

A new resting trace of echiuran worms from the Paleocene turbiditic deposits of the Northern Apennines and the Polish Outer Carpathians

ALFRED UCHMAN¹ and BRUNO RATTAZZI²

¹ Institute of Geological Sciences, Jagiellonian University, Gronostajowa 3a, 30-387 Kraków, Poland;
e-mail: alfred.uchman@uj.edu.pl

² Museo Paleontologico di Crocefieschi, Via alla Chiesa 12, 16010 Crocefieschi (Genova), Italy

ABSTRACT:

Uchman, A. and Rattazzi, B. 2026. A new resting trace of echiuran worms from the Paleocene turbiditic deposits of the Northern Apennines and the Polish Outer Carpathians. *Acta Geologica Polonica*, 76 (2), e78.

A new trace fossil, *Cochlearichnus tumidus* igen. nov. et isp. nov., is described from Paleocene deep-sea deposits of the Ropianka Formation (Magura Nappe, Polish Outer Carpathians) and the Pagliaro Formation (Northern Apennines, Italy). The trace occurs in fine-grained turbiditic sandstones and is preserved as a hyp-ichnial convex semi-relief with a consistent spoon-shaped outline. Comparison with the body outlines of extant echiuran worms indicates that *C. tumidus* igen. nov. et isp. nov. represents a resting trace, most likely produced by a deep-sea echiuran inhabiting soft, muddy substrates. The structure was formed in mud and subsequently scoured and cast by turbiditic sand. The deposits bearing this trace fossil are characterized by the *Paleodictyon* ichnosubfacies within the *Nereites* ichnofacies, typical of distal parts of the turbiditic depositional systems.

Key words: Ichnology; Ichnotaxonomy; Fossil behaviour; Flysch; Echiura.

urn:lsid:zoobank.org:pub:75F591EA-464A-49F6-95BF-D424742F4EA7

INTRODUCTION

Contemporary deep-sea environments constitute the largest yet least understood ecosystem on Earth, mostly because of their vast spatial extent and the predominance of biological activity hidden beneath the sediment surface, which makes their study technically, logistically, and financially challenging. Similar limitations apply to deep-sea environments of the geological past, where the vast majority of invertebrate organisms show a low preservation potential, even when hard external or internal skeletons are present. Consequently, biological activity is mainly recorded in the form of trace fossils, whose

diversity is particularly high in turbidite deposits (Uchman 2004).

New ichnotaxa from deep-sea deposits continue to be discovered; their assignment to narrowly defined groups of tracemakers remains, however, challenging. They are therefore often attributed to broadly defined, worm-like tracemakers. A notable exception is the new ichnogenus and ichnospecies described herein, occurring in flysch deposits of similar age and depositional environment in the Northern Apennines and the Carpathians (Text-fig. 1). The morphology of this trace does not match that of any previously described ichnogenus. The aim of this paper is to describe this new ichnotaxon and interpret its ethological category and probable tracemaker.



GEOLOGICAL SETTINGS

The trace fossil has been identified in the Pagliaro Formation (Northern Apennines) and in the Ropianka Formation (Polish Outer Carpathians), both representing Mesozoic–Cenozoic successions of the Tethyan domain. The Pagliaro Formation occurs within the Monte Antola Unit (north of Genoa), which is interpreted as an allochthonous slab within the Ligurid units. The formation is approximately 300–400 m thick (Abbate and Sagri 1967; Marroni *et al.* 2002) and grades upwards from the Bruggi/Selvapiana Formation (Antola Formation *s.l.*). Its lower part consists of mixed carbonate–siliciclastic, thin- to thick-bedded turbidites alternating with thick mudstones representing both turbiditic and background sedimentation. Massive, mostly grey and locally reddish, turbiditic marls are also present. Thin- to medium-bedded turbiditic sandstones alternating with thick beds of grey, partly turbiditic mudstones dominate the middle to upper part of the formation. The sandstones display Ta–d Bouma intervals and are rich in plant detritus. In some sections, sandstone beds show upward-thickening trends organized into packages approximately 10 m thick. Isolated thick beds of sandstones and marlstones are also present.

Calcareous nannoplankton data indicate an Early Paleocene to early Late Paleocene age (zones NP1–NP5; Marroni *et al.* 2001) or, alternatively, a late Maastrichtian to early Late Paleocene age (zones CC25b–NP5; Levi *et al.* 2006; Catanzariti *et al.* 2007). The formation is unconformably overlain by the lower Oligocene conglomerates of the Savignone Formation and locally by other Oligocene deposits, mainly the Ranzano Formation (e.g., Gnaccolini 1988). The trace fossils of the Pagliaro Formation are typical of the deep-sea *Nereites* ichnofacies (Uchman 2007).

The investigated trace fossil was recovered exclusively from loose sandstone slabs at the Celio locality (Text-fig. 1A; 44°40.823' N, 9°04.638' E; 538 m a.s.l.), west of the village, in a gorge above a side road, where a 20–30 m thick section is exposed. The section comprises yellowish and grey sandstones interbedded with thick packages of grey shales, which have isolated reddish marlstone intercalations, isolated thick sandstone-marlstone beds (up to 3 m thick) and scattered siderite concretions.

The Ropianka Formation (also known as the Inoceranian Beds), approximately 250 m thick, forms part of the sedimentary succession of the Magura Nappe in the Polish sector of the Outer

Western Carpathians. In the study area, it is separated tectonically from older deposits and grades upwards into the Variegated Shale. The lower part consists of grey to greenish, thin- to medium-bedded turbiditic flysch composed of fine- to very fine-grained, calcareous, muscovite-bearing sandstones intercalated with grey or greenish calcareous or non-calcareous mudstones and marlstones. Intercalations of thick-bedded, coarse- to medium-grained sandstones and red calcareous shales also occur. The upper part contains dark-grey, medium-bedded, very fine-grained, non-calcareous sandstones with glauconite and biotite, whereas the uppermost part is characterized by dark-grey, thin-bedded turbidites interbedded with light-grey mudstones. The formation is dated as Maastrichtian–Paleocene (Oszczypko *et al.* 2005). It overlies the thick-bedded Szczawina Sandstone and is overlain by the variegated shales of the Łabowa Shale Formation.

The investigated trace fossil was found in the Słopniczanka River section at Słopnice (Text-fig. 1B; 49°42.684' N, 20°20.752' E; 415 m a.s.l.), within a several-metre-thick interval of the Ropianka Formation exposed on the western bank of the river. This part of the section is composed of couplets of thin to very thin, fine-grained grey sandstones passing upward into grey calcareous mudstones (Text-fig. 2). The sandstones show sharp lower bedding surfaces and predominantly ripple lamination. Calcareous nannoplankton from the exposure indicate a Paleocene age (H. Egger, pers. comm. 2025).

Repositories

Nature Education Centre (CEP) of the Jagiellonian University – Museum of Geology in Kraków, Poland – specimens marked INGUAJ
Crocefieschi Museum (Province Genova) in Liguria, Italy – specimens with four-digit numbers.

