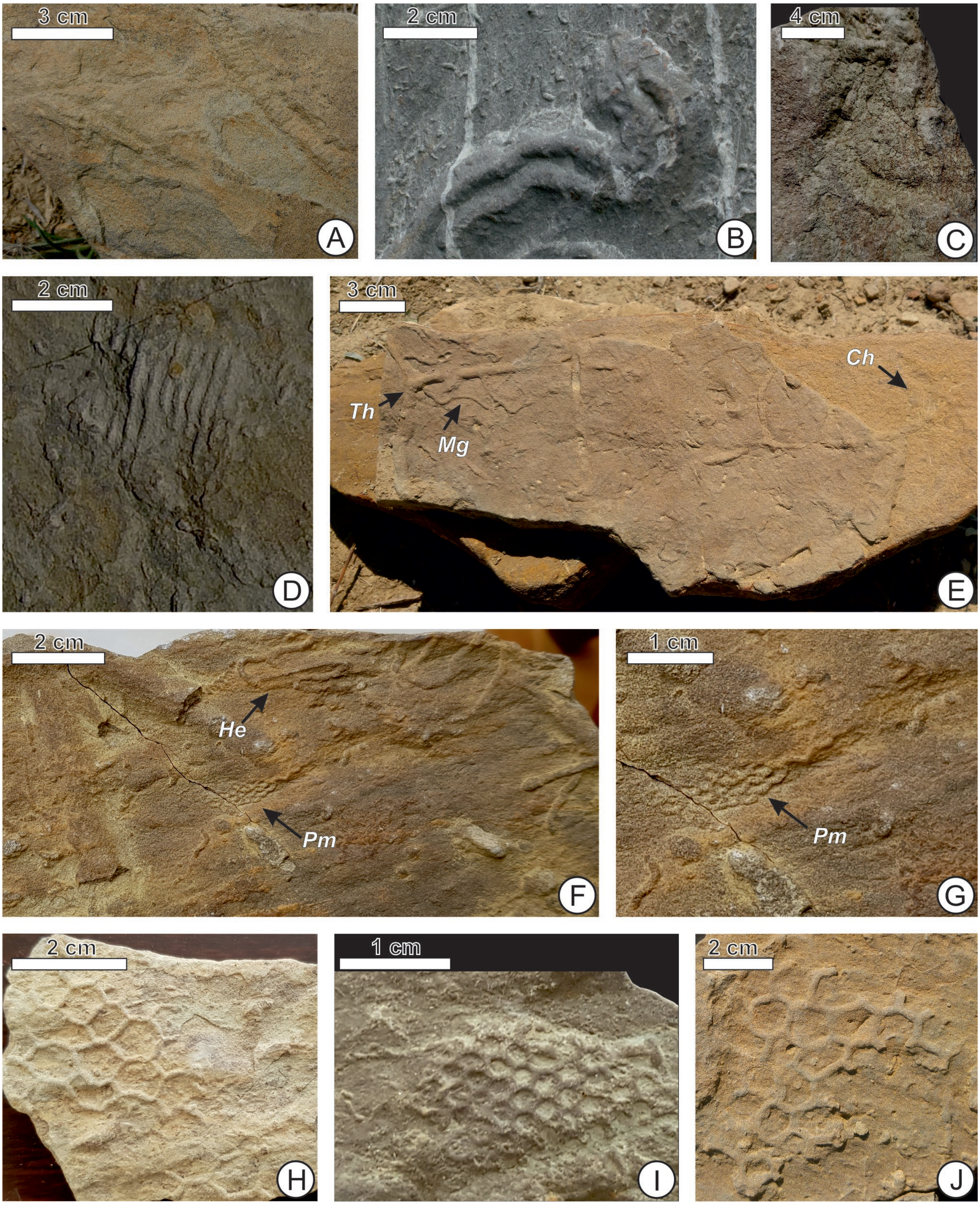

Fig. 19. Field photographs of remaining Haymana Fm (A–C) and Yeşilyurt Fm (D–J). **A.** *Scolicia prisca*, Haymana Fm, locality 4. **B.** *Scolicia strozzii*, Haymana Fm, locality 4. **C.** *Scolicia vertebralis*, Haymana Fm, locality 2. **D.** *Desmograpton* isp., Yeşilyurt Fm, locality 5. **E.** *Megagrapton submontanum*, Yeşilyurt Fm, locality 5. **F, G.** *Paleodictyon minimum,* Yeşilyurt Fm, locality 5. **H.** *Paleodictyon majus*, Yeşilyurt Fm, locality 5. **I.** *Paleodictyon latum*, Yeşilyurt Fm, locality 5. **J.** *Paleodictyon arvense*, Yeşilyurt Fm, locality 5.

Zoophycos isp. (Fig. 18B, C) is an endichnial, planar structure, filled with spreite laminae. The spreites are concordantly arcuate. The spreite lamellae may contain pellets, elliptical in outline, up to 1.5 mm long. *Zoophycos* Massalongo, 1855 is interpreted as feeding structure, which was produced by unknown deposit feeders (Bottjer *et al.,* 1988; Olivero, 2003). Mostly, It occurs in deep-sea sediments in the Cenozoic (Zhang *et al*., 2015).

Winding and meandering structures

?*Cochlichnis* isp. (Fig. 18D) is a hypichnial, semi-cylindrical ridge, 2–3 mm wide and preserved in semi-relief, forming meanders up to 7 mm wide and 8 mm in amplitude. Only one incomplete first-order meander is visible. It is poorly recognizable owing to incomplete preservation. *Cochlichnus* Hitchcock, 1858 has been interpreted as a locomotion or grazing trace fossil, which was produced by insect larvae and nematodes (Buatois *et al*., 1997; Metz, 1998). It has a wide facies range, including fluviatile and marginal-marine settings from the Precambrian to the Holocene (Häntzschel, 1975; Fillion and Pickerill, 1990; Buatois and Mángano, 1993).

Helminthopsis isp. (Fig. 18E) is a hypichnial, semi-cylindrical, loosely meandering, smooth, unbranched ridge, about 4–5 mm wide. *Helminthopsis* Wetzel & Bromley, 1996 is interpreted as a feeding or grazing trace fossil, produced by a vermiform endobiont detritus-feeder, probably a polychaete (Dam, 1990; Han and Pickerill, 1995; Uchman, 1998). It is a facies-crossing trace fossil, common in flysch (Książkiewicz, 1977). *Helminthopsis* occurs in the time interval ranging from the Cambrian to the Holocene in fully marine (Dam, 1990; Uchman, 1998; Uchman *et al*., 2005; Sarkar *et al*., 2009), deltaic (Bann and Fielding, 2004; Gani *et al*., 2007; Buatois *et al*., 2008) and non-marine settings (Buatois and Mángano, 1995, 2007; Mángano *et al*., 1996; Buatois *et al*., 1997; Krapovickas *et al*., 2009; Wetzel and Bromley, 1996).

