

Trace fossil *Artichnus pholeoides* igen. nov. isp. nov. in Eocene turbidites, Polish Carpathians: possible ascription to holothurians

GUOCHENG ZHANG¹, ALFRED UCHMAN², RAFAŁ CHODYŃ² & RICHARD. G. BROMLEY³

¹Department of Resources and Environmental Engineering, Henan Polytechnic University, 454100,
Jiaozuo City, Henan Province, PR China
E-mail: zhanggc@hpu.edu.cn

²Institute of Geological Sciences, Jagiellonian University, Poland
E-mail: alfred.uchman@uj.edu.pl; rafal.chodyn@uj.edu.pl

³Geological Museum, Øster Voldgade 5-7, DK-1350 Copenhagen K, Denmark
E-mail: rullard@geol.ku.dk

ABSTRACT:

ZHANG, G., UCHMAN, A., CHODYŃ, R. & BROMLEY, R.G. 2008. Trace fossil *Artichnus pholeoides* igen. nov. isp. nov. in Eocene turbidites, Polish Carpathians: possible ascription to holothurians. *Acta Geologica Polonica*, **58** (1), 75-86. Warszawa.

A hitherto unknown trace fossil was found in some abundance in turbidites of the Polish Outer Carpathians. The occurrence is within the Hieroglyphic Beds of the Silesian Nappe, within the Szczyrzyc Synclinorium, of Middle Eocene age. The trace fossil is a wide, J-shaped structure having a narrow, upward tapering shaft as a connection to the seafloor. The distal end also tapers, to a blind termination. The burrow lumen is surrounded by an irregular spreite structure. The trace fossil is compared with the work of burrowing holothurians, which show some comparative features that suggest a tracemaker belonging to the Apodida.

Key words: *Artichnus pholeoides*, Holothuroidea, Apodida, Turbidites, Carpathians, Poland, Eocene.

INTRODUCTION

Holothurians (sea cucumbers) are common burrowing organisms in different marine sediments. In some deep-sea areas they are dominant macrofauna (e.g., KITCHELL & *al.* 1978; GAGE & TYLER 1991), but surprisingly very few trace fossils have been attributed to them. GINSBURG & *al.* (1966, text-fig. 12) illustrated a fragment of core from young unconsolidated sediments showing an eccentric, thickly lined burrow attributed to holothurians, which in cross section is 20-30 mm wide, with a 4-8 mm wide lumen and jagged mar-

gin. KSIĄŻKIEWICZ (1977b) interpreted *Subphyllochorda* GÖTZINGER & BECKER, 1932 (now *Scolicia* DE QUATREFAGES, 1849) as a holothurian burrow on the basis of its trilobate underside referred to the trilobate ventral side of some holothurians. This view, however, is not followed because production of *Scolicia* by irregular echinoids is well documented (e.g., BROMLEY & ASGAARD 1975; SMITH & CRIMES 1983; ASGAARD & BROMLEY 2007).

Some modern surface traces, such as faecal coils, are attributed to elasipod and aspidochirote holothurians (HEEZEN & HOLLISTER 1971; HOLLISTER & *al.* 1975),

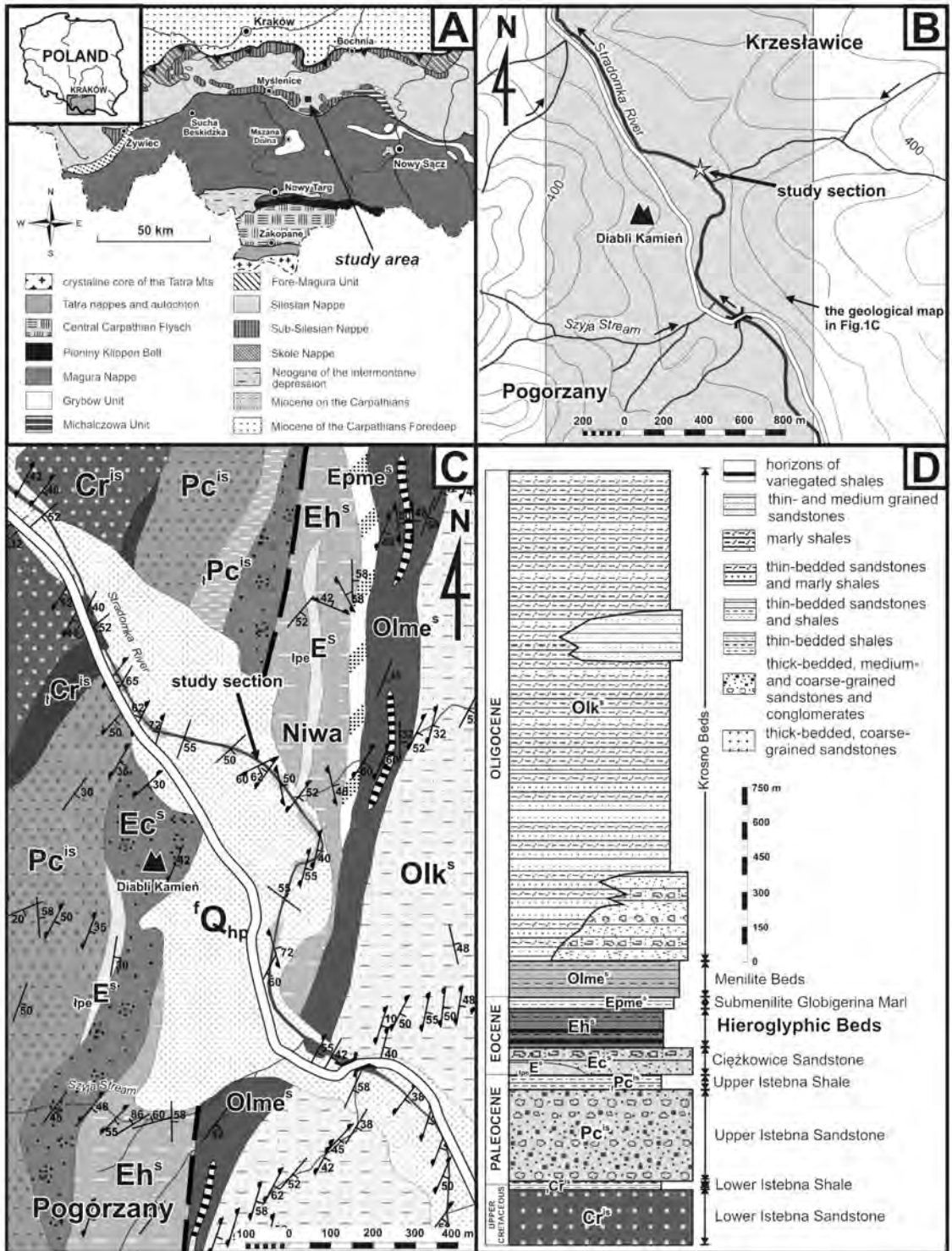


Fig. 1. Location maps and the Palaeogene-Upper Cretaceous lithostratigraphy. A — Structural map of the western part of the Polish Carpathians, indicating the study area. B — Topographic map showing the study section and location of the geological map in C. C — Geological map in the vicinity of the studied section (after CHODYN 2006). D — Maastrichtian-Palaeogene lithostratigraphy of the Silesian unit in the study area. Explanation for symbols in C-D: Cr^{is} - Lower Istebna Sandstone; $\bar{C}r^{is}$ - Lower Istebna Shale; Pc^{is} - Upper Istebna Sandstone; $\bar{P}c^{is}$ - Upper Istebna Shale; $\bar{I}pe^s$ - Variegated Shale; Ec^s - Ciężkowice Sandstone; Eh^s - Hieroglyphic Beds; Epme^s - Submenilite Globigerina Marl; Olme^s - Menilite Beds; Olk^s - Krosno Beds