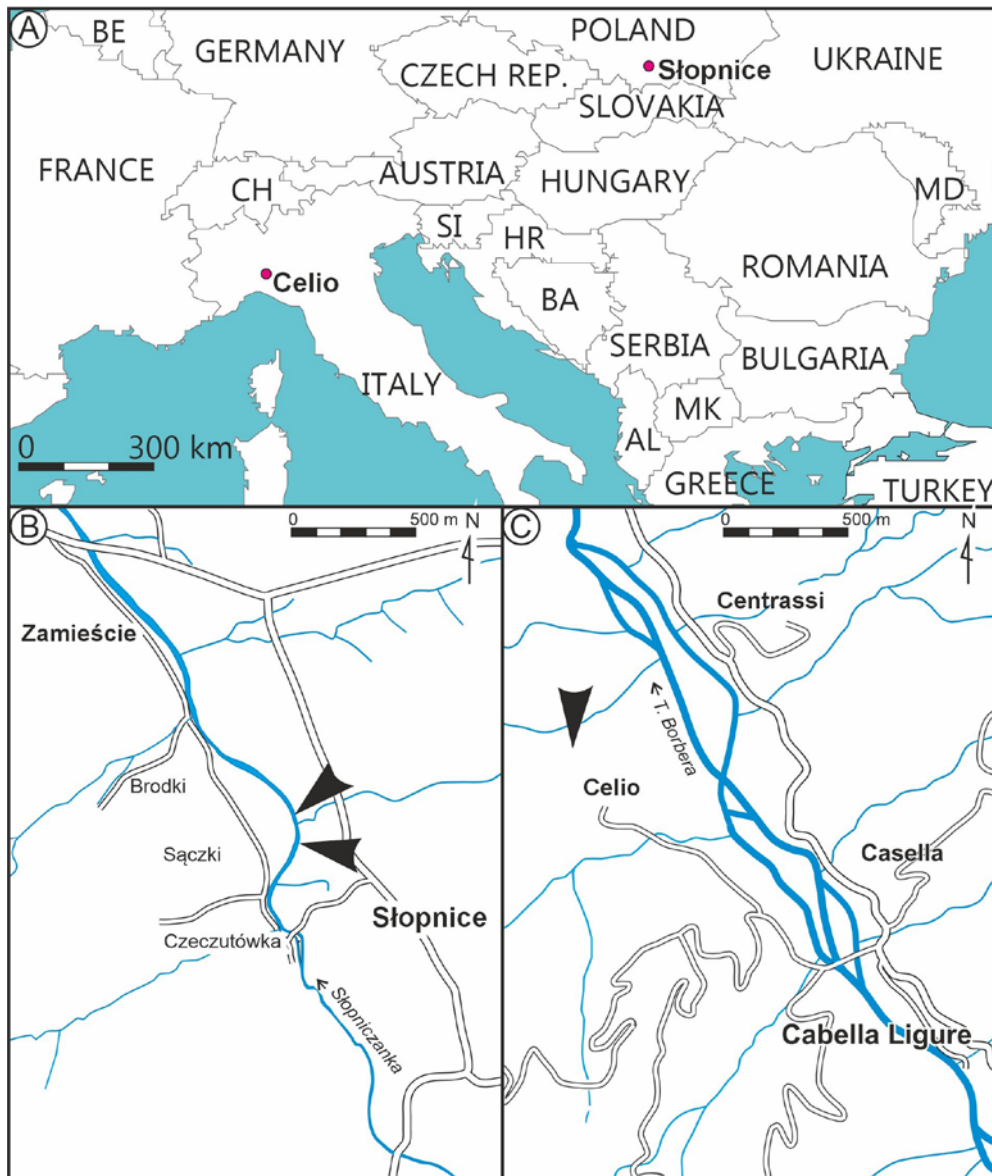
SYSTEMATIC ICHNOLOGY

Ichnogenus *Cochlearichnus* igen. nov.

urn:lsid:zoobank.org:act:A4D785E3-4D5A-42E4-8275-02BF5360AC3C

TYPE ICHNOSPECIES: *Cochlearichnus tumidus* isp. nov., by monotypy.

DIAGNOSIS: Hypichnial, elongate mound with a protruding neck-like ridge that may be enlarged at its termination. Fill is the same as the bearing bed.



Text-fig. 1. Location maps. A – General locations of Słopnice (Poland) and Celio (Italy). B – Site at Słopnice, Poland. C – Site at Celio, Italy. Abbreviations: AL – Albania, BA – Bosnia and Herzegovina, BE – Belgium, CH – Switzerland, HR – Croatia, MD – Moldova, MK – North Macedonia, SI – Slovenia.

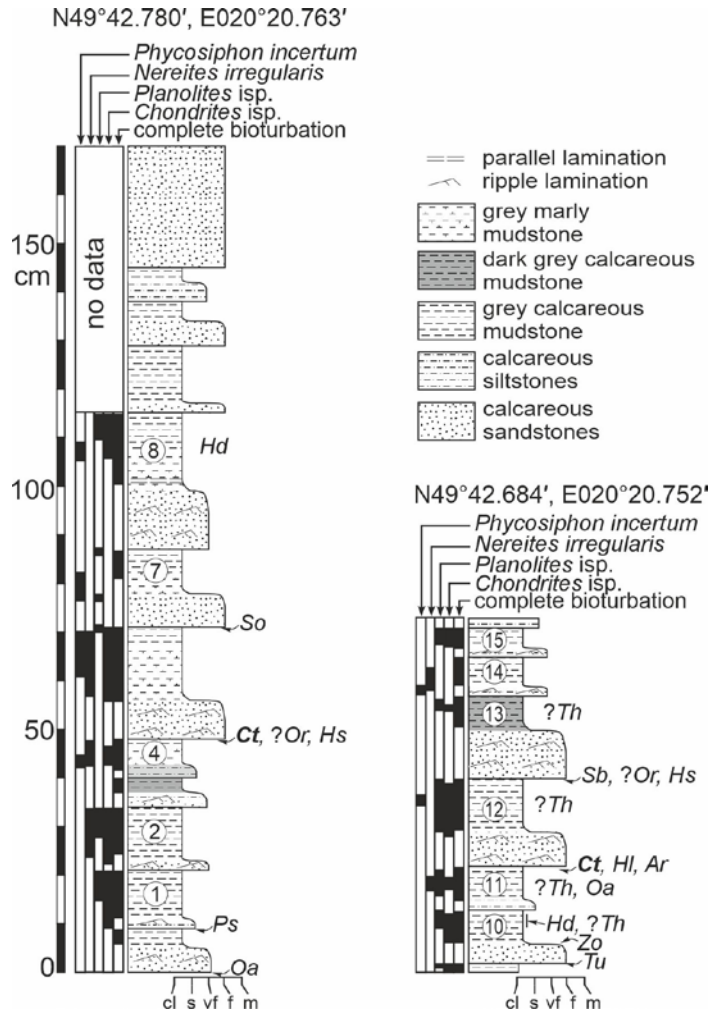
DERIVATION OF NAME: From the Latin *cochleāre* (spoon), referring to the overall shape.

REMARKS: *Cochlearichnus* gen. nov. shows partial similarity to *Artichnus* Zhang, Uchman, Chodyń and Bromley, 2008, typified by *A. pholeoides* Zhang, Uchman, Chodyń and Bromley, 2008, but differs in possessing a distinct neck-like ridge and a terminal widening. Furthermore, *Artichnus* forms a broad, J-shaped structure having an internal distinctive structure (Zhang *et al.* 2008).

Cochlearichnus tumidus gen. et isp. nov.
(Text-figs 3 and 4)

urn:lsid:zoobank.org:pub:75F591EA-464A-49F6-95BF-D424742F4EA7

TYPES AND OTHER MATERIAL: Three specimens from the Ropianka Formation: INGUI 144P210 (holotype; Text-fig. 3A), INGUI 144P211, and INGUI 144P239, and four specimens from the



Text-fig. 2. Paleocene intervals of the Ropianka Formation (Maastrichtian–Paleocene) exposed along the Słopniczanka River, Magura Nappe, Polish Carpathians, showing the distribution of trace fossils. In addition to the trace fossils listed on the left side of the columns, the sections contain *Cochlearichnus tumidus* igen. nov. et isp. nov. (*Ct*). *Ar* – *Arthroddendron* sp. (large foraminifer); *Hd* – *Halimedes* isp.; *Hl* – *Helminthopsis* isp.; *Hs* – *Helminthoidichnites* isp.; *Oa* – *Ophiomorpha annulata*; *?Or* – *?Ophiomorpha rudis*; *Ps* – *Paleodictyon strozzii*; *Sb* – “*Spirophycus*” *bicornis*; *So* – *Spongiomorpha oraviense*; *?Th* – *?Thalassinoides* isp.; *Tu* – *Tubulichnium incertum*; *Zo* – *Zoophycos* isp. Numbers 1–8 and 10–15 indicate samples examined for trace fossils. Grain-size fractions: cl – clay; s – silt; vf – very fine sand; f – fine sand; m – medium sand.