Helminthorhaphe flexuosa Uchman, 1995 (Figs 18F, 19F) is a hypichnial meandering string, without bulges in the turns of the meanders, preserved in semi-relief in fine-grained sandstones. The string is 0.6–1 mm in diameter; the amplitude of meanders attains 25–30 mm, and their depth 2–3 mm. *H. flexuosa* is a graphoglyptid, produced by an unknown worm from mostly flysch deposits (Seilacher, 1977) and it can be a grazing trace fossil, which occurs in deep-sea sediments on the soles of fine-grained turbidites (Fan *et al*., 2017). Its range is from Upper Cretaceous to Miocene (Fan *et al*., 2017). *H. flexuosa* was also found in turbiditic sediments in the Polish Carpathians (Campanian–Palaeocene), in the Northern Apennines, Italy (Palaeocene), and in the deep-sea fan fringe deposits (Miocene) of southern Turkey (Uchman and Demircan, 1999).

Nereites isp. (Fig. 18G–I) is a horizontal, endichnial, irregularly meandering band, visible on parting surfaces. It is 3–5 mm wide. The band is lighter in colour than the host siltstone and its margins are uneven. *Nereites* MacLeay, 1839 is a typical pascichnion, produced by a worm-like sediment-feeder (Uchman, 1995; Mángano *et al*., 2002; Martin and Rindsberg, 2007). It was formed just above the redox boundary (Wetzel, 2002). *Nereites* occurs in shallow- to deep-marine deposits in the Palaeozoic (Conkin and Conkin, 1968; Hakes, 1976; Seilacher, 1983; Chaplin, 1985; Fillion and Pickerill, 1990; Rindsberg, 1994) and commonly in deep-sea Mesozoic and Cenozoic deposits (McCann and Pickerill, 1988; Crimes and McCall, 1995; Uchman, 1995; Wetzel, 2002). It ranges from from the late Precambrian-early Cambrian (Aceñolaza and Durand, 1973; Crimes and Germs, 1982) to the Miocene (Uchman, 1995) and the Quaternary (Ekdale and Lewis, 1991).

Scolicia prisca de Quatrefages, 1849 (Fig. 19A) is an epichnial, trilobate, curved or meandering furrow, 12–15 mm wide and up to 2 mm deep. The middle lobe is convex-up and 6.5 mm wide, covered with perpendicular ribs. The lateral lobes are covered by oblique ribs. *Scolicia* Quatrefages, 1849 is a pascichnion produced by spatangoid echinoids (Uchman, 1995). It is observed from shelf to deep-water environments and is known since the Late Jurassic to Recent (Tchoumatchenco and Uchman, 2001).

Scolicia strozzii (Savi and Meneghini, 1850) (Fig. 19B) is a hypichnial, loosely meandering, bilobate ridge, 13–22 mm wide, preserved in semi-relief in fine-grained sandstone turbidites. *S. strozzi* represents the washed-out remnants and casts of burrows of spatangoid echinoids. Straight to gently winding specimens are assigned to *S. strozzi* var. *vagans* (Książkiewicz, 1977) and may correspond to the locomotion activity of echinoids (Uchman, 1995).

Scolicia vertebralis Książkiewicz, 1970 (Fig. 19C) is an epichnial, three-lobed, winding and meandering, V-shaped furrow ridge, 15–25 mm wide, in medium-grained turbiditic sandstones. *S. vertebralis* is a locomotion and feeding burrow (pascichnion) of a spatangoid echinoid (Smith and Crimes, 1983; Uchman, 1995; Bromley *et al*., 1997).

Branched winding and meandering structures

?*Desmograpton* isp. (Fig. 19D) is a hypichnial, parallel to subparallel ridge, 1–1.3 mm wide, 30 mm long, semi-circular or asymmetrically oval in cross-section, preserved in semi-relief in fine-grained, turbiditic sandstones. *Desmograpton* Fuchs, 1895 is considered to be a typical pre-turbidite, graphoglyptid trace fossil (agrichnion), produced most likely by vermiform organisms, which occurs in flysch deposits from the Silurian (McCann, 1989) to the Miocene (D'Alessandro, 1980; Uchman, 1995).

Networks

Megagrapton submontanum (Azpeitia-Moros, 1933) (Fig. 19E) is a hypichnial, incompletely preserved irregular net, composed of a winding, semi-circular string. Meshes of the net are 17 mm wide, and the string is 2.5 mm wide. *Megagrapton* Książkiewicz, 1968 typical graphoglyptid, is interpreted mainly as a farming (agrichnial) structure (Seilacher, 1977). It occurs in deep-water, mainly flysch deposits, from Cenomanian to Eocene (Uchman, 1998).

Paleodictyon minimum Sacco, 1888 (Fig. 19F, G) is a hypichnial net, composed of a string that is 0.1–0.3 mm wide and arranged in meshes which are 1–2 mm wide.

The taxonomy of *Paleodictyon* Meneghini in Savi and Meneghini, 1850 was classified by Uchman (1995), according its morphometric parameters. In this study, Uchman's morphometric classification was taken into consideration for the identification of *Paleodictyon* ichnospecies. Röder (1971) and Seilacher (1977) interpreted *Paleodictyon* as agrichnial burrow systems, made to cultivate or trap microorganisms. Garlick and Miller (1993) suggested a small, elongate crustacean as the tracemaker. It occurs particulary in deep-water, mainly flysch deposits (Uchman, 1998), occasionally occurring in shelf sediments in the Palaeozoic (Archer and Maples, 1984; Pacześna, 1985) and Mesozoic (Häntzschel, 1964; Gierlowski-Kordesch and Ernst, 1987; Hantzpergue and Branger, 1992). It ranges from the Cambrian (Crimes and Anderson, 1985) to the Holocene (Ekdale, 1980).

Paleodictyon majus Meneghini in Peruzzi, 1880 (Fig. 19H) is a hypichnial, sub-hexagonal network, preserved in convex-upward semi relief. The string is no wider than about 1–1.5 mm and the maximum mesh size ranges from 7 to 12 mm. This is a common ichnospecies of *Paleodictyon* in Cenozoic turbidites (Książkiewicz, 1977).

Paleodictyon latum Vialov and Golev, 1965 (Fig. 19I) is a regular net, composed of polygonal to hexagonal meshes that are 1.8–1.6 mm wide. The meshes are formed by semi-circular ridges (strings), which are 0.5–0.4 mm wide. *Paleodictyon latum* is common in thin- to medium-bedded, turbiditic sediments (Uchman, 2007).

Paleodictyon arvense Barbier, 1956 (Fig. 19J) is preserved as a regular, hexagonal net, the meshes of which are 13.2–16 mm wide and string is 2.14–2.5 wide mm.

Paleodictyon strozzii Meneghini in Savi and Meneghini, 1850 (Fig. 20A) is a hypichnial sub-hexagonal network, preserved in convex-upward semi-relief. The string is 0.3–1 mm wide and the maximum mesh size ranges from 4 to 5 mm.

Paleodictyon isp. (Fig. 20B) is a hypichnial sub-hexagonal network, preserved in convex-upward semi-relief. The string is flat and 3.18 mm wide, and the maximum mesh size ranges from 11 to 13 mm.