smooth ploughing traces to aspidochirote (e.g., *Pseudostichopus*) holothurians (HEEZEN & HOLLISTER 1971; YOUNG & *al.* 1985), surface patterned trails by elasipod holothurians (e.g. *Penagone*, *Psychropotes*) (HOLLISTER & *al.* 1975), or conical mounds and pits to molpadid holothurians (e.g. the ubiquitous *Molpadia blakei*) (YOUNG & *al.* 1985; GAGE & TYLER 1991, text-figs 14.6, 14.9a, table 14.1). Subsurface traces of *Thyone briareus* (LESEUR) have been studied by PEARSE (1908), HOWARD (1968) and BROMLEY (1996). Some worm-like holothurians are facile, deposit-feeding burrowers that cause much bioturbation, e.g., the apodate *Trochodota dendyi* of New Zealand (MORTON & MILLER 1968).

In Eocene turbiditic deposits of the Hieroglyphic Beds in the Polish Carpathians, post-depositional, wide J-shaped, turbinate trace fossils have been found. They are dissimilar to other flysch trace fossils and can be attributed to the work of holothurians, corresponding in many respects to the lebensspuren produced by *Thyone*.

Their description and interpretation is the main aim of this paper. The material is housed in the collections of the Institute of Geological Sciences of the Jgiellonian University (INGUJ).

Geological setting

The described trace fossil comes from the Hieroglyphic Beds, which is a lithostratigraphic unit of the Silesian Nappe in the middle part of the Polish Outer Carpathians. The area is located in the region of the Szczyrzyc Synclinorium (CHODYŃ 2002), which also was called the "Synclinal Basin" by KSIĄŻKIEWICZ (1977a) (Text-fig.1A). The Szczyrzyc Synclinorium consists of the Szczyrzyc Depression (KUŹNIAR 1924, 1935) and the Ciecień-Grodzisko Monocline (BURTAN 1974, 1978, 1984).

The synclinorium is filled with Lower Cretaceous to

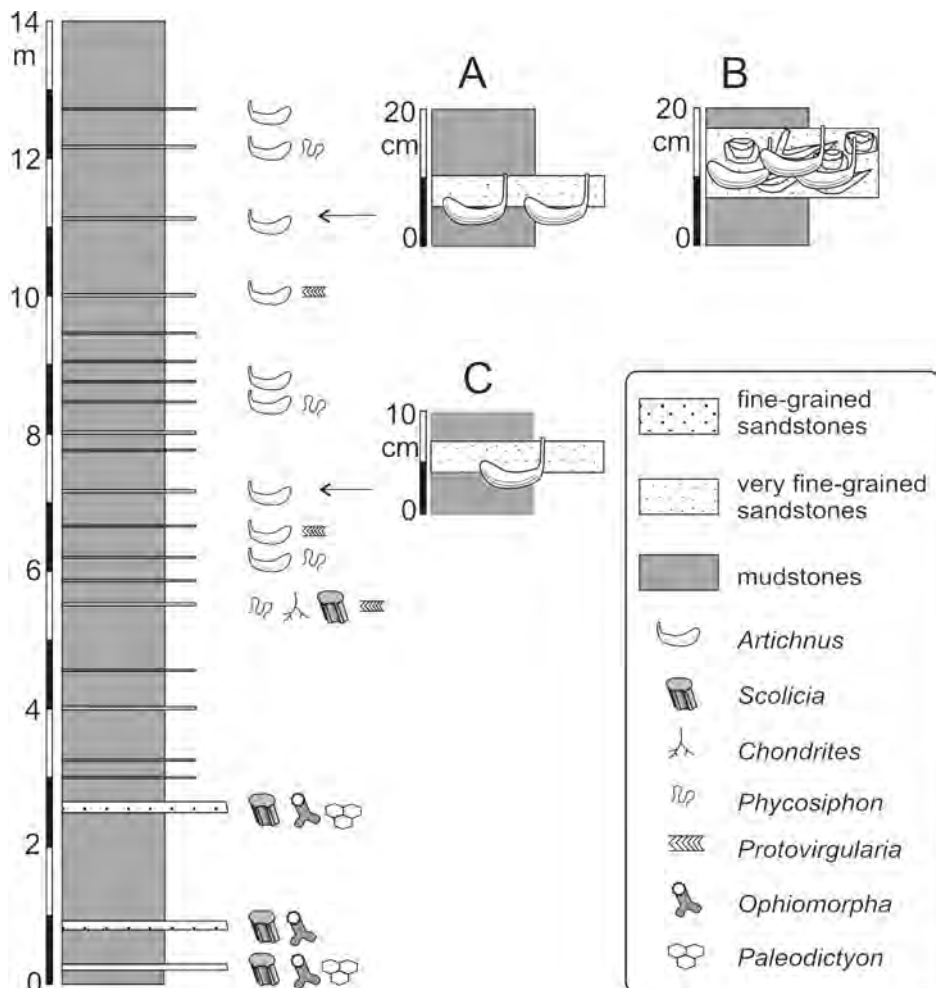


Fig. 2. Lithological log of the study section with indication of trace fossils. A-C are sections of the beds in the main column. A and B refer to the same bed but at different places

Oligocene flysch sediments. The Palaeogene lithostratigraphic units include the Upper Istebna Beds (Palaeocene), Ciężkowice Sandstones (Palaeocene to Middle Eocene), Variegated Shales (Paleocene), Hieroglyphic Beds (Middle to Upper Eocene), Submenilite Globigerina Marls (Late Eocene to Early Oligocene), Menilite Beds (Lower Oligocene) and Krosno Beds (Lower to Middle? Oligocene) (Text-fig. 1C).

The Hieroglyphic Beds are about 120-150 m thick in the research area. Their lower and middle parts crop out in discontinuous exposures along the Stradomka stream between the villages Krzesławice and Pogorzany (Text-fig. 1B). The Hieroglyphic Beds consist of thin- and medium-bedded sandstones interbedded with non-calcareous greyish-green and dark-brown clayey shales. They contain numerous thin bentonite layers that are similar to those described from the nearby Wiśniowa Tectonic Window (SALATA & *al.* 2001) or the Żegocina zone (WAŚKOWSKA-OLIWA & LEŚNIAK 2002). The Hieroglyphic Beds are dated to the Middle to Late Eocene on the basis of benthic foraminifers, which indicate the *Glomospira* div. sp.,

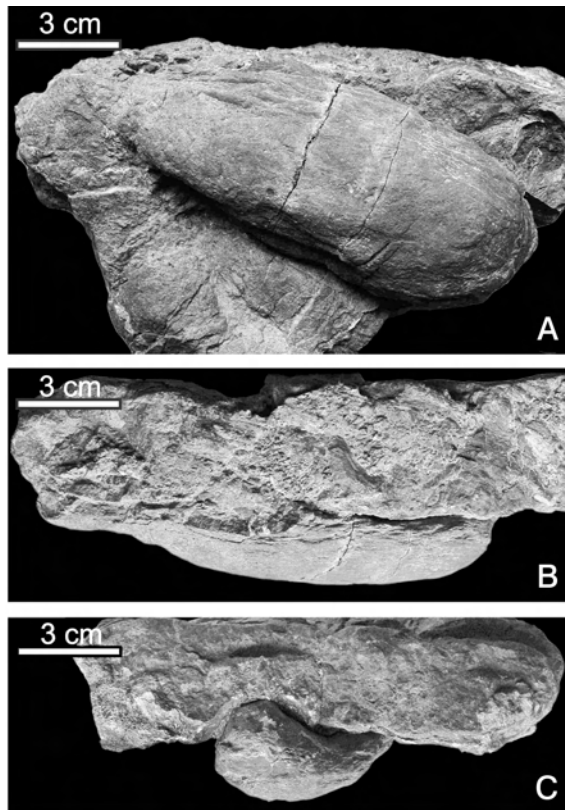


Fig. 3. *Artichnus pholeoides* holotype, INGJ 181P01, hypichnial full relief. A – Bottom view showing the slight narrowing toward the shaft and the local longitudinal striation. B – Side view, the vertical shaft becomes thinner upward. C – The bent-up, narrowing shaft