Pagliaro Formation: 6929 (paratype 2; Text-fig. 4C), 7297 (paratype 1; Text-fig. 4A), 7306, and INGUJ 149P386. Two additional specimens from the Ropianka Formation (INGUJ 144P238, INGUJ 144P240) are tentatively assigned to this ichno-species.

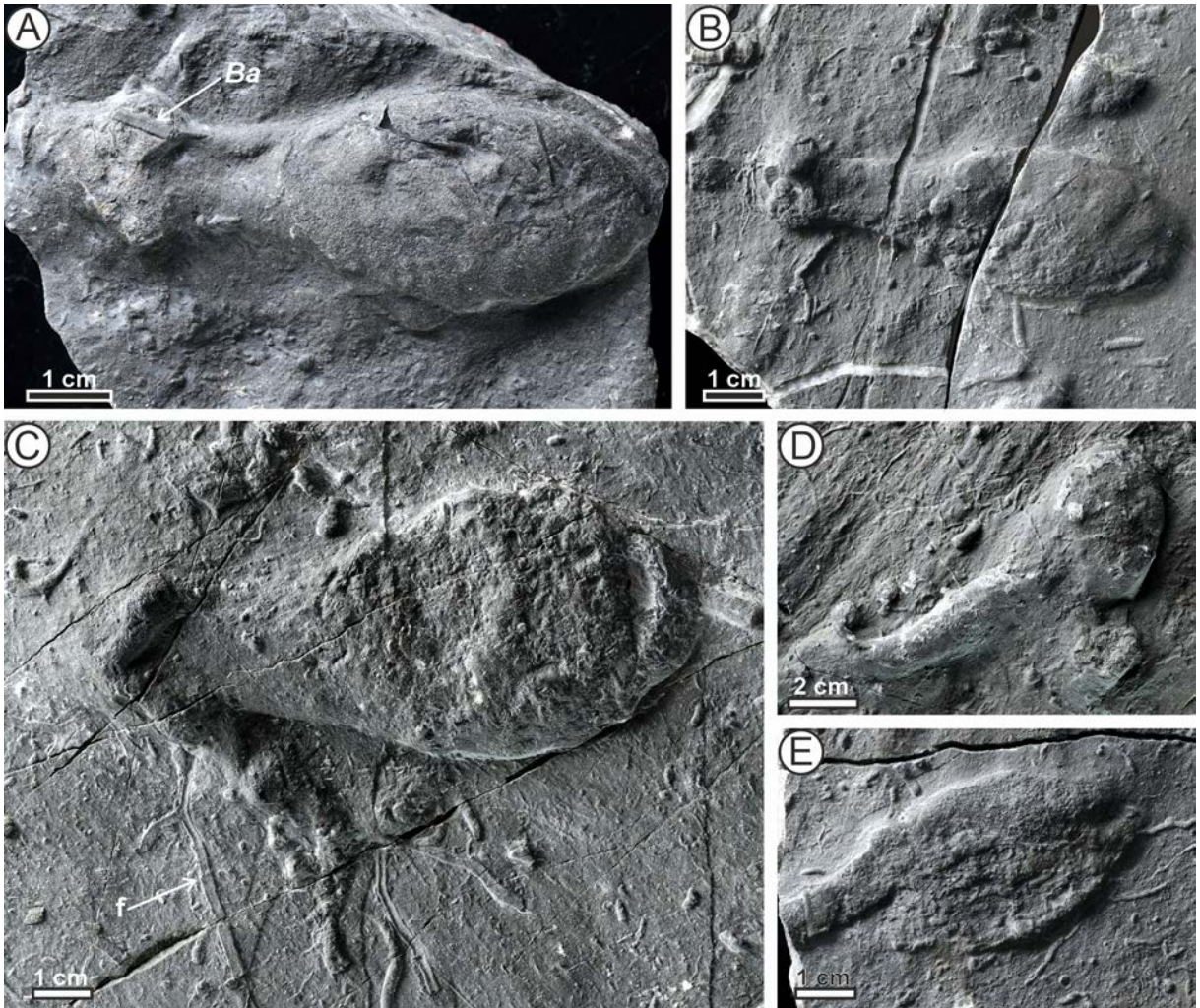
TYPE LOCALITIES: Słopniczanka River section at Słopnice (Text-fig. 1B) for holotype, and Celio locality (Text-fig. 1A) for paratypes 1 and 2.

TYPE HORIZON: Paleocene parts of the Ropianka Formation (Maastrichtian–Paleocene) for the

Słopniczanka section, and the Paleocene part of the Pagliaro Formation (Maastrichtian–Paleocene) for the Celio section.

DERIVATION OF NAME: From the Latin *tumidus*, -a, -um (swollen), referring to the swollen mound forming the main part of the trace fossil.

DIAGNOSIS: Hypichnial, spoon-shaped structure composed of an elliptical mound and a lower, neck-like ridge protruding from the mound along its long axis. The ridge terminates in a triangular widening. Filling is the same as the bearing bed.



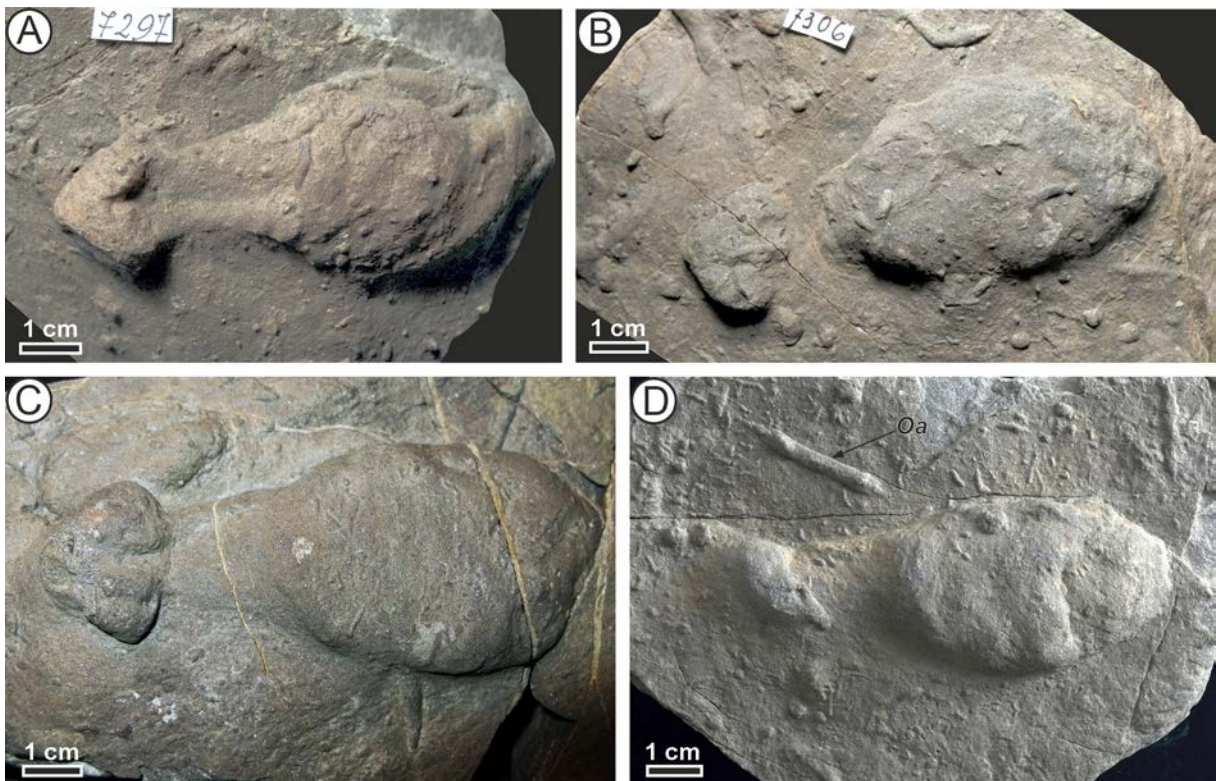
Text-fig. 3. *Cochlearichnus tumidus* igen. nov. et isp. nov. from the Paleocene part of the Ropianka Formation (Maastrichtian–Paleocene), Słopnice, Outer Carpathians, Poland. A – Holotype, INGUJ 144P210; Ba – *Bathysiphon* sp.; B – INGUJ 144P211; C – INGUJ 144P239, f – large protist; D – INGUJ 144P240, tentatively assigned to *C. tumidus*; E – INGUJ 144P238, tentatively assigned to *C. tumidus*.