DISTRIBUTION AND SIGNIFICANCE OF TRACE FOSSILS

Deposits of the section of locality 1 contain low diversity, post-depositional traces fossils (Table 3), dominated by non-graphoglyptid, including *Ophiomorpha annulata, Scolicia* isp. and *Nereites* isp. The trace fossils represent the *Ophiomorpha rudis* ichnosubfacies of the *Nereites* ichnofacies, which usually occurs in proximal depositional lobe and channel deposits of deep-sea fans (Uchman, 2009). Deposits of section of locality 2 contain a more diverse trace fossils, including non-graphoglyptid ichnotaxa (cf. *Asteriacites* isp., ?*Bergaueria* isp., *Chondrites intricatus*, ?*Cochlichnis* isp., *Helminthopsis* isp., *Ophiomorpha rudis*, *Scolicia vertebralis, Thalassinoides* isp., cf. *Thorichnus* isp.) and graphoglyptids (*Helminthorhaphe flexuosa, Paleodictyon minimum, P. strozzii*). They represent cubichnia, repichnia, pascichnia, domichnia, fodinichnia and agrichnia (Table 3). Agrichnia dominante. This ethological category occurs mostly in deep-sea turbiditic environments and characterized the *Paleodictyon* ichnosubfacies of the *Nereites* ichnofacies, which is typical of distal and some middle parts of depositional system (Uchman and Wetzel, 2012). The obtained trace fossil data suggest that the deposits from the section of locality 2 are deeper than the deposits in section of locality 1.

The sections of localities 3 and 4 contain low-diversity, non-graphoglyptid trace fossils ?*Bergaueria* isp., *Halopoa storeana*, ?*Halopoa* isp., *Ophiomorpha annulata, O. rudis, Planolites* isp., and *Thalassinoides* isp. Trace-fossils in the locality 4 section are low diverse (*Halopoa* isp., *Planolites* isp., *Scolicia prisca*, *S. strozzii*, *Thalassinoides* isp.). They represent pascichnia, domichnia and fodinichnia

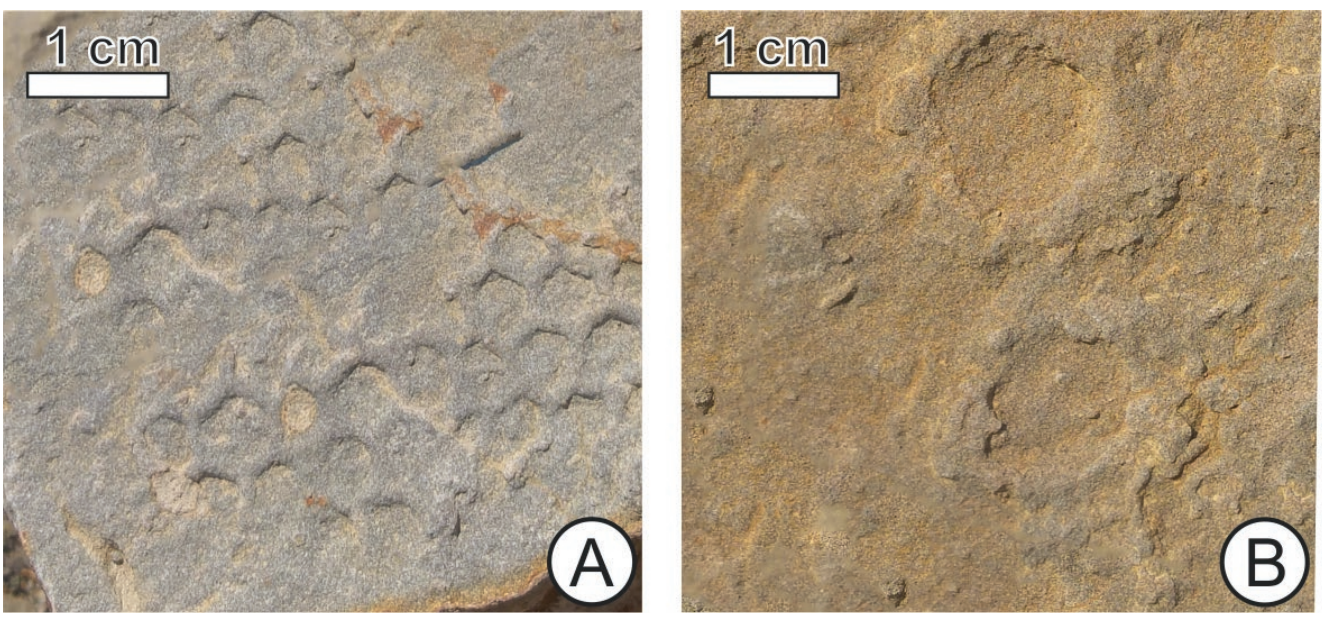

Fig. 20. Some *Paleodictyon* in the studied sections from the Yeşilyurt Fm, locality 5. **A.** *Paleodictyon strozzii*. **B.** *Paleodictyon* isp.

Table 3

Presence of ichnogenera in the Haymana and the Yeşilyurt formations, their ethology, relationship to turbiditic beds, morphological affiliation with indication of graphoglyptids. BWM –branched winding and meandering; WM – winding and meandering.

Ichnotaxa	Pre–/Post–depositional	Ethological Category	Morphological Group	Graphoglyptids
cf. *Asteriacites* isp.	Post	Cubichnia	Radial structures	
?*Bergaueria* isp.	Pre	Cubichnia	Circular and elliptical	
Chondrites isp.	Post	Chemichnia	Simple and branched	
Chondrites affinis	Post	Chemichnia	Simple and branched	
Chondrites intricatus	Post	Chemichnia	Simple and branched	
?*Cochlichnis* isp.	Pre	Repichnia	WM	
?*Desmograpton* isp.	Pre	Agrichnia	BWM	X
?*Halopoa* isp.	Post	Fodichnia	Simple and branched	
Halopoa storeana	Pre	Fodichnia	Simple and branched	
Helminthopsis isp.	Pre/Post	Pascichnia	WM	
Helminthorhaphe flexuosa	Pre	Agrichnia	WM	X
Lockeia isp.	Pre	Cubichnia	Circular and elliptical	
Megagrapton submontanum	Pre	Agrichnia	Network	X
Nereites isp.	Post	Pascichnia	WM	
Ophiomorpha annulata	Post	Domichnia	Simple and branched	
Ophiomorpha rudis	Post	Domichnia	Simple and branched	
Paleodictyon isp.	Pre	Agrichnia	Network	X
Paleodictyon arvense	Pre	Agrichnia	Network	X
Paleodictyon latum	Pre	Agrichnia	Network	X
Paleodictyon majus	Pre	Agrichnia	Network	X
Paleodictyon minimum	Pre	Agrichnia	Network	X
Paleodictyon strozzii	Pre	Agrichnia	Network	X
Palaeophycus isp.	Post	Fodichnia/Domichnia	Simple and branched	
Phycosiphon incertum	Post	Fodichnia	Spreiten	
Planolites isp.	Post	Pascichnia	Simple and branched	
Planolites beverleyensis	Post	Fodichnia	Simple and branched	
Planolites montanus	Post	Fodichnia	Simple and branched	
Scolicia prisca	Post	Pascichnia	WM	
Scolicia strozzii	Pre	Pascichnia	WM	
Scolicia vertebralis	Post	Pascichnia	WM	
Thalassinoides isp.	Post	Fodichnia/Domichnia	Simple and branched	
cf. *Thorichnus* isp.	Post	Pascichnia	Simple and branched	
Trichichnus isp.	Post	Chemichnia	Simple and branched	
?*Trichichnus linearis*	Post	Chemichnia	Simple and branched	
Zoophycos isp.	Post	Fodichnia	Spreiten	

(Cummings and Hodgson, 2011). The abundance of domichnia and fodinichnia (*Ophiomorpha annulata, O. rudis, Halopoa* isp., *Thalassinoides* isp.) indicates a proximal part of the depositional system, with a high rate of deposition.