Saccamminoides carpathicus, *Reticulophragmium amplexens*, *Prasphaerammina subgaleata* and *Ammodiscus latus* zones (CHODYŃ & WAŚKOWSKA-OLIWA 2006). The foraminiferal zones were distinguished on the basis of the deep-sea Carpathian foraminiferal assemblages (MORGIEL & OLSZEWSKA 1981; GEROCH & NOWAK 1984; OLSZEWSKA 1997).

The studied trace fossil occurs in a 13.7 m-thick, shale-dominated interval in the lowermost part of the Hieroglyphic Beds (Middle Eocene) cropping out on the western bank of the Stradomka stream (Text-fig. 1) about 85 m down-stream from the foot-bridge over the stream (GPS co-ordinates: N49°48'16.5"; E020°10'22.3"; ± 5 m). Azimuth of the bed strike is 30° and dip almost vertical. The shales are grey and greenish-grey non-calcareous mudstones intercalated with thin, fine-grained, commonly ferruginous sandstone beds (Text-fig. 2). Only two medium-grained sandstone beds occur in the lower part. The trace fossils occur in eight thin sandstone beds, which represent very distal turbidite, probably fan-fringe facies. Associated trace fossils include *Phycosiphon incertum* FISCHER-OOSTER 1858, *Protovirgularia* isp. and *Scolicia strozzi* (SAVI & MENEGHINI 1850). In the underlying turbiditic sandstones, *Paleodictyon strozzi* SAVI & MENEGHINI 1850, *Ophiomorpha annulata* (KŚIAŻKIEWICZ 1977b) and *Chondrites targionii* (BRONGNIART 1828) occur. Below the section, an about 15 m-thick interval of red, grey and greenish-grey shales contains very few, thin sandstone beds.

DESCRIPTION OF THE TRACE FOSSIL

Artichnus igen. nov.

TYPE ICHNOSPECIES: *Artichnus pholeoides* isp. nov. (in this study).

DERIVATION OF NAME: *arter* – felt shoe in Greek, corresponding to the overall shape; *ichnus*, latinized Greek *ikhnos* – trace.

DIAGNOSIS: Wide J-shaped, generally cylindrical structure, turbinate in the distal part towards the blind termination, and tapering in the proximal part. The proximal part comprises a steeply upward bent, narrowing shaft, tapering upwards. The burrow lumen lies within a thickly laminated, short, vertical, mostly retrusive spreite, which is best developed in the lower part of the structure. The outer margin is longitudinally striated in some specimens.

REMARKS: The only ichnospecies, *Artichnus pholeoides*, is similar to *Pholeus abomasoformis* FIEGE 1944, but the latter displays a thin, vertical shaft protruding from the distal part (KNAUST 2002). It is also similar to *Macanopsis plataniformis* MUÑIZ & MAYORAL 2001, which may belong to *Artichnus*, but the type ichnospecies of *Macanopsis* MACSOTAY 1967, *M. pagueyi* MACSOTAY 1967, displays a shaft associated with a basal chamber (HÄNTZSCHEL 1975). Furthermore, *Artichnus pholeoides* displays a vertically

stacked spreite structure in the basal part, somewhat similar to that in *Teichichnus* SEILACHER 1955, but its type ichnospecies, *T. rectus* SEILACHER 1955, displays a much thicker spreite structure, which dominates the trace fossil, without lateral swellings. The same concerns other *Teichichnus* ichnospecies (e.g., FILLION & PICKERILL 1990; SCHLIRF 2000; SCHLIRF & BROMLEY 2007). But in *Artichnus*, the spreite wraps around the lumen and continues thinly above it. The basal part of *Diplocraterion parallelum* var. *arcum* EKDALE &