DESCRIPTION: The trace fossil is preserved in semi-relief in fine- to very fine-grained, ripple-laminated, micaceous, calcareous sandstones. The elliptical mound is 4–10 mm high with respect to the bedding plane, with the highest point in its central part. Minor, irregular, second-order elevations or shallow depressions may occur on the mound surface. The surface is smooth or covered with fine corrugations, and the slopes of the mound are either steep or locally gently grade into the bedding plane.

The neck is straight or gently curved and is generally less elevated than the mound. It narrows slightly toward its termination and is semi-elliptical in cross-section; in the holotype and paratypes,

a shallow axial moat is present, narrowing distally (Text-figs 3A and 4A). In one specimen, the neck is depressed and gradually fades (Text-fig. 4B).

In the most complete specimens, the neck terminates in a symmetric, triangular widening, elevated relative to the neck (Text-figs 3A and 4A–C). In outline, this part of the trace fossil resembles an arrowhead oriented along the longitudinal axis of the trace. The apex angle of the arrowhead ranges from 65° to 100°. The axial moat of the neck may extend slightly into the termination, and a shallow sinus is commonly present on the opposite side of the arrowhead. In some specimens, the termination is asymmetric, representing approximately half of the



Text-fig. 4. *Cochlearichnus tumidus* igen. nov. et isp. nov. from the Pagliaro Formation (Paleocene), Celio, Italy. A – Paratype 1, specimen 7297; B – Specimen 7306; C – Paratype 2, specimen 6929; D – INGUI 149P386; *Oa* – *Ophiomorpha annulata*.

complete triangular form (Text-figs 3C, D, 4D). The surface of the termination may be corrugated, locally displaying small knobs or depressions.

The surface of some specimens contains fragments of the tubular, siliceous agglutinated foraminifer *Bathysiphon* sp. and other agglutinated forms, including the chambered foraminifer *Arthrodendron* sp., as well as small shell fragments. Locally, short, semicircular ridges or knobs attributable to small tubular trace fossils (e.g., *Helminthoidichnites* isp., *Planolites?* isp.) are present.

Morphometric parameters of *C. tumidus* igen. nov. et isp. nov. are presented in Table 1 and Text-fig. 5.

REMARKS: *Cochlearichnus tumidus* igen. nov. et isp. nov. displays a high degree of morphological consistency, reflected by a strong correlation of morphometric parameters (Text-fig. 5). The most variable feature is the morphology of the neck termination, which is largely influenced by preservation.

Despite the limited number of specimens, morphometric parameters of *C. tumidus* igen. nov. et

isp. nov. are consistent (Text-fig. 5), with high coefficients of correlation (r) and determinations (r^2) between maximum width *versus* total length ($r = 0.93$, $R^2 = 0.93$) and maximum width *versus* length of the elliptical mound ($r = 0.86$, $R^2 = 0.74$), which confirms that the new ichnotaxon is not an accidental structure.

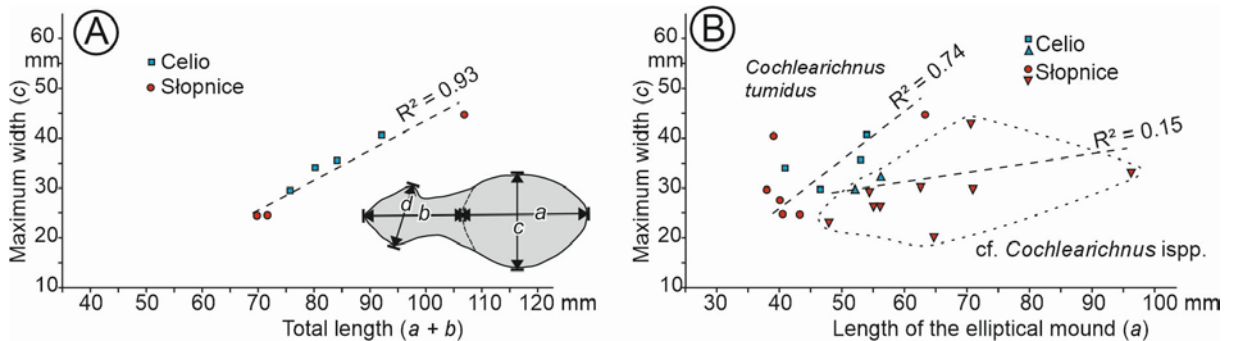
cf. *Cochlearichnus* ispp.

(Text-fig. 6)

DESCRIPTION: In the studied sections at Celio and Słopnice, as well as in one additional section of the Pagliaro Formation at Campo dei Re (44°39.440' N, 9°02.438' E), a dozen trace fossils resembling *Cochlearichnus* igen. nov. have been observed and collected. They occur as elongated mounds, elliptical in outline, 8–25 mm high with respect to the bedding plane. Their surface is smooth or partly to entirely corrugated. Some specimens are covered with thin, semicircular ridges and knobs, which may represent superimposed traces, such as *Helminthoidichnites*

Specimen or photograph	Formation	a	b	c	d	a + b
<i>Cochlearichnus tumidus</i> igen. nov. et isp. nov.						
INGUJ 144P211	Ropianka Formation	40.5	29	24.6	15.1	69.5
INGUJ 144P210		43.4	28.1	24.7	17.1	71.5
INGUJ 144P270		63.3	42.3	44.51	26.4	106.6
INGUJ 149P386	Pagliaro Formation	46.6	29.1	29.6	18.4	75.7
6929		54	38	40.5	26	92
7297		41	39	34	24	80
7306		53	31	35.5	22.5	84
INGUJ 144P238	Ropianka Formation	40.05	20+	27.4	nd	60.05+
INGUJ 144P240		37.9	63.2	29.4	nd	101.1
INGUJ 144P211		40.5	29	24.6	15.1	69.5
INGUJ 144P210		43.4	28.1	24.7	17.1	71.5
cf. <i>Cochlearichnus</i> isp.						
INGUJ 144P213	Ropianka Formation	96.2	-	32.8	-	-
INGUJ 144P212		47.85	-	23.3	-	-
INGUJ 144P246		54.5	-	29.2	-	-
INGUJ 144P584		64.7	-	20.15	-	-
INGUJ 144P247		62.5	-	30.3	-	-
INGUJ 144P392	Pagliaro Formation	52.1	-	29.8	-	-
P1150901*		57	-	32	-	-
DSCN5122*	Ropianka Formation	72	-	30	-	-
DSCN5123*		57	-	26	-	-
DSCN5124*		71	-	43	-	-

Table 1. Morphometric parameters of *Cochlearichnus tumidus* igen. nov. et isp. nov. and cf. *Cochlearichnus* isp. Explanations: * – field photographs housed by AU; a, b, c, d – morphometric parameters explained in Text-fig. 5; nd – no data (morphological element not preserved); + – minimum value (morphological element incomplete).