The section of locality 5 (Yeşilyurt Fm, Paleocene) contains pascichnia, domichnia, fodinichnia and especially agrichnia, which are more abundant than in the Haymana Formation (Table 3). The graphoglyptids (?*Desmograpton* isp., *Helminthorhaphe flexuosa, Megagrapton submontanum, Paleodictyon* isp., *P. arvense, P. latum*, *P. majus, P. minimum, P. strozzii*) are more abundant than non-graphoglyptids (*Chondrites* isp., *C. affinis, C. intricatus,* ?*Halopoa* isp., *Halopoa storeana*, *Lockeia* isp., *O. annulata, Planolites* isp., *P. beverleyensis*, *P. montanus*, *Scolicia prisca*, *S., strozzii, Thalassinoides* isp., and *Zoophycos* isp.). The graphoglyptids are most characteristic for deep-sea, ichnological assemblages, typical of the *Paleodictyon* ichnosubfacies of the *Nereites* ichnofacies (Uchman, 2003; Uchman & Wetzel, 2012). The assemblage of the trace fossils does not show any significant difference with respect to trace fossils of the same ichnosubfacies in the Cretaceous Haymana Formation. This indicates that the Cretaceous-Palaeogene extinction did not influence the tracemakers over longer time intervals (cf. Uchman, 2004).

CONCLUSIONS

Trace fossils of the Haymana and the Yeşilyurt formations in the Haymana Basin are moderately diverse in both Maastrichtian and Paleocene deposits. Their main features are as follows:

1. Thirty-five ichnospecies, belonging to 21 ichnogenera and six morphologic groups, are recognized. The following ichnofossils were identified: cf. *Asteriacites* isp., ?*Bergaueria* isp., *C. intricatus*, *C. affinis, Chondrites* isp., ?*Cochlichnus* isp., ?*Desmograpton* isp., *H. storeana*, ?*Halopoa* isp., *Helminthopsis* isp., *Helminthorhaphe flexuosa*, *Lockeia* isp., *Megagrapton submontanum, Nereites* isp., *Ophiomorpha rudis, O. annulata, Palaeophycus* isp., *Paleodictyon* isp., *P. arvense, P. latum, P. majus,*

P. minimum, P. strozzii, *Phycosiphon incertum, P. beverleyensis, P. montanus, Planolites* isp., *Scolicia strozzii, S. prisca*, *S. vertebralis*, *Thalassinoides* isp., cf. *Thorichnus* isp., ?*Trichichnus linearis, Trichichnus* isp., *Zoophycos* isp. Among these *Chondrites intricatus*, *C. affinis, Chondrites* isp., ?*Halopoa* isp., *O. annulata, P. minimum, P. strozzii*, *Planolites* isp., *Scolicia strozzii, S. prisca*, *Thalassinoides* isp., and *Zoophycos* isp. are the most common. Most of the traces represent pascichnia, domichnia, fodinichnia and agrichnia (Table 3). They belong to the *Nereites* ichnofacies.

2. In this study, the specimen of cf. *Thorichnus* isp. the Haymana Formation was described for the first time in deep-sea deposits.
3. According to the identified ichnosubfacies identified, the Haymana Formation (Maastrichtian) represents the proximal to middle and partly distal parts of deep-sea fans, while the Yeşilyurt Formation (Paleocene) indicates the middle to distal fan deposits.
4. The trace fossils do not show any significant change above the K-Pg boundary with respect to these below the boundary. However, the boundary interval was not examined.
5. The larger benthic foraminifera present in the formations studied were derived from nearby, shallow parts of the Haymana Formation. They were redeposited in a turbiditic environment.

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REFERENCES

Aceñolaza, F. G. & Durand, F. R., 1973. Trazas fósiles del basamento cristalino del Noroeste argentino. *Boletín de la Asociación Geológica de Córdoba,* 2: 45–55.

Amirov, E., 2008. *Planktonic Foraminiferal Biostratigraphy, Sequence Stratigraphy and Foraminiferal Response to Sedimentary Cyclicity in the Upper Cretaceous–Paleocene of the Haymana Basin (Central Anatolia, Turkey)*. MSc Thesis, Middle East Technical University, 213 pp.

Archer, A. W. & Maples, C. G., 1984. Trace fossil distribution across a marine to nonmarine gradient in the Pennsylvanian of South Western Indiana. *Journal of Paleontology*, 58: 448–466.

Archiac, E. J. A. D. d'., 1837. Mémoire sur la formation Crétacée du sud-ouest de la France. *Mémoires de la Société géologique de France,* 2: 157–192.

Astre, G., 1924. Etude paléontologique des *Nummulites* du Crétacé Supérieur de Cézan-Lavardens (Gers) [*Nummulites mengaudi* n. sp.]. *Bulletin de la Société géologique de France, Série 4*, 23 [for 1923]: 360–368.

Atıcı, G., Dönmez, M., Çobankaya, M., Sevin, M., Gündoğdu-Atakay, E., Esirtgen, E. & Şimşek, E., 2014. *MTA Genel Müdürlüğü 1/100000 ölçekli Türkiye Jeoloji Haritaları No: 209 Ankara J29 Paftası*. MTA Jeoloji Etüdleri Dairesi. [In Turkish.]

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.

Bann, K. L. & Fielding, C. R., 2004. An integrated ichnological and sedimentological comparison of non-deltaic shoreface and subaqueous delta deposits in Permian reservoir units of Australia. In: McIlroy, D. (ed.), *The application of ichnology to palaeoenvironmental and stratigraphic analysis*. *The Geological Society of London, Special Publication,* 228: 273–310.

Barbier, R., 1956. Decouverte d'un *Palaeodictyon* dans le Dogger ultradauphinois de la region des Aiguilles d'Arves. *Travaux du Laboratoire de la Faculte des Sciences de l'Universite de Grenoble*, 33: 125–133.

Bednarz, M. & McIlroy, D., 2009. Three-dimensional reconstruction of "phycosiphoniform" burrows: Implications for identification of trace fossils in core. *Palaeontologia Electronica*, 12: 13A.

Billings, E., 1862. *New species of fossils from different parts of the Lower, Middle and Upper Silurian rocks of Canada. Palaeozoic Fossils, Volume I (1861–1865)*. Geological Survey of Canada, Dawson Brothers, Montreal, pp. 96–168.

Bottjer, D. J., Droser, M. L. & Jablonski, D., 1987. Bathymetric trends in the history of trace fossils. In: Bottjer, D. J. (ed.), *New Concepts in the Use of Biogenic Sedimentary Structures for Palaeoenviromental Interpretation*. SEPM, Pacific Section, Los Angeles, pp. 57–65.

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

Boubée, N., 1832. Présentation à Ia Société de deux nouvelles espèces de *Nummulites*. *Bulletin de la Société géologique de France,* 2: 444–445.

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

Bromley, R. G., Asgaard, U. & Jensen, M., 1997. Experimental study of sediment structures created by a spatangoid echinoid, *Echinocardium mediterraneum. Proceedings of the Geologists' Association,* 108: 183–189.

Brongniart, A. T., 1823. Observations sur les *Fucoides*. *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*. Dufour et d' Ocagne, Paris, 488 pp.