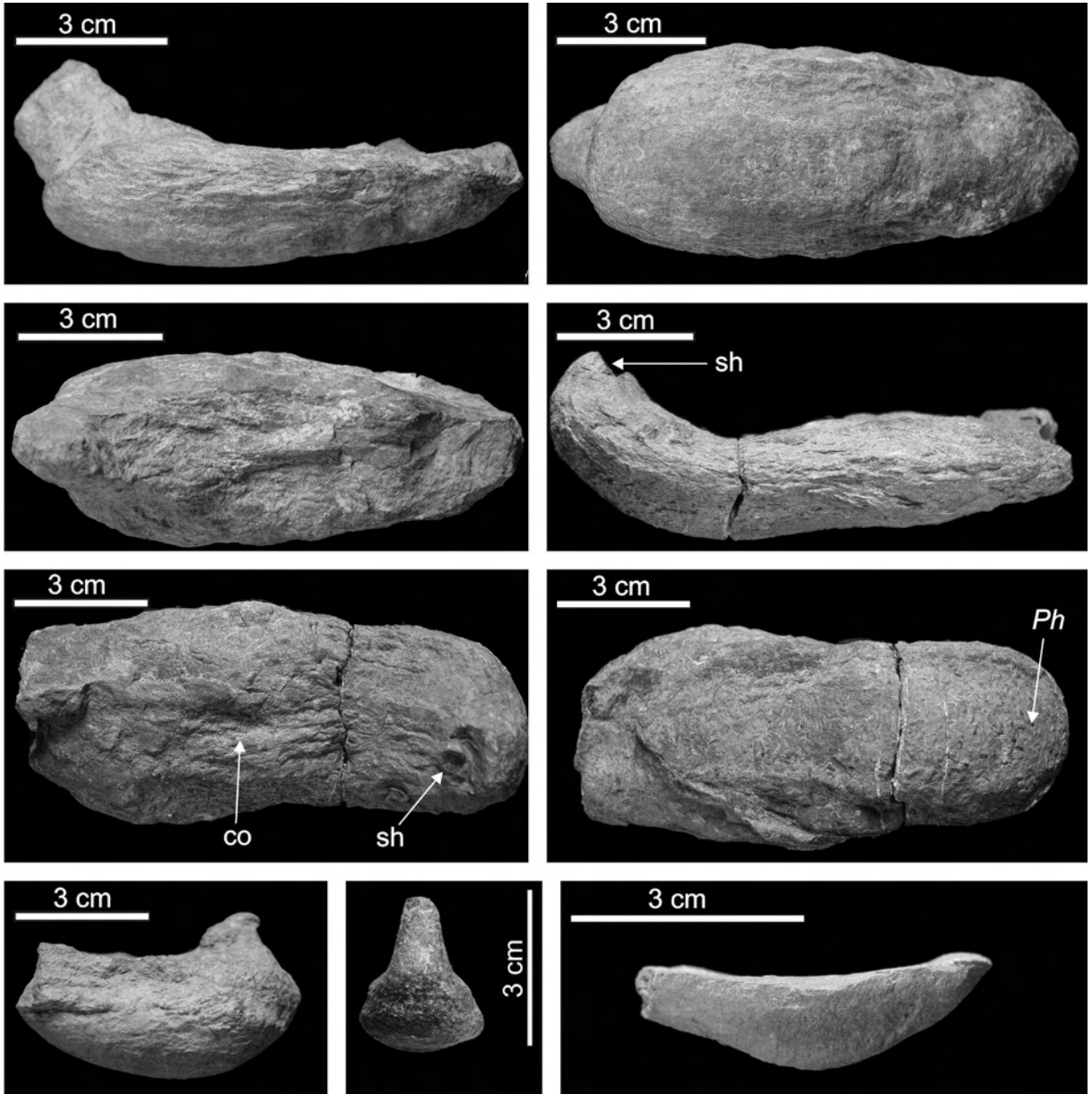
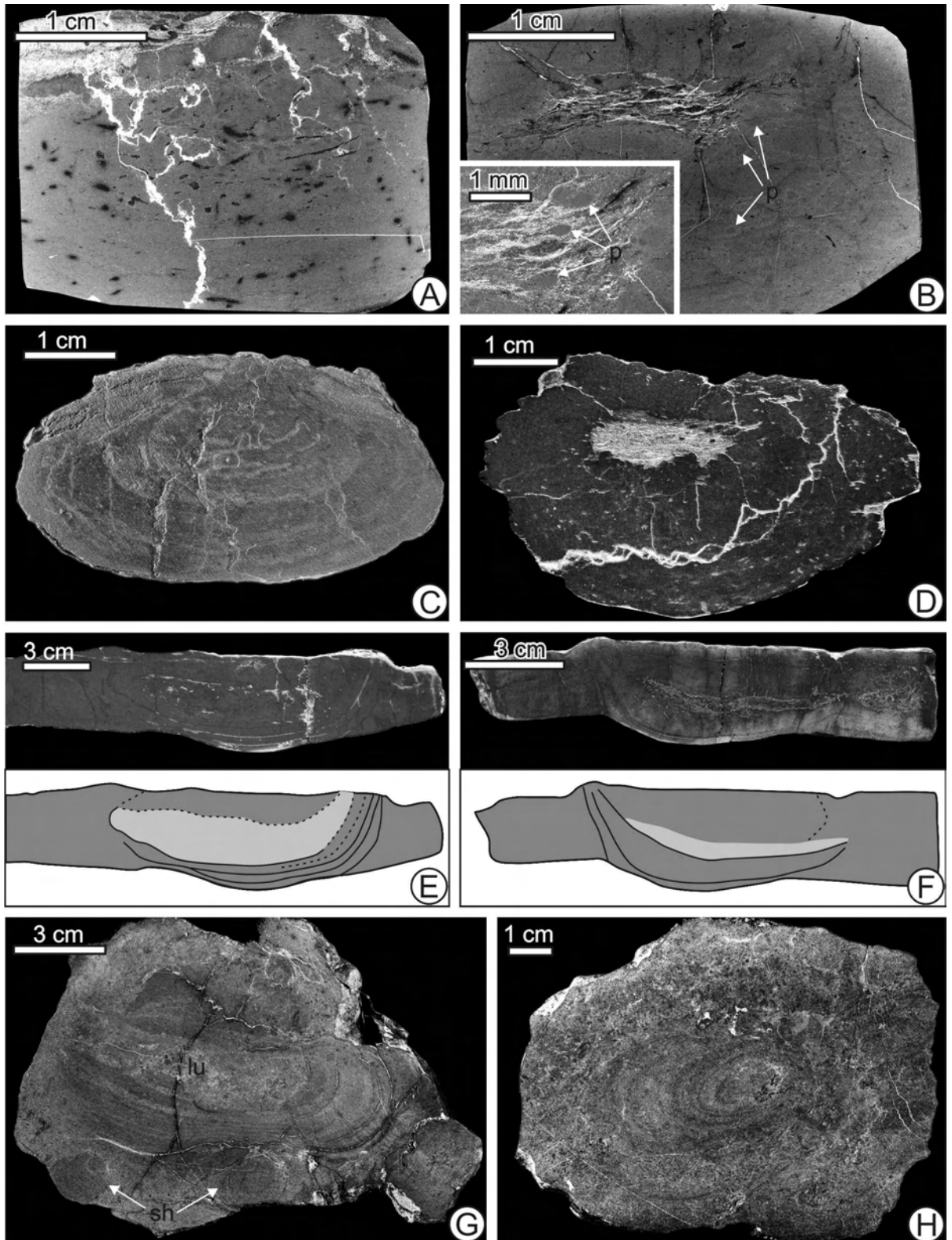


Fig. 4. *Artichnus pholeoides*, endichnial full reliefs. A-C – Paratype, INGUJ 181P02; side, bottom and top views, respectively. D-F – Specimen INGUJ 181P08, side, top and bottom views, respectively; the shaft (sh) in D and E, collapsed lumen (co) in E, *Phycosiphon incertum* (Ph) appears as irregularities on the surface in F. G – Paratype, INGUJ 181P49, side view. H – Specimen INGUJ 181P58, a view of the narrowing shaft.

I – Specimen INGUJ 181P48, the smallest *Artichnus pholeoides*

LEWIS (1991, text-fig. 10) displays some similarities to *Artichnus* by its turbinate shape and spreite around a lumen but it is a deep U-shaped structure. Thus, *Ar-*

tichnus differs from other similar ichnogenera in many important features allowing its separation at the ichnogeneric level.