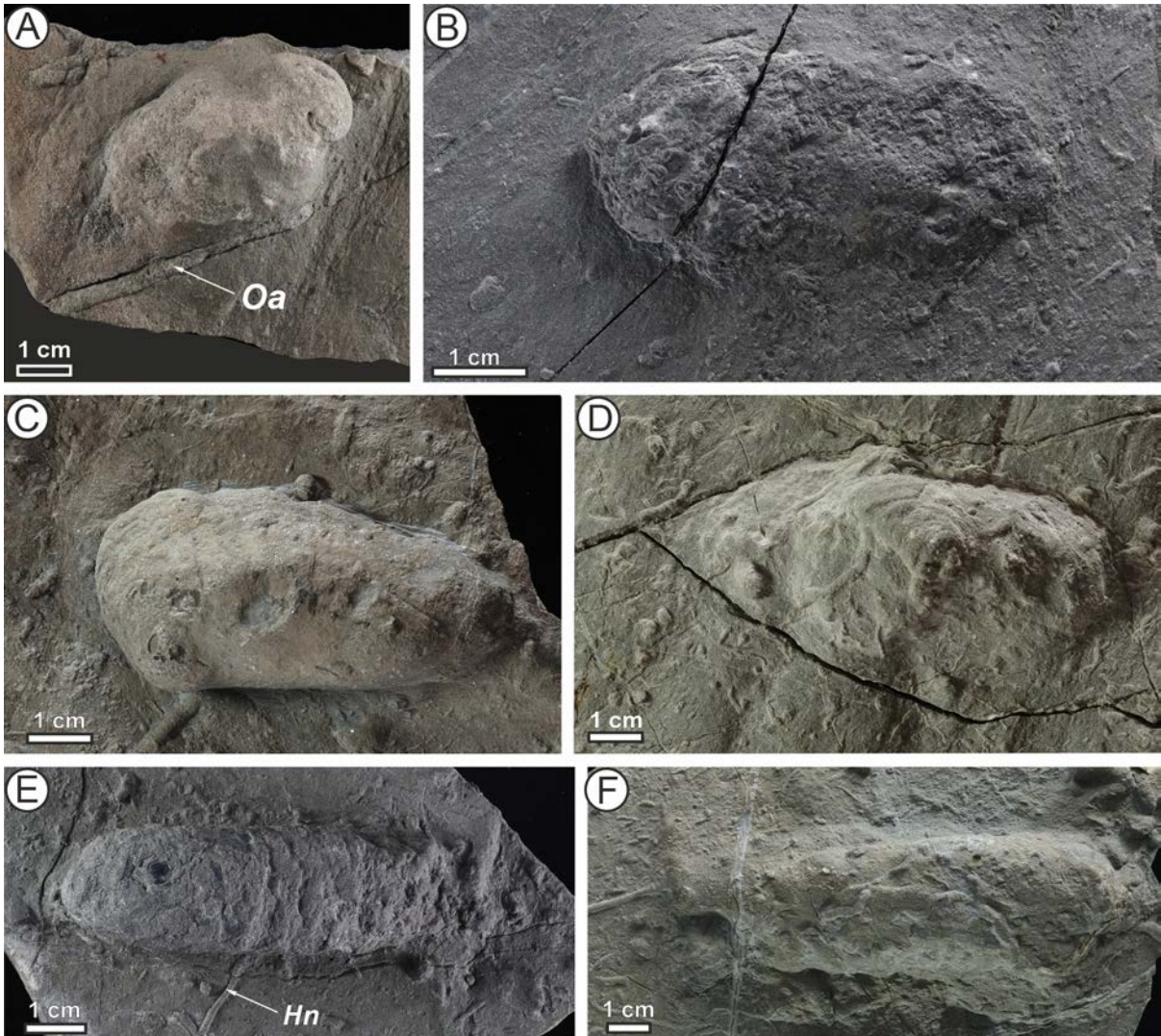


Text-fig. 5. Morphometric parameters. A – Definition of the morphometric parameters on the sketch drawing of *Cochlearichnus tumidus* igen. nov. et isp. nov. and a scatter plot of maximum width versus total length of this trace fossil. B – Scatter plot of maximum width versus length of the elliptical mound in *Cochlearichnus tumidus* igen. nov. et isp. nov. and cf. *Cochlearichnus* ispp.

isp. or *Planolites?* isp. Their morphometric parameters are presented in Table 1 and Text-fig. 5B.

Most specimens show proportions very similar to the elliptical mound of *C. tumidus* igen. nov. et isp. nov., whereas others (Text-fig. 6E, F) are distinctly more elongated. Some exhibit a short neck (Text-fig. 6A, F), while in others the neck is undeveloped or not preserved.

REMARKS: These trace fossils are interpreted as probable representatives of *Cochlearichnus* igen. nov., in which the neck is poorly preserved or entirely absent. This may be related to the position of the trace-maker within the sediment, or to the degree of scouring of the mudstone substrate beneath the sandstone bed in which the trace fossil is preserved. However, the morphometric parameters of the discussed traces



Text-fig. 6. cf. *Cochlearichnus* spp. from the Pagliaro Formation in Campo dei Re, Northern Apennines, Italy (A) and the Ropianka Formation at Słopnice, Outer Carpathians, Poland (B–F). A – INGUJ149P392; *Oa* – *Ophiomorpha annulata*. B – INGUJ144P212; C – INGUJ144P247; D – INGUJ144P246; E – INGUJ144P584; *Hn* – *Helminthoidichnites* isp.; F – INGUJ144P213.

are highly dispersed. The coefficients of correlation (r) and determinations (r^2) between maximum width versus total length are very low ($r = 0.39$, $R^2 = 0.15$). This suggests that the traces may belong to another ichnospecies of *Cochlearichnus* igen. nov., but limited data prevents its formal distinction.

ASSOCIATED TRACE FOSSILS

In the Pagliaro Formation at the studied locality, *Cochlearichnus tumidus* igen. nov. et isp. nov. co-occurs with circular and elliptical structures, simple and

branched structures (Text-figs 4D, 6B), radial structures, spreite structures, winding and meandering structures, spiral structures, branched winding and meandering structures, and networks (Uchman 2007; for a complete list of ichnotaxa see Appendix 1).

In the Ropianka Formation at the studied locality, *Cochlearichnus tumidus* igen. nov. et isp. nov. co-occurs with simple and branched structures, radial structures, spreite structures, winding and meandering structures (Text-fig. 6E), spiral structures, branched winding and meandering structures, and networks (Uchman 2008; Uchman and Wetzel 2017; Uchman and Szczech 2022; AU personal observa-

tions; for a complete list of ichnotaxa see Appendix 2). On the same bedding planes, the agglutinated, chambered foraminifer *Arthrodendron* sp. and other large tubular agglutinated foraminifers (*Bathysiphon* sp.) are also present.

DISCUSSION

The preservation of *Cochlearichnus tumidus* igen. nov. et isp. nov. in hypichnial semi-relief indicates a pre-depositional origin with respect to its casting sand layer. The structure was formed in soft mud and was subsequently scoured and cast by sand transported during the ripple phase of a turbiditic flow. Scouring was relatively gentle, as evidenced by the preservation of low-relief flute marks and lineations on the same bedding surfaces.

The recurrent and consistent morphology of *C. tumidus* igen. nov. et isp. nov., combined with the absence of any clear evidence of locomotion, suggests that it represents a resting trace (cubichnion) of an animal that was entirely or partly buried within the mud. The tracemaker likely left its resting position prior to sand deposition, and the shallow depression left behind was subsequently infilled by sand.

The overall outline of *Cochlearichnus tumidus* igen. nov. et isp. nov. corresponds closely to the body shape of echiuran worms, including the trunk and proboscis (Text-fig. 7). Echiurans are common components of modern deep-sea faunas. Commonly referred to as spoon worms, they are treated either as a separate phylum or as a derived group within Annelida that has lost external segmentation (Goto *et al.* 2020) and comprise more than 230 extant species (Zhang 2011). Echiurans possess a cylindrical to elliptical, sac-like body and an elongate proboscis. Most species are deposit feeders, using the proboscis to collect organic detritus from the seafloor (Stephen and Edmonds 1972). In some taxa, the proboscis bears a triangular terminal expansion, closely resembling the terminal widening of the neck observed in *C. tumidus* igen. nov. et isp. nov. This morphological correspondence strongly supports the interpretation of echiuran worms as the tracemakers of this ichnotaxon.