Brönnimann, P. & Wirz, A., 1962. New Maastrichtian rotaliids from Iran and Libya. *Eclogae Geologicae Helvetiae,* 55: 519–528.

Buatois, L. A., Jalfin, G. & Aceñolaza, F. G., 1997. Permian nonmarine invertebrate trace fossils from Southern Patagonia, Argentina: ichnologic signatures of substrate consolidation and colonization sequences. *Journal of Paleontology*, 71: 323–336.

Buatois, L. A. & Mángano, M. G., 1993. Trace fossils from a Carboniferous turbiditic lake: implications for the recognition of additional nonmarine ichnofacies. *Ichnos*, 2: 237–258.

Buatois, L. A. & Mángano, M. G., 1995. The paleoenvironmental and paleoecological significance of the lacustrine *Mermia* ichnofacies: an archetypical subaqueous nonmarine trace fossil assemblage. *Ichnos*, 4: 151–161.

Buatois, L. A. & Mángano, M. G., 2007. Invertebrate ichnology of continental freshwater environments. In: Miller, W., III (ed.), *Trace Fossils Concepts, Problems, Prospects*. Elsevier, Amsterdam, pp. 285–323.

Buatois, L. A., Santiago, N., Parra, K. & Steel, R., 2008. Animal-substrate interactions in an Early Miocene wave-dominated tropical delta: delineating environmental stresses and depositional dynamics (Tácata Field, eastern Venezuela). *Journal of Sedimentary Research*, 78: 458–479.

Chaplin, J. R., 1985. Early Mississippian deltaic sedimentation in northeastern Kentucky. In: Haban, S. M. (ed.), Carboniferous of Eastern Kentucky. *Guidebook Field Excursion 6, Sixth Gondwana Symposium*. Columbus, Ohio, pp. 26–35.

Chaput, E., 1935. L'Éocène du Plateau de Galatie (Anatolie Centrale). *Comptes Rendus de l'Académie des Sciences,* 200: 767–768.

Cizancourt, M. de, 1949. Matériaux pour Ia paléontologie et la Stratigraphie des régions Caraibes. *Bulletin de la Société géologique de France,* 18: 663–674.

Conkin, J. E. & Conkin, B. M., 1968. *Scalarituba missouriensis* and its stratigraphic distribution. *The University of Kansas Paleontological Contributions*, 31: 1–7.

Cox, P., 1937. The genus *Loftusia* in South Western Iran. *Eclogae Geologicae Helvetiae*, 30: 431–450.

Crimes, T. P., 1987. Trace fossils and correlation of late Precambrian and early Cambrian strata. *Geological Magazine*, 124: 97–119.

Crimes, T. P. & Anderson, M. M., 1985. Trace fossils from late Precambrian–Early Cambrian of southeastern Newfoundland (Canada): temporal and environmental implications. *Journal of Paleontology*, 59: 310–343.

Crimes, T. P. & Crossley, J. D., 1991. A diverse ichnofauna from Silurian flysch of the Aberystwyth Grits formation, Wales. *Geological Journal*, 26: 27–64.

Crimes, T. P. & Germs, G. J. B, 1982. Trace fossils from the Nama Group (Precambrian-Cambrian) of southwest Africa (Namibia). *Journal of Paleontology*, 56: 890–907.

Crimes, T. P. & McCall, G. J. H., 1995. A diverse ichnofauna from Eocene–Miocene rocks of the Makran Range (S.E. Iran). *Ichnos,* 3: 231–258.

Cummings, J. P. & Hodgson, D. M., 2011. Assessing controls on the distribution of ichnotaxa in submarine fan environments, the Basque Basin, Northern Spain. *Sedimentary Geology,* 239: 162–187.

Cushman, J. A., 1947. *Ammobaculites paleocenicus* Cushman, a new name. *Contributions from the Cushman Laboratory for Foraminiferal Research*, 22: 23–77.

Cushman, J. A. & Bermúdez, P. J., 1947. Some Cuban foraminifera of the genus *Rotalia*. *Contributions from the Cushman Laboratory for Foraminiferal Research,* 2: 23–29.

D'Alessandro, A., 1980. Prime osservazioni sulla ichnofauna miocenica della "formazione di Gorgolione" (Castelmezzano, Potenza). *Rivista Italiana di Paleontologia e Stratigrafia*, 86: 357–398.

Dam, G., 1990. Taxonomy of trace fossils from the shallow marine Lower Jurassic Neill Klinter Formation, East Greenland. *Bulletin of the Geologic Society Denmark*, 38: 119–144.

Demircan, H. & Uchman, A., 2016. Trace fossils from deep sea sediments of the Ceylan Formation (SW Thrace, Turkey). *Bulletin of the Mineral Research and Exploration*, 153: 91–111.

Demircan, H. & Uchman, A., 2017. Short distance variability of trace fossils in submarine slope and proximal basin plain deposits: a case study from the Ceylan Formation (upper Eocene), Gelibolu Peninsula, NW Turkey. *Bollettino della Società Paleontologica Italiana*, 56: 253–275.

Demirel, İ. H. & Şahbaz, A., 1994. Haymana, Paşadağ-Aladağ havzalarının petrofasiyes ve provenans karakteristikleri ile petrol potansiyeli. In: TMMOB Petrol Mühendisleri Odası, Türkiye Petrol Jeologları Derneği & Jeofizik Mühendisleri Odası (ed.), Türkiye 10. *Petrol Kongresi ve Sergisi Bildiri Özleri (10th Petroleum Congress and Exhibition of Turkey). Conference Papers and Proceedings*. Chamber of Petroleum Engineers of Turkey, Ankara, pp. 5–19. [In Turkish.]

Dinçer, F., 2016. Eocene benthic foraminiferal assemblages from Central Anatolia (Turkey): Biostratigraphy, stable isotope data, paleoenvironmental and paleontological interpretations. *Journal of African Earth Sciences,* 114: 143–157.

Dizer, A., 1964. Sur quelques alveolines de l'Eocene de Turquie. *Revue de Micropaléontologie*, 7: 265–279.

Dizer, A., 1968. Etude micropaléntologique du nummulitique de Haymana (Turquie). *Revue de Micropaléontologie*, 11: 13–21.

Drobne, K., 1974. Les grandes miliolides des couches paleogenes de la Yugoslavie du nord-ouest. *Razprave 4 Razreda Slovenska Akademija Znanosti in Umetnosti,* 17: 125–184.

Duru, M. & Gökçen, N., 1990. Polatlı (GB Ankara) güneyi Monsiyen-Küiziyen istifinin ostrakod biyostratigrafisi ve ortamsal yorumu. *Bulletin of the Mineral Research and Exploration*, 110: 165–174. [In Turkish.]

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

Ekdale, A. A., 1980. Graphoglyptid burrows in modern deep-sea sediment. *Science*, 207: 304–306.

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

Esmeray, S., 2008. *Cretaceous/Paleogene Boundary in the Haymana Basin, Central Anatolia, Turkey: Micropaleontological, Mineralogical and Sequence Stratigraphic Approach.* MSc Thesis. The Graduate School of Natural and Applied Sciences of Middle East Technical University, 271 pp.

Esmeray-Senlet, S., Özkan-Altıner, S., Altıner, D., & Miller, K. G., 2015. Planktonic foraminiferal biostratigraphy, microfacies analysis, sequence stratigraphy, and sea-level changes across the Cretaceous-Paleogene boundary in the Haymana Basin, Central Anatolia, Turkey. *Journal of Sedimentary Research,* 85: 489–508.