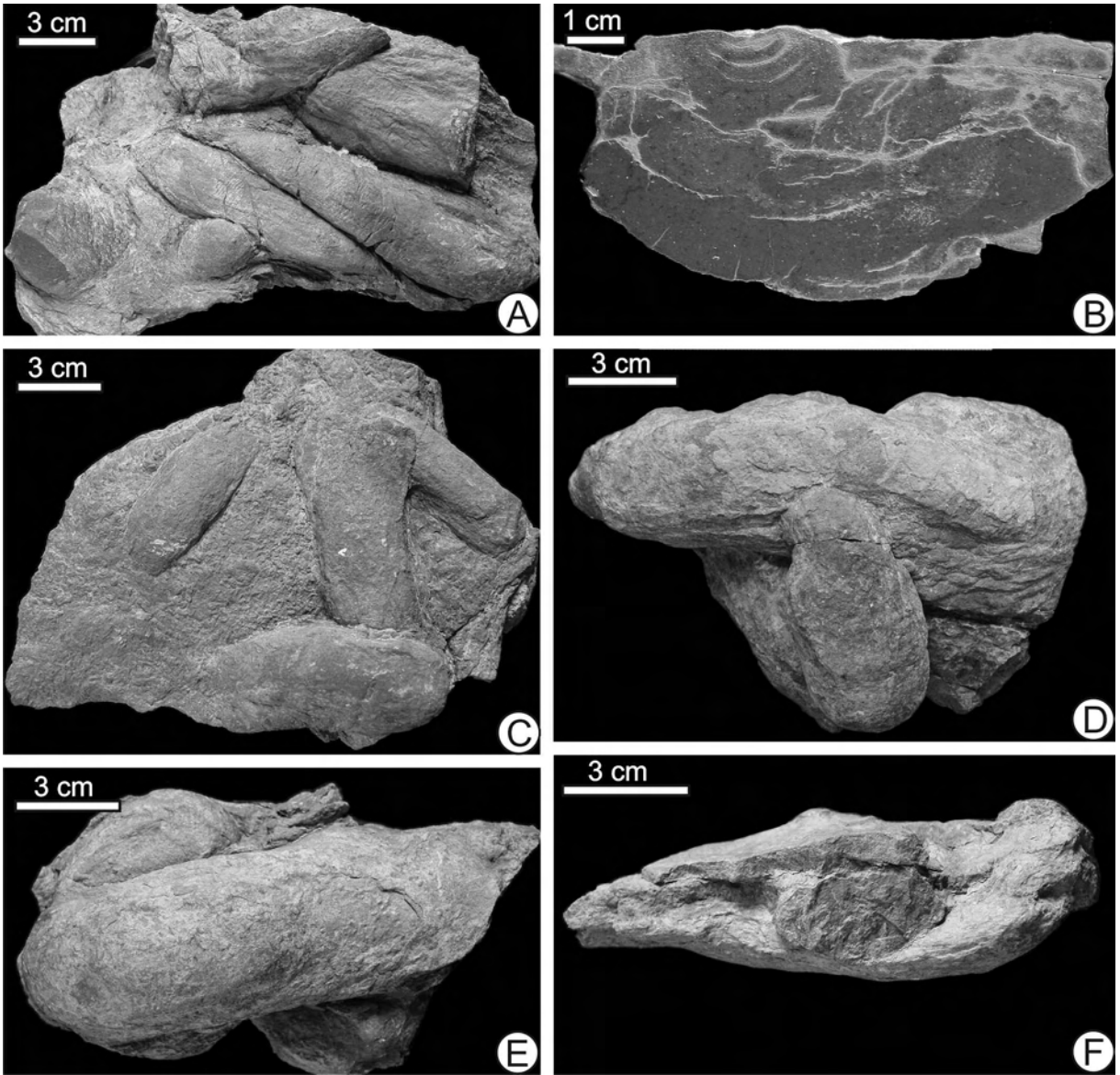


Fig. 6. Gregarious occurrences and intersections in *Artichnus pholeoides*. A – Preferred directional arrangement and intersections; longitudinal wrinkles in the upper right, specimen INGUJ 181P16. B – Polished cross section, specimen INGUJ 181P53. C – Random intersections, bottom view; specimen INGUJ 181P15. D – Perpendicular intersection of two *A. pholeoides*, bottom view; specimen INGUJ 181P22. E – Oblique intersection, bottom view; specimen INGUJ 181P26. F – Perpendicular intersection; side view; specimen INGUJ 181P45

Fig. 5. Details of sectioned *Artichnus pholeoides*. A – Thin section perpendicular to the main axis of the trace fossil. Faint lamination in the lower part and the black spots of irregularly oriented *Phycosiphon incertum*, specimen INGUJ 181P54. B – Thin section perpendicular to the main axis of the trace fossil. Faint lamination in the lower part. The collapsed burrow lumen in the centre is filled with dolomitic and calcareous mud and sparse elongated pellets (p). Diagenetic compaction has flattened the lumen and caused radial fractures, specimen INGUJ 181P55. The insert shows more pellets (p). C – Polished section perpendicular to the main axis of the trace fossil showing the eccentric spreite lamellae, specimen INGUJ 181P54. D – Polished section perpendicular to the main axis of the trace fossil showing the collapsed lumen and related fractures inside and the uneven top and side margin; sideritic *Phycosiphon incertum* can be seen as white spots; specimen INGUJ 181P55. E – Longitudinal polished section and corresponding sketch; the pale zone in the sketch is the collapsed lumen containing calcium carbonate, specimen INGUJ 181P51. F – As in E, specimen INGUJ 181P61a. G – Horizontal cross section showing the collapsed lumen (lu) surrounded by spreite laminae; the spreite laminae cut through another specimen to the upper left; two sectioned shafts (sh) in the lower part; specimen INGUJ 181P30. H – Horizontal cross section showing the proximal part of the burrow surrounded by spreite laminae; the surrounding sediment totally bioturbated with *Phycosiphon incertum*; specimen INGUJ 181P62

Artichnus pholeoides isp. nov.
(Text-figs 3-8)

DERIVATION OF NAME: having a similarity with the general shape of the ichnogenus *Pholeus* FIEGE 1944.

DIAGNOSIS: As for the ichnogenus.

MATERIAL: 60 slabs preserving over 80 specimens, housed in the Institute of Geological Sciences, Jagiellonian University, Kraków, Poland, trace fossil collec-

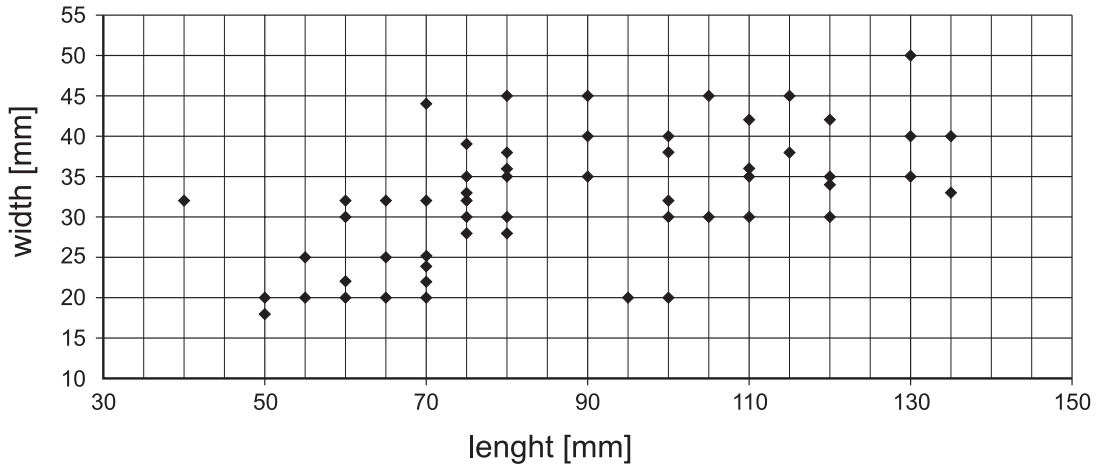


Fig. 7. Diagram of the mean length and width of *Artichnus pholeoides* (data summarized in Table 1)

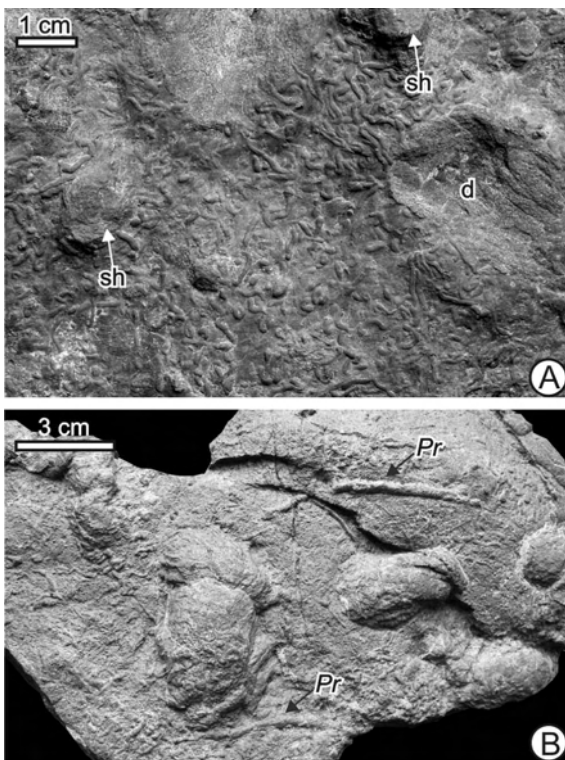


Fig. 8. Associated trace fossils. A – *Phycosiphon incertum* on the upper bedding plane with shafts (sh) of *Artichnus pholeoides*. The depression (d) is probably after an *Artichnus pholeoides* that was emplaced in the overlying shale and impressed into the upper sandstone surface; specimen INGUI 181P15 (its lower surface is shown in Fig. 6C). B – Lower bedding surface with *Artichnus pholeoides*, *Phycosiphon incertum* and *Protovirgularia* isp. (Pr); specimen INGUI 181P52

tion no. 181P01 to 181P60. Additionally, many field observations.