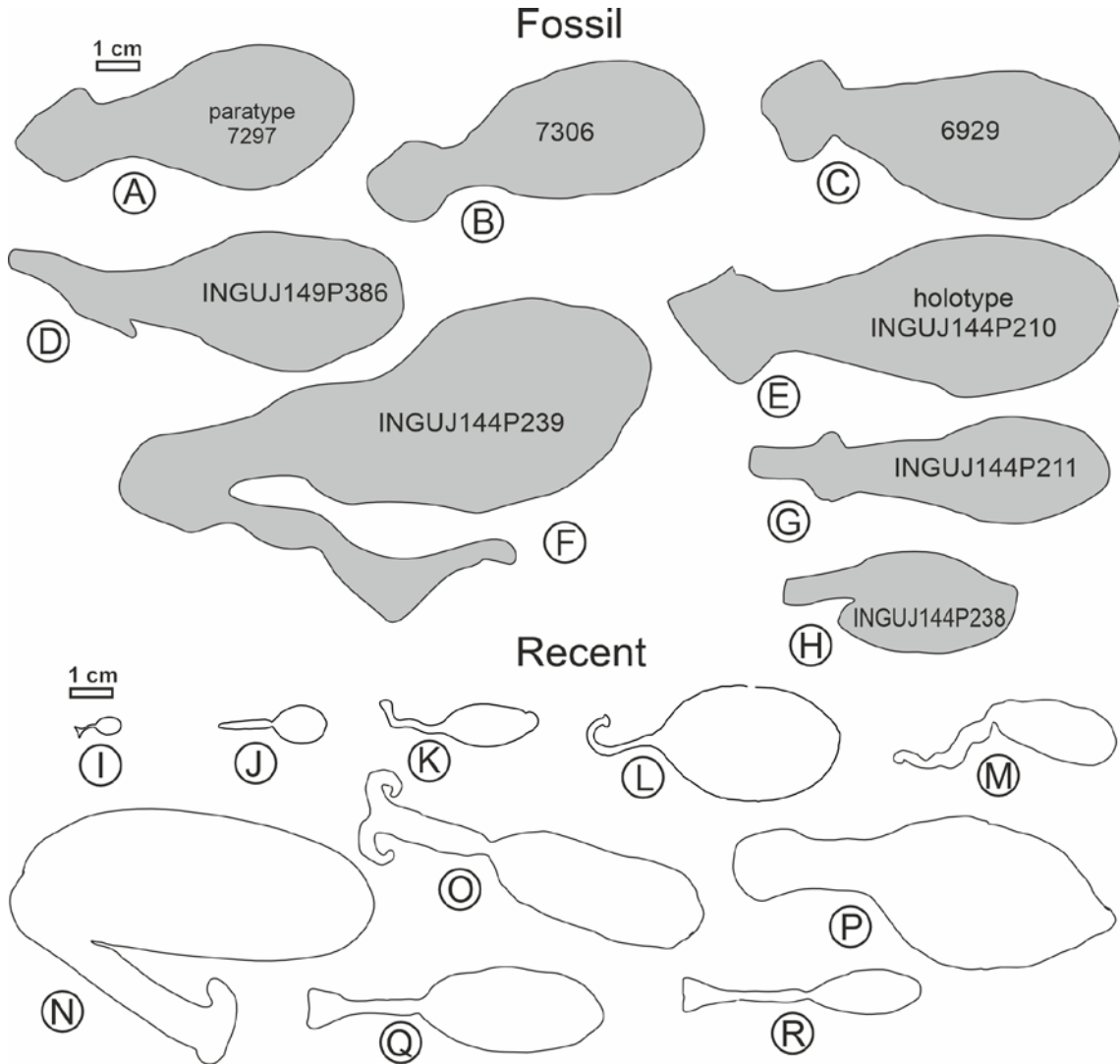
Because of the correspondence between trace morphology and body shape, it cannot be entirely excluded that some specimens of *C. tumidus* igen. nov. et isp. nov. also preserve a cast of the echiuran body itself, which may have died as a result of the deposition of sand upon it. In such a scenario, the sediment subsequently infilled the space left by the decaying carcass, or the carcass may have been removed

by currents prior to infilling. However, no evidence of collapse of the overlying sediment is observed. In addition, fragments of macroscopic agglutinated foraminifera and shell debris are locally trapped within the scoured depressions, supporting interpretation of the structure as a trace fossil rather than a body fossil. Fine corrugations on the surface may be related to faecal material or minor surface bioturbation.

The traces identified as cf. *Cochlearichnus* isp. (Text-fig. 6) may also have been produced by a different echiuran taxon exhibiting slightly different behaviour, or by the same producer as *C. tumidus* igen. nov. et isp. nov. In the latter case, the proboscis trace is not preserved because it did not intersect the sandstone bedding plane. The more elongated forms (Text-fig. 6E, F) deviate from the typical elliptical mound morphology of *C. tumidus* igen. nov. et isp. nov. and may represent a distinct ichnotaxon; the limited number of specimens, however, prevents a definitive interpretation pending the availability of additional material.

Resting traces are generally uncommon in turbiditic settings and are limited to a few ichnogenera. These include the irregular echinoid traces *Cardioichnus* Smith and Crimes, 1983 and *Sursumichnus* Uchman, Lebanidze, Kobakhidze, Beridze, Makadze, Lobzhanidze, Khutsishvili, Chagelishvili, Koiava and Khundadze, 2022, the actinian trace *Bergaueria* Prantl, 1945 (see Książkiewicz 1977; Uchman 1998), the asteroid trace *Asteriacites* von Schlotheim, 1820 (see Riahi *et al.* 2014), and the bivalve trace *Lockeia* James, 1879 (see Uchman 1991). *Cochlearichnus* igen. nov. representing a different group of tracemakers, therefore substantially expands this list.

Based on the associated trace-fossil assemblages in the studied sections, particularly the presence of diverse graphoglyptids such as *Paleodictyon*, *Megagraption*, *Urohelminthoida*, and *Lorenzina* (see Appendices 1 and 2), *C. tumidus* igen. nov. et isp. nov. is assigned to the *Paleodictyon* ichnosubfacies of the *Nereites* ichnofacies. This ichnosubfacies is characteristic of distal settings within deep-sea turbiditic systems (Uchman and Wetzel 2012). The Paleocene occurrence of *Cochlearichnus* igen. nov. is consistent with the post-Mesozoic increase in trace-fossil diversity in deep-sea turbiditic environments following the Mesozoic Marine Revolution, which intensified on the deep-sea floor during the Cretaceous (e.g., Uchman 2004; Buatois *et al.* 2016). Nevertheless, echiuran worms are known from as early as the Ordovician (Botting and Muir 2023) and the Pennsylvanian (Jones and Thompson 1977),