Fan, R. Y., Uchman, A. & Gong, Y. M., 2017. From morphology to behaviour: Quantitative morphological study of the trace fossil *Helminthorhaphe*. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 485: 946–955.

Fillion, D. & Pickerill, R. K., 1990. Ichnology of the Upper Cambrian to Lower Ordovician Bell Islands 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 und Companie, Bern, 72 pp.

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

Frey, R. W., Howard, J. D. & Pryor, W. A., 1978. *Ophiomorpha*: Its morphologic, taxonomic, and environmental significance. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 23: 199–229.

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.

Gani, M. R., Bhattacharya, J. P. & MacEachern, J. A., 2007. Using ichnology to determine relative influence of waves, storms, tides and rivers in deltaic deposits: examples from Cretaceous delta complexes in the Western Interior Seaway, Wyoming – Utah, USA. In: MacEachern, J. A., Bann, L. K., Gingras, M. K. & Pemberton, S. G. (eds), *Applied ichnology*. *SEPM, Short Course Notes,* 52: 209–225.

Garlick, G. D. & Miller, W. C., III., 1993. Simulations of burrowing strategies and construction of *Paleodictyon*. *Journal of Geological Education*, 41: 159–163.

Gierlowski-Kordesh, E. & Ernst, G., 1987. A flysch trace fossil assemblage from the Upper Cretaceous shelf o f Tanzania. In: Mathesis, G. & Schandelmeier, H. (eds), *Current Research in African Earth Sciences*, *14th Colloquium on African Geology, Berlin, 18–22 August.* Balkema, Rotterdam, pp. 217–221.

Goldring, R., Pollard, J. E. & Taylor, A. M., 1991. *Anconichnus horizontalis*: A perspective ichnofabric-forming trace fossil in post-Paleozoic offshore siliciclastic facies. *Palaios*, 6: 250–263.

Görmüş, M., Demircan, H., Kadıoğlu, Y. K., Yağmurlu, F. & Us, M. S., 2019. Microborings as indication of cryptic life modes in the foraminifer *Orbitoides*: Maastrichtian sediments of the Haymana and Nallıhan districts (Ankara, Turkey). *Turkish Journal of Earth Sciences,* 28: 232–251.

Hakes, W. G., 1976. Trace fossils and depositional environment of four clastic units, Upper Pennsylvanian megacyclothems, northeast Kansas. *University of Kansas Paleontological Contributions*, 63: 1–46.

Hall, J., 1847. *Palaeontology of New York, Volume I, Containing Descriptions of the Organic Remains of the Lower Division of the New York System (Equivalent to the Lower Silurian rocks of Europe).* C. Van Benthuysen, Albany, 338 pp.

Han, Y. & Pickerill, R. K., 1995. Taxonomic revision of the ichnogenus *Helminthopsis* Heer 1877 with a statistical analysis of selected ichnospecies. *Ichnos*, 4: 83–118.

Hantzpergue, P. & Branger, P., 1992. L'ichnogenre *Paleodictyon* dans les depots neritiques de l'Oxfordien superieur Nord Aquitaine (France). *Geobios*, 25: 195–205.

Häntzschel, W., 1964. Spurenfossilien und Problematica im Campan von Beckum (Westfalen). *Fortschritte in der Geologie von Rheinland und Westfalen*, 7: 295–308.

Häntzschel, W., 1975. Trace fossils and problematica. In: Teichert, C. (ed.), *Treatise on Invertebrate Paleontology. Part W, Miscellanea, Supplement I.* Geological Society of America and University of Kansas Press, Colorado, Boulder, Lawernce, Kansas, 269 pp.

Hitchcock, E., 1858. *Ichnology of New England. A Report on the Sandstone of the Connecticut Valley, Especially Its Fossil Foot Marks*. W. White, Boston. 220 pp.

Hoşgör, İ., 2012. *Haymana-Polatlı havzası paleosen mollusklarının taksonomik tanımlanması, paleoekolojisi, Paleocoğrafyası ve bentik foraminiferlerle biyostratigrafik deneştirilmesi.* Doktora tezi, Ankara Üniversitesi, Fen Bilimleri Enstitüsü, 145 pp. [In Turkish.]

Howard, J. D. & Frey, R. W., 1984. Characteristic trace fossils in nearshore to offshore sequences, Upper Cretaceous of eastcentral Utah. *Canadian Journal of Earth Sciences,* 21: 200–219.

Inan, N., 1988. Sur la présence de la nouvelle espèce Cuvillierina sireli dans le Thanétien de la montagne de Tecer (Anatolie Centrale, Turquie). *Revue de Paléobiologie,* 1: 121−127.

Inan, N., 1996. *Selimina spinalis* n.gen. n.sp., a new upper Maastrichtian foraminifer from northeastern Turkey. *Revue de Paléobiologie,* 15: 215−223.

James, U. P., 1879. Description of new species of fossils and remarks on some others, from the Lower and Upper Silurian rocks of Ohio. *The Palaeontologist*, 3: 17–24.

Karabeyoğlu, A. U., 2017. *Planktonic Foraminiferal Diversity and Abundance Changes Across Cretaceous-Paleogene Boundary Beds ın the Haymana Basin and New Observations on the Extinction Horizon.* MSc Thesis. The Graduate School of Natural and Applied sciences of Middle East Technical University, 299 pp.

Kędzierski, M., Uchman, A., Sawlowicz, Z. & Briguglio, A., 2015. Fossilized bioelectric wire – the trace fossil *Trichichnus*. *Biogeosciences*, 12: 2301–2309.

Kern, J. P. & Warme, J. E., 1974. Trace fossils and bathymetry of the Upper Cretaceous Point Loma formation, San Diego, California. *Geological Society of America Bulletin*, 85: 893–900.

Knaust, D., 2017. *Atlas of Trace Fossils in Well Core: Appearance, Taxonomy and Interpretation.* Springer, *Dordrecht,* 271 pp.

Krapovickas, V., Ciccioli, P. L., Mángano, M. G., Marsicano, C. A. & Limarino, C. O., 2009. Paleobiology and paleoecology of an arid-semiarid Miocene South American ichnofauna in anastomosed fluvial deposits. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 284: 129–152.

Książkiewicz, M., 1968. On some problematic organic traces from the flysch of the Polish Carpathians. *Rocznik Polskiego Towarzystwa Geologicznego***,** 38: 3–17. [In Polish, with English abstract.]

Książkiewicz, M., 1970. Observations on the ichnofauna of the Polish Carpathians. In: Crimes, T. P. & Harper, J. 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.

Lamarck, J. B., 1801. *Système des animaux sans vertèbres, ou tableau général des classes, des ordres et des genres de ces animaux; Présentant leurs caractères essentiels et leur distribution, d'apres la considération de leurs rapports naturels et de leur organisation, et suivant l'arrangement établi dans les galeries du Muséum d'Histoire Naturelle, parmi leurs dépouilles conservées; Précédé du discours d'ouverture du Cours de Zoologie, donné dans le Muséum National d'Histoire Naturelle l'an 8 de la République*. Published by the author and Deterville, Paris, 432 pp.