TYPES: holotype INGUI 181P01 (Text-fig. 2A-C); paratypes INGUI 181P02-04, 08, 09, 47.

TYPE HORIZON AND LOCALITY: Lowermost part of the Hieroglyphic Beds (Middle-Late Eocene), Silesian Nappe, Polish Carpathians (Text-figs 1, 2) at Krzesławice along the Stradomka River.

DESCRIPTION: Hypichnial or endichnial, wide, J-shaped cylindrical or sub-cylindrical, turbinate structures, asymmetrical along their longer axis. They taper distally and display a gently upward bent and then vertical shaft in the proximal part, connecting the main part of the trace fossil and host bed upper surface (Text-figs 3, 4). Length of the structure varies between 55 and 135 mm, commonly 70 to 100 mm (Table 1, Text-fig. 7). The burrow is up to 20-50 mm wide in the distal part, becoming narrower towards both ends. The shaft (Text-figs 4H, 5G, 8B) is commonly short but in some specimens it attains 50 mm. Its outlet ranges between 6 and 9 mm in diameter and its filling commonly projects above the upper bedding plane (Text-fig. 8A). Some

Length (mm)	<55	56-70	71-85	86-100	101-115	116-130	>131
Number of specimens	5	16	23	20	10	8	2

Table 1. Morphometric data of 84 individuals of *Artichnus pholeoides*

specimens display a local, weak, longitudinal striation (Text-figs 4A, E, 6A). In longitudinal cross-section, spreite structures (lamellae) can be seen, mostly in the lowest part, below the collapsed lumen (Text-fig. 5C-F). The lumen rarely occurs at the very top of the spreite, but usually at a short distance beneath the top. Commonly, the lumen is vertically flattened to some degree or even completely compressed (Text-fig. 5B). In horizontal sections, the lumen is surrounded by spreite lamellae. The lamellae also occur around the shaft (Text-fig. 5G, H).

In thin sections, the compactional effect can be seen: the lumen is collapsed and radial cracking runs toward the burrow margins (Text-fig. 4B). The collapsing effect is also seen on the surface of the burrow as a longitudinal depression (Text-fig. 4E). The contents of the lumen may include rare ovoid pellets, probable broken spicules and dolomitic and calcareous mud (Text-figs 4A, B, 5E, F). The pellets have the same grain size as the surrounding sediment. Pellets are also present in the spreite but are here less visible on account of some iron diagenesis.

A. pholeoides is quite abundant on the lower bedding surfaces and the specimens commonly intersect (Text-figs 6, 7). Two weakly perpendicularly preferred orientations are seen, though random occurrence is common (Text-figs 6A-F, 8B). The intersecting specimens are commonly coated with a muddy film.

REMARKS: *A. pholeoides* has undergone some compactional diagenesis that has led to distortion of the spreite and collapse of the burrow lumen. However, the underside of the spreite commonly has a smooth central region that appears to represent the original width and forms the basal part of the burrow.

A. pholeoides occurs commonly together with post-depositional *Phycosiphon incertum* in muddy turbidites. It is cut by *P. incertum* (Text-figs 4F, 5A, D, G, H, 8B) but the reverse intersection pattern also is present (Text-fig. 8B). In sandier turbidites, *A. pholeoides* is commonly associated with post-depositional *Protovirgularia* sp. (Text-fig. 8B), which probably occupy the same tier. In other beds of the Hieroglyphic Beds in the surrounding section, *Chondrites* sp., *Ophiomorpha annulata* and *Paleodictyon strozzii* occur.

DISCUSSION

General form of the burrow

The trace fossil is a complex structure based on a wide, J-formed morphology. The central lumen, al-

though diagenetically compacted to various degrees, indicates a more or less horizontal, tubular form, having a single near-vertical shaft, which tapers slightly upward. Surrounding this is a laminated, thick envelope of sediment representing a spreite. There is only the one connection with the sea floor. The structure suggests the stationary, long-term abode of a deposit- or suspension-feeding, worm-like animal.

Probable holothurian tracemaker

Sea cucumbers are common in shallow seas today, but they are the largest and most numerous invertebrate animals on the deep-sea floor (HYMAN 1955; HANSEN 1956, 1975; HEEZEN & HOLLISTER 1971; GAGE & TYLER 1991). Both sea-depth and morphology encourage comparison of *Artichnus pholeoides* with the burrows of sea cucumbers.

However, in contrast to most of the holothurians, observations on burrowing species are extremely sparse, for two reasons. First, these echinoderms react to disturbance by evisceration (expelling their internal organs) and autotomy (breaking into several pieces). This renders them highly unsuitable subjects for aquarium studies (HYMAN 1955; RICKETTS & CALVIN 1962). Second, the group of holothurians we know least about are the deep-sea endobenthic species, because deep-sea sampling most usually is by benthic sledges, which take epibenthic organisms almost exclusively. Benthic sledges are relatively cheap and easy to use, and cover large areas quickly; not so with box-corers (GAGE & BILLETT 1986). In the published collections of deep-sea floor photographs, endobenthic life is represented by burrow openings and faecal cones (e.g., HEEZEN & HOLLISTER 1971; LEMCHE & *al.* 1976).

An exception to this is the classic study on the shallow-water dendrochirotan holothurian *Thyone briareus* by PEARSE (1908). This careful work was later backed up by X-radiographs of the burrowing sea cucumber by HOWARD (1968). This species makes a vertical U-burrow in soft sediments, exposing its feeding tentacles at one aperture and its anus at the other. The burrower remains more or less stationary in the burrow, collecting planktonic food with its tentacles. On the whole, holothurians are sluggish animals, often remaining in one place for long periods of time if conditions are suitable. Several dendrochirotes and aspidochirotes are known to live in U-burrows, suspension feeding like *Thyone*, or deposit feeding by brushing the tentacles over the surrounding seafloor (HYMAN 1955), but details are less well recorded.

These sea cucumbers need to have the anus in contact with seawater because they respire by pumping

water in and out of large structures called “respiratory trees” within their body. However, one of the five orders of the Holothuroidea, the Apodida, lacks respiratory trees, respiring instead directly through the surface skin. These worm-like apodeans are the most active burrowers among the holothurians and, furthermore, are most abundant in the deep sea.

On this basis, we may envisage the following scenario for *Artichnus pholeoides* (Text-fig. 9). The tubular lumen of the burrow corresponds well to a worm-like apodid holothurian burrower. The single entrance is available for the tentacle crown to pass through during feeding periods, when either suspension feeding or surficial deposit feeding was undertaken. This would be withdrawn into the burrow at other times for protection. Faecal matter would be deposited within the burrow as a laminar deposit (Text-fig. 5) around and especially beneath the inhabitant, forming the spreite. Remaining organic material in this sediment would attract the *Phycosiphon incertum* producer.