Text-fig. 7. Comparison of outlines of *Cochlearichnus tumidus* igen. nov. et isp. nov. from the Northern Apennines (A–D) and the Outer Carpathians (E–H) with selected extant, mostly deep-sea echiuran worms (I–R). I – *Bonellia plumosa* Datta-Gupta, 1981 (North Atlantic, 330 m; Datta-Gupta 1981, pl. 3, fig. E); J – *Maxmuelleria verrucosa* (Studer, 1879) (North Atlantic, 4829 m; Datta-Gupta 1981, pl. 5, fig. B); K – *Charcotus charcotus* Datta-Gupta, 1981 (North Atlantic, 2878 m; Datta-Gupta 1981, pl. 4, fig. D); L – *Alomasoma nordpacificum* Zenkevitch, 1958 (North Atlantic, 2177–3056 m; Datta-Gupta 1981, pl. 5, fig. I); M – *Bengalus* sp. (Sea of Okhotsk, 3299–3552 m; Maiorova and Adrianov 2018, fig. 2A); N – *Alomasoma nordpacificum* Zenkevitch, 1958 (Sea of Okhotsk, 520–7820 m; Maiorova and Adrianov 2018, fig. 1A); O – *Eubonella valida* Fisher, 1946 (Sea of Okhotsk, 138 m; Fisher 1946, pl. 28, fig. 3); P – *Acanthohamlingia paradola* Fisher, 1946 (Kagoshima Gulf, Japan, 216 m; Fisher 1946, pl. 31, fig. 1); Q – *Alomasoma behyaevi* Zenkevitch, 1964 (Antarctic, 280–2816 m; Saiz-Salinas *et al.* 2000, fig. 1B); R – *Sluiterina flabellorhynchum* Murina, 1976 (Antarctic, 2240–5225 m; Saiz-Salinas *et al.* 2000, fig. 1C).

suggesting that similar ichnotaxa may exist in older strata and other deep-marine depositional settings.

CONCLUSIONS

Cochlearichnus tumidus igen. nov. et isp. nov. is described as a new deep-sea ichnotaxon from Paleocene turbiditic deposits of the Ropianka

Formation (Outer Carpathians, Poland) and the Pagliaro Formation (Northern Apennines, Italy), thereby contributing to the known diversity of deep-marine trace fossils.

The trace is consistently preserved as a hypichnial, spoon-shaped convex semi-relief and represents a pre-depositional structure formed in soft mud, which was subsequently scoured and cast by fine-

grained turbiditic sand during the low-energy phases of turbidity currents.

Its regular morphology and lack of locomotion features support the interpretation as a resting trace (cubichnion) produced by a stationary organism that was entirely or partly buried within the substrate.

Close morphological correspondence with the body plan of extant echiuran worms indicates that deep-sea echiurans were the most probable tracemakers.

Specimens referred to cf. *Cochlearichnus* igen. nov. likely reflect preservation variants, a different producer, or other ichnotaxa, foremost in the case of the more elongate forms, although additional material is required for confirmation.

Associated graphoglyptid-dominated assemblages assign *C. tumidus* igen. nov. et isp. nov. to the *Paleodictyon* ichnosubfacies of the *Nereites* ichnofacies, which is characteristic of distal deep-sea turbiditic systems.

The Paleocene record of *Cochlearichnus* igen. nov. is consistent with the post-Mesozoic expansion of deep-sea behavioural diversity.

Acknowledgments

AU was supported by the Fondazione Luigi, Cesare e Liliana Bertora and by the Jagiellonian University, through the Strategic Programme Excellence Initiative. Dirk Knaust (Norway) and Francisco J. Rodríguez-Tovar (Spain) are acknowledged for their constructive reviews.

REFERENCES

- Abbate, E. and Sagri, M. 1967. Suddivisioni litostratigrafiche nei calcari ad elmintoidi auct. della Placca dell'Ebbero-Antola e correlazioni con terreni simili affioranti tra Voghera e Castelnovo ne' Monti (Appennino Settentrionale). *Memorie della Società Geologica Italiana*, **6**, 23–65.
- Botting, P.J. and Muir, L.A. 2023. A new thalassematid echiuran worm from the Middle Ordovician Castle Bank Biota of Wales, UK. *Acta Palaeontologica Polonica*, **68**, 571–581.
- Buatois, L.A., Carmona, N.B., Curran, H.A., Netto, R.G., Mángano, M.G. and Wetzel, A. 2016. The Mesozoic marine revolution. In: Mángano, M.G. and Buatois, L.A. (Eds), *The Trace-Fossil Record of Major Evolutionary Events: Volume 2: Mesozoic and Cenozoic*, pp. 19–134. Springer Netherlands; Dordrecht.
- Catanzariti, R., Ellero, A., Levi, N., Ottria, G. and Pandolfi, L. 2007. Nannofossil biostratigraphy of the Antola Unit succession (Northern Apennines, Italy): new age constraints for the upper Cretaceous Helminthoid Flysch. *Cretaceous Research*, **28**, 841–860.
- Datta-Gupta, A.K. 1981. Atlantic echiurans. Part I. Report on twenty-two species of deep sea echiurans of the North and the South Atlantic Ocean. *Bulletin du Muséum national d'Histoire naturelle*, **3**, 353–378.
- Fisher, W.K. 1946. Echiuroid worms of the north Pacific Ocean. *Proceedings of the United States National Museum*, **96**, 215–292.
- Gnaccolini, M. 1988. Osservazioni sui conglomerati Oligocenici affioranti nell'area compresa tra Roccaforte Ligure e Gordona (Alessandria). *Rivista di Paleontologia e Stratigrafia Italiana*, **93**, 521–532.
- Goto, R., Monnington, J., Sciberras, M., Hirabayashi, I. and Rouse, G.W. 2020. Phylogeny of Echiura updated, with a revised taxonomy to reflect their placement in Annelida as sister group to Capitellidae. *Invertebrate Systematics*, **34**, 101–111.
- 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 Paleontologist*, **3**, 17–24.
- Jones, D. and Thompson, I.D.A. 1977. Echiura from the Pennsylvanian Essex Fauna of northern Illinois. *Lethaia*, **10**, 317–325.
- Książkiewicz, M. 1977. Trace fossils in the flysch of the Polish Carpathians. *Palaeontologia Polonica*, **36**, 1–208.
- Levi, N., Ellero, A., Ottria, G. and Pandolfi, L. 2006. Poly-orogenic deformation history recognized at very shallow structural levels: the case of the Antola Unit (Northern Apennines, Italy). *Journal of Structural Geology*, **28**, 1694–1709.
- Maiorova, A.S. and Adrianov, A.V. 2018. Deep-sea spoon worms (Echiura) from the Sea of Okhotsk and the adjacent slope of the Kuril-Kamchatka Trench. *Deep Sea Research Part II: Topical Studies in Oceanography*, **154**, 177–186.
- Marroni, M., Feroni, A.C., Biase, D. di, Ottria, G., Pandolfi, L. and Taini, A. 2002. Polyphase folding at upper structural levels in the Borbera Valley (northern Apennines, Italy): implications for the tectonic evolution of the linkage area between Alps and Apennines. *Comptes Rendus Geoscience*, **334**, 565–572.
- Marroni, M., Mollia, G., Ottria, G. and Pandolfi, L. 2001. Tectono-sedimentary evolution of the External Liguride units (Northern Apennines, Italy): insights in the pre-collisional history of a fossil ocean-continent transition zone. *Geodinamica Acta*, **14**, 307–320.
- Murina, V.V. 1976. New abyssal species of echiurans from the Pacific and Atlantic Oceans. *Zoologicheskii Zhurnal*, **55**, 837–843.
- Oszczypko, N., Malata, E., Bąk, K., Kędzierski, M. and Oszczypko-Clowes, M. 2005. Lithostratigraphy and biostratigraphy of the Upper Albian–Lower/Middle Eocene