Lamarck, J.-B. M., de, 1816. *Histoire naturelle des animaux sans vertèbres. Tome second.* Paris, Verdière, 568 pp.

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

Mángano, M. G. & Buatois, L. A., 2016. The Cambrian explosion. In: Mángano, M. G. & Buatois, L. A. (eds), *The Trace-Fossil Record of Major Evolutionary Events, Vol. 1, Precambrian and Paleozoic*. *Topics in Geobiology*, 39: 71–126.

Mángano, M. G., Buatois, L. A. & Claps, G. L., 1996. Grazing trails formed by soldier fly larvae (Diptera: Stratiomyidae) and their paleoenvironmental and paleoecological implications for the fossil record. *Ichnos*, 4: 163–167.

Mángano, G. M., Buatois, L., A., 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.

Martin, A. J. & Rindsberg, A. K., 2007. Arthropod trace makers of *Nereites*? Neoichnological observations of juvenile limulids and their paleoichnological applications. In: Miller, W., III (ed.), *Trace Fossils. Concepts, Problems, Prospects*. Elsevier, Amsterdam, pp. 478–491.

Massalongo, A., 1855. *Zoophycos*, *novum genus plantorum fossilium*. Antonelli, Verona, 52 pp.

McCann, T., 1989. The ichnogenus *Desmograpton* from the Silurian of Wales – first record from the Paleozoic. *Journal of Paleontology*, 58: 950–953.

McCann, T. & Pickerill, R. K., 1988. Flysch trace fossils from the Cretaceous Kodiak Formation of Alaska. *Journal of Paleontology*, 62: 330–348.

Meriç, E., 1979. *Loftusia ketini* (Foraminifèra) nouvelle espèce du Maestrichtian. *Revista Española de Micropaleontologia*, 11: 509–516.

Meriç, E., 1984. *Scandonea de castro* (1971) nin Paleosen' deki varlığı hakkında. *Türkiye Jeoloji Kurumu Bülteni,* 27: 41–44. [In Turkish.]

Metz, R., 1998. Nematode trails from the Late Triassic of Pennsylvania. *Ichnos,* 5: 303–308.

Mikuláš, R., 1992. The ichnogenus *Asteriacites*: paleoenvironmental trends. *Vêstnik Ceského geologického ústavu*, 67: 423–433.

Müller, A. H., 1980. Zur Ichnologie und Lebensweise triadischer Asterozoa. *Freiberger Forschungsheft Reiche C: Geowissenschaften Mineral Geochemische*, 357: 69–76.

Naruse, H. & Nifuku, K., 2008. Three-dimensional morphology of the ichnofossil *Phycosiphon incertum* and its implication for paleoslope inclination. *Palaios*, 23: 270–279.

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.

Okay, A. I. & Altıner, D., 2016. Carbonate sedimentation in an extensional active margin: Cretaceous history of the Haymana region, Pontides. *International Journal of Earth Sciences,* 105: 2013–2030.

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

Özcan, E. & Özkan-Altıner, S., 1997. Late Campanian-Maastrichtian evolution of orbitoidal foraminifera in Haymana Basin succession (Ankara, Central Turkey). *Revue de Paleobiologie*, 16: 271–290.

Pacześna, J., 1985. Ichnogenus *Paleodictyon* Meneghini from the Lower Cambrian of Zbilutka (Góry Świętokrzyskie). *Kwartalnik Geologiczny*, 29: 589–596. [In Polish, with English summary.]

Pacześna, J., 2010. Ichnological record of the activity of Anthozoa in the early Cambrian succession of the Upper Silesian Block (southern Poland). *Acta Geologica Polonica*, 60: 93–103.

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

Pemberton, G. S., Frey, R. W. & Bromley, R. G., 1988. The ichnotaxonomy of *Conostichus* and other plug-shaped ichnofossils. *Canadian Journal of Earth Sciences,* 25: 866–892.

Peruzzi, D. G., 1880. Osservazioni sui generi *Paleodictyon* e *Paleomeandron* dei terreni cretacei ed eocenici dell' Appennino settentrionale e centrale. *Atti della Società Toscana di Scienze Naturali Residente in Pisa, Memorie,* 5: 3–8.

Pickerill, R. K., 1989. *Bergaueria perata* Prantl, 1945 from the Silurian of Cape George, Nova Scotia. *Atlantic Geology*, 25: 191–197.

Pokorný, R., Krmíček, L. & Sudo, M., 2017. An endemic ichnoassemblage from a late Miocene paleolake in SE Iceland. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 485: 761–773.

Prantl, F., 1945. Two new problematic trails from the Ordovician of Bohemia. *Académie Tcheque des Sciences, Bulletin International, Classe des Sciences Mathematiques, Naturelles et de la Médicine*, 46: 49–59.

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

Rahaghi, A., 1983. Stratigraphy and Faunal assemblage of Paleocene–Lower Eocene in Iran. *Geological Laboratory Publication,* 10: 1–73.

Reichel, M., 1936–1937. Etude sur les Alvéolines. *Mémoires de la Société Paléontologique Suisse,* 57: 1–93; 59: 95–147.

Reichel, M., 1949. Sur un nouvel Orbitoidé du Crétacé supérieur hellénique. *Eclogae Geologicae Helvetiae,* 2: 480–485.

Reuss, A. E., 1860. Die Foraminiferen der westphälischen Kreideformation. *Sitzungsberichte der mathematisch--naturwissenschaflichen Classe der kaiserlichen Akademie der Wissenschaften,* 8: 147–238.

Reuss, A. E., 1862. Paläontologische Beiträge II. Die Foraminiferen des Kreidetuffs von Maastricht. *Sitzungsberichte der kaiserlichen Akademie der Wissenschaften in Wien, Mathematisch-naturwissenschaftliche Classe*, 1: 304–324.

Riahi, S., Uchman, A., Stow, D., Soussi, M. & Ben Ismail-Lattrache, K., 2014. Deep-sea trace fossils of the Oligocene-Miocene Numidian Formation, northern Tunisia. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 414: 155–177.

Richter, R., 1937. Marken und Spuren aus allen Zeiten. I–II. *Senckenbergiana,* 19: 150–163.

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.

Röder, H., 1971. Gangsysteme von *Paraonis fulgens* Levinsen 1883 (Polychaeta) in ökologischer, biologischer ethologischer und aktuo-paläontologischer Sicht. *Senckenbergiana Maritima*, 3: 3–51.

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

Sarkar, S., Ghosh, S. K. & Chakraborty, C., 2009. Ichnology of a Late Palaeozoic ice-marginal shallow marine succession: Talchir Formation, Satpura Gondwana Basin, central India. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 283: 28–45.

Savi, P. & Meneghini, G. G., 1850. Osservazioni stratigrafiche e paleontologiche concernenti la geologia della Toscana e dei paesi limitrofi, In: Murchison, R. L., *Memoria sulla struttura geologica delle Alpi, degli Apennini e dei Carpazi.* Stamperia granducale, Firenze, pp. 246–528.

Savrda, C. E., Browning, J. V., Krawinkel, H. & Hesselbo, S. P., 2001. Firmground ichnofabrics in deep-water sequence stratigraphy, Tertiary clinoform-toe deposits, New Jersey slope. *Palaios*, 16: 294–305.

Schlirf, M., 2003. Palaeoecologic significance of Late Jurassic trace fossils from the Boulonnais, N France. *Acta Geologica Polonica*, 53: 123–142.