Concerning the presence of ovoid pellets in the spreite sediment, holothurians do not have gut morphology that allows pellet formation. These pellets must have an earlier date of origin, having been collected outside the burrow by the sea cucumber, thereby indicating detritus or deposit feeding rather than suspension feeding. Since the fill of the burrow and spreite are consid-

ered to represent sediment that has passed through the gut of the burrower, the pellets must have been firm to hard in order to have survived this passage intact.

As food supplies were depleted, and further compaction of excreted sediment was becoming difficult, the sea cucumber would have left the burrow, squeezing out of the shaft, and produced a new burrow nearby, as suggested by the crowded and intersecting *A. pholeoides* (Text-fig. 6).

Stationary feeding suggests abundance of food. In general, one expects to find a greater proportion of mobile than stationary types of trace fossil when food resources (i.e., organic carbon content of the sediment) are low (e.g., YOUNG & *al.* 1985). The unusual occurrence of *A. pholeoides* in the thin sand turbidites suggests an origin for this sediment in, for example, shallow, organically productive areas.

CONCLUSIONS

A new, wide, J-shaped, post-depositional spreite trace fossil was found in Eocene turbiditic deposits of the Hieroglyphic Beds of the Silesian Nappe (Middle Eocene) of the Polish Outer Carpathians.

The trace fossil is named *Artichnus pholeoides* *igen.et isp. nov.*

Morphology and structure suggest a likely trace-maker in the echinoderm class Holothuroidea (sea cucumbers), possibly order Apodida.

Acknowledgements

ZG’s visit to Poland was supported by the scholarship of the Henan Province, China. Additional support was provided by the Jagiellonian University (DS funds). Luis A. BUATOIS (Saskatoon, Canada) and Eduardo MAYORAL (Huelva, Spain), the journal referees, provided helpful reviews of the paper.

REFERENCES

- ASGAARD, U. & BROMLEY, R.G. 2007. Co-occurrence of schizasterid echinoids and the trace fossil *Scolicia*, Pleistocene, Greece: facts, myths and fascioles. *In*: R.G. BROMLEY, L.A. BUATOIS, M.G. MÁNGANO, J.F. GENISE, & R.N. MELCHOR (Eds), *Sediment-Organism Interactions: A Multifaceted Ichnology*. *SEPM Special Publications*, **88**, 85-94.
- BROMLEY, R.G. 1996. Trace Fossils: Biology, Taphonomy and Applications, pp. 1-361. *Chapman & Hall*; London.
- BROMLEY, R.G. & ASGAARD, U. 1975. Sediment structures

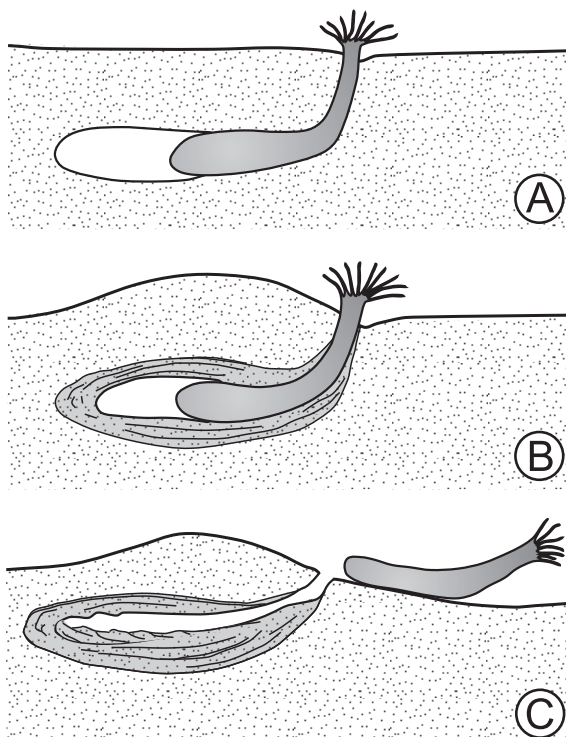


Fig. 9. Reconstruction of the holothurian producing *Artichnus pholeoides*. A, B, C refer to following stages of the burrow formation

- produced by a spatangoid echinoid: a problem of preservation. *Bulletin of the Geological Society of Denmark*, **24**, 261-281.
- 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, pp. 1-136. *G. Dufour & E. d'Ocagne*; Paris.
- BURTAN, J. 1974. Szczegółowa Mapa Geologiczna Polski, 1: 50 000, Ark. Mszana Dolna. *Wydawnictwa Geologiczne*; Warszawa. [In Polish]
- 1978. Objasnienia do Szczegółowej Mapy Geologicznej Polski, 1: 50 000, Ark. Mszana Dolna, pp. 1-70 *Wydawnictwa Geologiczne*; Warszawa. [In Polish]
- 1984. Tektonika Karpat fliszowych na południe od Wieliczki. *Biuletyn Instytutu Geologicznego*, **340**, 7-22. [In Polish with English summary]
- CHODYŃ, R. 2002. Szczyrzyc Synclinorium in the Silesian Unit, Outer Carpathians, Poland-case study. In: Extended Abstracts, Proceedings of the XVII. Congress of Carpathian-Balkan Geological Association, Bratislava, September 1st - 4th, 2002, *Extended Abstracts. Geologica Carpathica, Special Issue*, **53**. [Electronic version]
- 2006. Lithostratigraphy and tectonics of the Silesian Nappe on the area of Szczyrzyc depression. Unpublished PhD Thesis, Institute of Geological Sciences of the Jagiellonian University; Cracow, 189 pp. [In Polish]
- CHODYŃ, R. & WAŚKOWSKA-OLIWA, A. 2006. Lithostratigraphy and biostratigraphy of the Paleocene-Early Oligocene Flysch sediments in the western part of the Szczyrzyc Synclinorium, Silesian Nappe (Polish Outer Carpathians). *Proceedings XVIIIth Congress of the Carpathian-Balkan Geological Association*, September 3-6, 2006 Belgrade, Serbia, *Abstracts Book*, 57-60.
- EKDALE, A.A. & LEWIS, D.W. 1991. Trace fossils and paleoenvironmental control of ichnofacies in a late Quaternary gravel and loess fan delta complex, New Zealand. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **81**, 253-279.
- FIEGE, K. 1944. Lebensspuren aus dem Muschelkalk Nordwestdeutschlands. *Neues Jahrbuch für Mineralogie, Geologie, Paläontologie, Abhandlungen B*, **88**, 401-426.
- 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, pp. 72. *Huber*; Bern.
- GAGE, J.D. & BILLETT, D.S.M. 1986. The family Myriotrichidae Théel (Echinodermata: Holothuroidea) in the deep northeast Atlantic Ocean. *Zoological Journal of the Linnaean Society*, **88**, 229-276.
- GAGE, J.D. & TYLER, P.A. 1991. Deep-sea Biology: A Natural History of Organisms at the Deep-sea Floor, pp. 1-504. *Cambridge University Press*; Cambridge.
- GEROCH, S. & NOWAK, W. 1984. Proposal of zonation for the Late Tithonian – Late Eocene based upon arenaceous foraminifera from the Outer Carpathians, Poland. In: H. OERTLI (Ed.), *Benthos '83; 2nd International Symposium on Benthic Foraminifera Pau (France)*, April 11-15 1983, pp. 225-239. *Elf Aquitaned, ESSO REP and TOTAL CFP*; Pau-Bordeaux.
- GINSBURG, R.N., BERNARD, H.A., MOODY, R.A. & DAIGLE, E.E. 1966. The Shell method of impregnation cores of unconsolidated sediments. *Journal of Sedimentary Petrology*, **36** (4), 1118-1125.
- GÖTZINGER, G. & BECKER, H. 1932. Zur geologischen Gliederung des Wienerwaldflysches (Neue Fossilfunde). *Jahrbuch der Geologische Bundesanstalt*, **82**, 343-396.
- HANSEN, B. 1956. Holothurioidea from depths exceeding 6000 meters. *Galathea Report*, **2**, 33-54.
- 1975. Systematics and biology of the deep-sea holothurians. Part 1. Elaspoda. *Galathea Report*, **13**, 262 pp.
- HÄNTZSCHEL, W. 1975. Trace fossils and problematica. In: C. TEICHERT (Ed.), *Treatise on Invertebrate Paleontology*, part W, Miscellanea, Supplement 1, pp. W1-W269. *Geological Society of America, Boulder, Colorado and University of Kansas*; Lawrence – Kansas.
- HÉEZEN, B.C. & HOLLISTER, C.D. 1971. The Face of the Deep, pp. 659. *Oxford University Press*; New York – London – Toronto.
- HOLLISTER, C.D., HÉEZEN, B.C. & NAFE, K.E. 1975. Animal traces on the deep-sea floor. In: R.W. FREY (Ed.), *The Study of Trace Fossils*, pp. 493-510. *Springer*; New York.
- HOWARD, J.D. 1968. X-ray radiography for examination of burrowing in sediments by marine invertebrate organisms. *Sedimentology*, **11**, 249-258.
- HYMAN, L.H. 1955. The Invertebrates 4 – Echinodermata, The Coelomate Bilateria. pp. 763, *McGraw-Hill*; New York.
- KITCHELL, J.A., KITCHELL, J.E., JOHNSON, G.L. & HUNKINS, K.L. 1978. Abyss traces and megafauna: comparison of productivity, diversity and density in the Arctic and Antarctic. *Paleobiology*, **4**, 171-180.
- KNAUST, D. 2002. Ichnogenus *Pholeus* Fiege, 1944, revisited. *Journal of Paleontology*, **76**, 882-891.
- KŚIAŹKIEWICZ, M. 1977a. The tectonics of the Carpathians. In: *Geology of Poland. Volume 4. Tectonics, Part. 3*, pp. 476-620. *Wydawnictwa Geologiczne*; Warszawa.
- 1977b. Trace fossils in the Flysch of the Polish Carpathians. *Palaeontologia Polonica*, **36**, 1-208.
- KUŹNIAR, C. 1924. Sprawozdanie z badań geologicznych na arkuszu Wieliczka–Myślenice (Compte-rendu des recherches géologiques pour la revision de la feuille Wieliczka-Myślenice de l'Atlas géol. de la Galicie).