- flysch deposits in the Bystrica and Rača subunits of the Magura Nappe (Beskid Wyspowy and Gorce ranges; Poland). *Annales Societatis Geologorum Poloniae*, **75**, 27–69.
- Prantl, F. 1945. Two strange fossils (traces) from the Chrustenice Beds – d83. *Rozprawy II. Třidy České Akademie*, **55**, 3–8. [In Czech]
- Riahi, S., Uchman, A., Stow, D., Soussi, M. and Ben Ismail Lattrache, K. 2014. Deep-sea trace fossils of the Oligocene–Miocene Numidian Formation, northern Tunisia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **414**, 155–177.
- Saiz-Salinas, J.I., Dean, H.K. and Cutler, E.B. 2000. Echiura from Antarctic and adjacent waters. *Polar Biology*, **23**, 661–670.
- Schlotheim, F. von, 1820. Die Petrefactenkunde auf ihrem jetzigen Standpunkte durch die Beschreibung seiner Sammlung versteinerter und fossiler Überreste des Thier- und Pflanzenreichs der Vorwelt, LXII + 438 pp. Becker; Gotha.
- Smith, A.B. and Crimes, T.P. 1983. Trace fossils formed by heart urchins – a study of *Scolicia* and related traces. *Lethaia*, **16**, 79–92.
- Stephen, A.C. and Edmonds, S.J. 1972. The phyla Sipuncula and Echiura, 528 pp. British Museum (Natural History); London.
- Studer, T. 1879. Die Fauna von Kerguelensland. Verzeichniss der bis jetzt auf Kerguelensland beobachteten Thierspecies nebst kurzen Notizen über ihr Vorkommen und ihre zoogeographischen Beziehungen. *Archiv für Naturgeschichte*, **45**, 104–141.
- 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. 1991. Shallow-water trace fossils in the Paleogene flysch of the Magura Nappe, Polish Outer Carpathians. *Annales Societatis Geologorum Poloniae*, **61**, 61–75.
- Uchman, A. 2004. Phanerozoic history of deep-sea trace fossils. In: McIlroy, D. (Ed.), The application of ichnology to palaeoenvironmental and stratigraphic analysis. *Geological Society, London, Special Publication*, **228**, 125–139.
- Uchman, A. 2007. Trace fossils of the Pagliaro Formation (Paleocene) in the North Apennines, Italy. *Beringeria*, **37**, 217–237.
- Uchman, A. 2008. Stop 11 – Słopnice – Ropianka Formation (Senonian–Palaeocene) and Variegated Shale (Eocene). In: Pieńkowski, G. and Uchman, A. (Eds), Ichnological Sites of Poland; The Holy Cross Mountains and the Carpathian Flysch; The Second International Congress on Ichnology, Cracow, Poland, August 29–September 8, 2008; Pre-Congress and Post-Congress Field Trip Guidebook, pp. 136–138. Polish Geological Institute; Warszawa.
- Uchman, A., Lebanidze, Z., Kobakhidze, N., Beridze, T., Makadze, D., Lobzhanidze, K., Khutsishvili, S., Chagelishvili, R., Koiava, K. and Khundadze, N. 2022. Unusual echinoid resting trace records change in the position of the redox boundary (Palaeogene of the Lesser Caucasus in Georgia). *Acta Geologica Polonica*, **72**, 317–330.
- Uchman, A. and Szczęch, M. 2022. Cretaceous deep-sea facies, stratigraphy, and ichnology in the Polish Flysch Carpathians. In: Walaszczyk, I. and Todes, J.P. (Eds), Cretaceous of Poland and the Adjacent Areas. Field Trip Guides, 249–296. Faculty of Geology, University of Warsaw; Warsaw.
- Uchman, A. and Wetzel, A. 2012. Deep-sea fans. In: Bromley, R.G. and Knaust, D. (Eds), Trace Fossils as Indicators of Sedimentary Environments. *Developments in Sedimentology*, **64**, 643–671.
- Uchman, A. and Wetzel, A. 2017. Hidden subsurface garden on own faeces — the trace fossil *Tubulichnium rectum* (Fischer-Ooster, 1858) from the Cretaceous–Palaeogene deep-sea sediments. *Palaeontologia Electronica*, **20.2.40A**, 1–18.
- Zenkevitch, L.A. 1958. The deep-sea echiurids of the north-western part of the Pacific Ocean. *Trudy Instituta Okeanologii*, **27**, 192–203. [In Russian].
- Zhang, G., Uchman, A., Chodyń, R. and Bromley, R.G. 2008. Trace fossil *Artichnus pholeoides* igen. nov. isp. nov. in Eocene turbidites, Polish Carpathian Mountains: possible ascription to holothurians. *Acta Geologica Polonica*, **58**, 75–86.
- Zhang, Z.-Q. 2011. Animal biodiversity: An introduction to higher-level classification and taxonomic richness. *Zootaxa*, **3148**, 7–12.

Manuscript submitted: 3rd February 2026

Revised version accepted: 27th March 2026

Appendix 1

List of trace fossils found in the Pagliaro Formation at Celio, Italy
(after Uchman 2007):

- a) circular and elliptical structures:
 - Cardioichnus?* isp.
 - Mammilichnis aggeris* Chamberlain, 1971
- b) simple and branched structures:
 - Chondrites intricatus* (Brongniart, 1823)
 - Chondrites targionii* (Brongniart, 1828)
 - Ophiomorpha annulata* (Książkiewicz, 1977) (Text-figs 4D, 6B)
 - Ophiomorpha rudis* (Książkiewicz, 1977)
 - Planolites beverleyensis* (Billings, 1862)
 - Planolites* isp.
 - Trichichnus linearis* Frey, 1970
- c) Radial structures:
 - Fascisichnium extantum* Książkiewicz, 1968
 - Lorenzina carpathica* (Zuber, 1910)
- d) Spreite structures:
 - Phycosiphon incertum* Fischer-Ooster, 1858
- e) Winding and meandering structures:
 - Cosmorhapse carpathica* Uchman, 1998
 - Cosmorhapse?* isp.
 - Helicorhapse tortilis* Książkiewicz, 1970
 - Helminthoidichnites* isp.
 - Helminthopsis hieroglyphica* Wetzel and Bromley, 1996
 - Helminthopsis* isp.
 - Helminthorhapse flexuosa* Uchman, 1995
 - Helminthorhapse miocenica* Sacco, 1886
 - Nereites irregularis* (Schafhüttl, 1851)
 - Ptychoplasma vagans* (Książkiewicz, 1977)
 - Scolicia strozzii* (Savi and Meneghini, 1850)
- f) Spiral structures:
 - “*Spirophycus*” *bicornis* (Heer, 1877)
- g) Branched winding and meandering structures:
 - Acanthorhapse delicatula* Książkiewicz, 1977
 - Belocosmorhapse aculeata* (Książkiewicz, 1977)
 - Desmograption?* isp.
 - Protopaleodictyon minutum* Książkiewicz, 1977
 - Ubinia alternans* (Seilacher, 1977)
 - Urohelminthoida appendiculata* (Heer, 1877)
- h) Networks:
 - Megagraption submontanum* (Azpetia Moros, 1933)
 - Paleodictyon miocenicum* Sacco, 1886

Appendix 2

List of trace fossils found in the Ropianka Formation at Słopnice, Poland (Uchman 2008; Uchman and Wetzel 2017; Uchman and Szczęch 2022; AU personal observations):

a) simple and branched structures:

Chondrites intricatus (Brongniart, 1823)

Chondrites targionii (Brongniart, 1828)

Chondrorhaphe bifida Seilacher, 1977

Halopoa isp.

Ophiomorpha annulata (Książkiewicz, 1977)

Planolites isp.

Spongeliomorpha oraviense (Książkiewicz, 1961)

Thalassinoides isp.

Tubulichnium rectum (Fischer-Ooster, 1858)

b) Radial structures:

Cladichnus fisheri (Heer, 1877)

Glockerichnus alata (Seilacher, 1977)

c) Spreite structures:

Phycosiphon incertum Fischer-Ooster, 1858

Zoophycos isp.

d) Winding and meandering structures:

Helminthopsis isp.

Helminthoidichnites isp. (Text-fig. 6E)

Nereites irregularis (Schafhäütl, 1851)

e) Spiral structures:

Rotundusichnium zumayensis (Gómez de Llarena, 1946)

“*Spirophycus*” *bicornis* (Heer, 1877)

f) Branched winding and meandering structures:

Acanthorhaphe delicatula Książkiewicz, 1977

Desmograption isp.

g) Networks:

Paleodictyon strozzii Meneghini in Savi and Meneghini, 1850