Schlotheim, E. F. B., von, 1820. *Die Petrefactenkunde auf ihrem jetzigen Standpunktedurch die Beschreibung seiner Sammlung versteinerter und fossiler Überreste des Thier- und Pflanzenreichs der Vorwelterläutert*. Becker, Gotha, 437 pp.

Schlumberger, C., 1902. Première note sur les Orbitoïdes. *Bulletin de la Société Géologique de France,* 4: 459–467.

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. Use of trace fossil assemblages for recognizing depositional environments. In: Basan, P. B. (ed.), *Trace fossil concepts. Society of Economic Paleontologists and Mineralogists, Short Course*, 5: 185–20l.

Seilacher, A., 1983. Upper Paleozoic trace fossils from the Gilf Kebir-Abu Ras area in southwestern Egypt. *Journal of African Earth Sciences,* 1: 21– 34.

Seilacher, A., 1990. Aberrations 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.

Sirel, E., 1973. Description of a new *Cuvillierina* species from the Maastrichtian of Cide (Northern Turkey). *Bulletin of the Geological Society of Turkey,* 2: 69–76.

Sirel, E., 1981. *Bolkarina*, new genus (Foraminiferida) and some associated species from the Thanetian limestone (Central Turkey). *Eclogae Geologicae Helvetiae*, 1: 75–95.

Sirel, E., 1998. Foraminiferal description and biostratigraphy of the Paleocene-Lower Eocene shallow-water limestones and discussion on the Cretaceous-Tertiary boundary in Turkey. *General Directorate of the Mineral Research and Exploration, Monography Series*, 2, 117 pp.

Sirel, E., 1999. Four new genera (*Haymanella, Kayseriella, Elazigella* and *Orduella*) and one new species of *Hottingerina* from the Paleocene of Turkey. *Micropaleontology*, 45: 113–137.

Sirel, E., 2009. Reference sections and key localities of the Paleocene stages and their very shallow/shallow-water three new benthic foraminifera in Turkey. *Revue de Paléobiologie* 28: 413–435.

Sirel, E., 2010. Paleojen katlarının Türkiye'deki başvuru kesitleri, anahtar lokaliteleri ve onların karakteristik çok sığ/sığ su denizel bentik foraminiferleri. *Jeoloji Mühendisleri Odası Yayınları,* 105, *Special Issue* 3, 145 pp. [In Turkish.]

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

Stachacz, M., 2012. Ichnology of Czarna Shale Formation (Cambrian, Holy Cross Mountain, Poland), *Annales Society Geologia Polonica,* 82: 105–120.

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

Tanık, G., 2017. *Upper Paleocene-Lowemost Eocene Planktonic Foraminiferal Biostratigraphy and Record of the Paleocene-Eocene Thermal Maximum in the Haymana Basin (Ankara, Turkey).* Ms. Thesis. Middle East Technical University, 258 pp.

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.

Thiadens, A. A, 1937. Cretaceous and Tertiary foraminifera from Southern Santa Clara Province. *Journal of Paleontology*, 11: 91–101.

Toker, V., 1975. *Haymana yöresinin (Güneybatı Ankara) planktonic foraminifera ve nannoplanktonlarla biyostratigrafik incelenmesi.* Doktora tezi, Ankara Üniversitesi Fen Fakültesi, Ankara, 57 pp. [In Turkish.]

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

Twitchett, R. J. & Wignall, P. B., 1996. Trace fossils and the aftermath of the Permo-Triassic mass extinction: evidence from northern Italy. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 124: 137–151.

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: Mcllroy, D. (ed.), Application of ichnology to palaeoenvironmental and stratigraphic analysis. *The Geological Society of London Special Publication,* 228: 125–139.

Uchman, A., 2007. Trace fossils of the Pagliaro Formation (Paleocene) in the Northern Apennines, Italy. *Beringeria*, 37: 217–237.

Uchman, A., 2009. The *Ophiomorpha rudis* ichnosubfacies of the *Nereites* ichnofacies: Characteristics and constraints. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 276: 107–119.

Uchman, A., Caruso, C. & Sonnino, M., 2012. Taxonomic review of *Chondrites affinis* (Sternberg, 1833) from Cretaceous-Neogene offshore-deep-sea Tethyan sediments and recommendation for its further use. *Rivista Italiana di Paleontologia e Stratigrafia,* 118: 313–324.

Uchman, A. & Demircan, H., 1999. Trace fossils of Miocene deep-sea fan fringe deposits from the Cingöz Formation, southern Turkey. *Annales Societatis Geologorum Poloniae*, 69: 125–135.

Uchman, A., Hanken, N. & Binns, R., 2005. Ordovician bathyal trace fossils from metasiliciclastics in Central Norway and their sedimentological and paleogeographical implications. *Ichnos*, 12: 105–133.

Uchman, A. & Wetzel, A., 2012. Deep-sea fans. In: Knaust, D. & Bromley, R. G. (eds), Trace fossils as indicators of sedimentary environments. Developments in Sedimentology, 64: 643–671.

Ünalan, G., Yüksel, V., Tekeli, T., Gönenç, D., Seyirt, Z. & Hüseyin, S., 1976. Haymana-Polatlı yöresinin Üst Kretase-Alt Tersiyer stratigrafisi ve paleocoğrafik evrimi: *Türkiye Jeoloji Kurumu Bülteni,* 19: 159–176. [In Turkish.]

Vardar, E., 2018. *Deep Sea Benthic Foraminiferal Diversity and Abundance Changes Across Cretaceous–Paleogene Boundary Beds in the Haymana Basin (Ankara, Turkey): Paleoenvironmental Implications.* MSc Thesis. The Graduate School of Natural and Applied Sciences of Middle East Technical University, Ankara, 272 pp.

Vialov, O. S. & Golev, B. T., 1965. O. drobnom podrazdieleni gruppy Paleodictyonidae. *Byulletin Moskovskovo Obshchestva Ispityvania Prirody, Otdiel Gieologii,* 40: 93–114.

Wetzel, A., 1983. Biogenic structures in modern slope to deep-sea sediments in the Sulu Sea Basin (Philippines). *Palaeogeography, Palaeoclimatology, Palaeoecology,* 42: 285–304.

Wetzel, A., 2002. Modern *Nereites* in the South China Sea – ecological association with redox conditions in the sediment. *Palaios,* 17: 507–515.

Wetzel, A., 2008. Recent bioturbation in the deep South China Sea: A uniformitarian ichnologic approach. *Palaios*, 23: 601–615.

Wetzel, A., 2010. Deep-sea ichnology: Observations in modern sediments to interpret fossil counterparts. *Acta Geologica Polonica*, 60: 125–138.

Wetzel, A. & Bromley, R. G., 1994. *Phycosiphon incertum* revisited: *Anconichnus horizontalis* is its junior subjective synonym. *Journal of Paleontology,* 68: 1396–1402.

Wetzel, A. & Bromley, R.G., 1996. Re-evaluation of the ichnogenus *Helminthopsis* – a new look at type material. *Palaeontology,* 39:1–19.

Wetzel, A. & Uchman, A., 2001. Sequential colonization of muddy turbidites in the 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.

Zhang, L, Fan, R. & Gong, Y., 2015. *Zoophycos* macroevolution since 541 Ma. *Scientific Reports*, 5, 14954.