- Posiedzenia Naukowe Państwowego Instytutu Geologii (Comptes-Rendus des Séances du Service Géologique de Pologne)*, **7**, 4-5. [In Polish with French title]
1935. Sprawozdanie z badań na obszarze arkusza Wieliczka, wykonanych w r. 1934 (Compte-rendu des recherches exécutées sur le feuille Wieliczka en 1934). *Posiedzenia Naukowe Państwowego Instytutu Geologii (Comptes-Rendus des Seances du Service Geologique de Pologne)*, **41**, 7. [In Polish with French title]
- LEMICHE, H., HANSEN, B., MADSEN, F.J., TENDAL, O.S. & WOLFF, T. 1976. Hadal life as analyzed from photographs. *Videnskabelige Meddelelser fra Dansk Naturhistorisk Forening*, **139**, 263-336.
- MACSOTAY, O. 1967. Huellas problematicas y su valor paleoecológico en Venezuela. *Géos*, **16**, 7-39.
- MORGIEL, J. & OLSZEWSKA, B. 1981 Biostratigraphy of the Polish External Carpathians based on agglutinated foraminifera. *Micropaleontology*, **27**, 1-30.
- MORTON, J. & MILLER, M. 1968. The New Zealand Sea Shore, pp. 638. *Collins*; London – Auckland.
- MUÑIZ, F. & MAYORAL, E. 2001. *Macanopsis plataniformis* nov. ichnosp. from the Lower Cretaceous and upper Miocene of the Iberian Peninsula. *Geobios*, **34** (1), 91-98.
- OLSZEWSKA, B. 1997. Foraminiferal stratigraphy of the Polish Outer Carpathians: a record of basin geohistory. *Annales Societatis Geologorum Poloniae*, **67**, 325-337.
- PEARSE, A.S. 1908. Observations on the behavior of the holothurian, *Thyonebriareus* (Leseur). *Biological Bulletin of the Marine Biological Laboratory, Woods Hole*, **15**, 259-288.
- QUATREFAGES, DE, M.A. 1849. Note sur la *Scolicia prisca* (A. de Q.) annélide fossile de la Craie. *Annales des Sciences Naturelles, 3 série, Zoologie*, **12**, 265-266.
- RICKETTS, E.F. & CALVIN, J. 1962. Between Pacific Tides, 3rd Edition, pp. 516. *Stanford University Press*; Stanford.
- SALATA, D., WAŚKOWSKA-OLIWA, A., CIESZKOWSKI, M. 2001. Analysis of small foraminifera assemblages and clay minerals from bentonite-like layers within Czerwin beds (Subsilesian Unit, Polish Flysch Carpathians)-preliminary results. *Slovak Geological Magazine*, **7** (1), 43-44.
- SAVI, P. & MENEGHINI, G. 1850. Osservazioni stratigraphiche e paleontologiche concerneti la geologia della Toscana e dei paessi limitrofi. *Appendix in R.I MURCHISON, Memoria sulla Struttura Geologica delle Alpi, degli Apennini e dei Carpazi*, pp. 1-249. *Stamperia Grandiducale*; Firenze.
- SCHLIRF, M. 2000. Upper Jurassic trace fossils from the Boulonnais (northern France). *Geologica et Palaeontologica*, **34**, 145-213.
- SCHLIRF, M. & BROMLEY, R.G. 2007. *Teichichmus duplex* n. isp., new trace fossil from the Cambrian and the Triassic. *Beringeria*, **37**, 133-141.
- SEILACHER, A. 1955. Spuren und Fazies im Unterkambrium. In: O.H. SCHINDEWOLF & A. SEILACHER, Beiträge zur Kenntnis des Kambriums in der Salt Range (Pakistan). *Akademie der Wissenschaften und der Literatur in Mainz. Abhandlungen der mathematisch-naturwissenschaftlichen Klasse*, **10**, 373-399.
- SMITH, A.B. & CRIMES, T.P. 1983. Trace fossils formed by heart urchins – a study of *Scolicia* and related traces. *Lethaia*, **16**, 79-92.
- WAŚKOWSKA-OLIWA, A., LEŚNIAK, T. 2002. Lower Eocene tuffites in the Żegocina zone (Polish Flysch Carpathians). In: Proceedings of the XVII. Congress of Carpathian-Balkan Geological Association, Bratislava, September 1st-4th, 2002, *Extended Abstracts. Geologica Carpathica, Special Issue*, **53**, 45-47.
- YOUNG, D.K., JAHN, W.H., RICHARDSON, M.D. & LOHANICK, A.W. 1985. Photographs of deep-sea Lebensspuren: a comparison of sedimentary provinces in the Venezuela Basin, Carribean Sea. *Marine Geology*, **68**, 269-301.

Manuscript submitted: 10th October 2007

Revision version accepted: 25th January 2008