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ICHNOLOGY OF THE CAMBRIAN OCIESĘKI SANDSTONE FORMATION (HOLY CROSS MOUNTAINS, POLAND)

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Stachacz, M., 2016. Ichnology of the Cambrian Ociesęki Sandstone Formation (Holy Cross Mountains, Poland). *Annales Societatis Geologorum Poloniae*, 86: 291–328.

Abstract: Quartz arenites and wackes with intercalations of silty shales of the Ociesęki Formation were analysed in small outcrops and one core. The succession contains about forty-three ichnogenera and seventy-four ichnospecies, among which thirty-three ichnogenera and fifty-three ichnospecies are described by present author. The formation belongs to the *Schmidtiellus-Holmia* Superzone and to the *Protolenus-Issafeniella* Zone. Most strata are totally bioturbated. The diverse and numerous trace fossils represent the *Cruziana* ichnofacies in the lower part of the formation and the *Skolithos* ichnofacies in the upper part. A few possibly new ichnospecies of different ichnogenera have been described in open nomenclature. Sedimentary structures and trace fossil assemblages indicate that the older part of this formation was deposited on the upper offshore to lower shoreface, while its younger part was deposited on the lower to middle shoreface, where storm episodes were the main factor controlling sedimentation and the activity of benthos. The trace fossil associations studied are similar to those from the lower Cambrian in many places around the world. The ichnoassociations from the Polish part of the East European Platform and from Sweden, which represent the Baltica palaeocontinent, display the closest similarity.

Key words: Cambrian, trace fossils, shallow-water marine deposition, Holy Cross Mountains.

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INTRODUCTION

The lower Cambrian (corresponding to the Terreneuvian and Cambrian Series 2, Peng *et al.*, 2012) of the Holy Cross Mountains is developed as siliciclastic series that is 2,500–?3,500 m thick; however, the thickness is difficult to determine because of tectonic deformation (Orłowski, 1975, 1988; Łydka and Orłowski, 1978). The object of this study is the ichnology of the Cambrian Series 2 Ociesęki Sandstone Formation (also called the Ociesęki Formation), cropping out in the southern part of the Holy Cross Mountains.

The formation studied covers a large part of the Palaeozoic massif of the Holy Cross Mountains and forms the Chęciny-Klimontów Anticlinorium. Both laterally and vertically, the formation passes into the silty Czarna and Kamieniec formations (Orłowski, 1975; Kowalczewski, 1995). These formations were deposited in a shallow sea of the Małopolska Block, which according to recent ideas was located in close proximity to Baltica (Cocks and Torsvik, 2005).

The lower Cambrian of the Holy Cross Mountains and its fossils have been the subjects of many papers, especially by Orłowski (1974, 1975, 1987, 1988, 1989, 1992a–c, 1997), Żylińska and Masiak (2007), and Żylińska (2013). Previous publications on the trace fossils emphasize the systematic description of numerous ichnotaxa and their stratigraphical distribution (e.g., Kowalski, 1987; Orłowski, 1989, 1992b; Orłowski and Żylińska, 1996, 2002). Recently, Stachacz (2012a, 2013) presented a systematic description of *Rusophycus* and interpreted selected body fossils, trace fossils and sedimentary structures of the lower Ociesęki Formation as typical of storm deposits. A more complex study on the ichnology of this formation, containing ichnofabric analysis and the distribution of trace fossils according to facies, has not been made so far, except in conference abstracts (Stachacz, 2008) and unpublished research (M. Stachacz, unpubl. data, 2011). Previous research has not shown the precise distribution of the trace fossils within the sections studied.

In this paper, the results of a comprehensive ichnological analysis of the Ociesęki Formation are presented, comprising taxonomic analysis, ethology and palaeoecology, and bioturbation degree analysis. The locations of the outcrops containing the trace fossils and their detailed distribution in lithologic sections are presented.

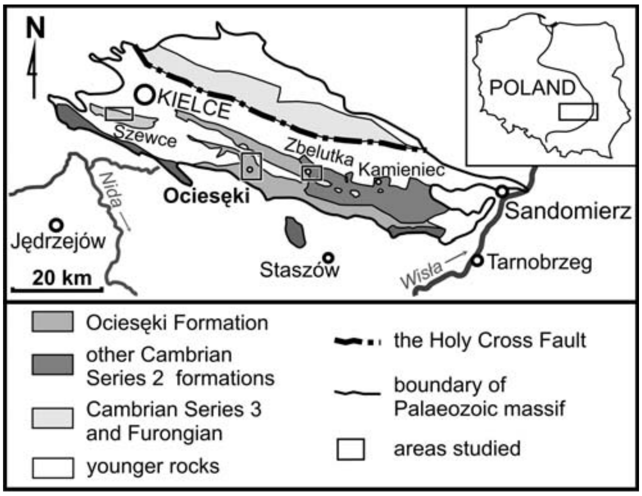


Fig. 1. Surface exposure of the Ocieseki Formation in the Palaeozoic massif of the Holy Cross Mountains (according to: Orłowski, 1975; Mizerski *et al*., 1991).

GEOLOGIC SETTING

The study area is located in the Kielce Region of the Holy Cross Mountains, which is in the northern part of the Małopolska Block (e.g., Buła, 2000). This region differs in its geological history and lithology from the Łysogóry Region in the northern part of the Holy Cross Mountains (e.g., Czarnocki, 1957). Rocks of the Ocieseki Formation crop out exclusively in the Kielce Region within the large Chęciny-Klimontów Anticlinorium, mostly along its axis. They crop out mostly in the central (Ocieseki area) and western (Kielce area) parts of the anticlinorium. The Kielce-Łagów Synclinorium located to the north is filled mostly with Devonian rocks. To the west and south-west, the Chęciny-Klimontów Anticlinorium is covered by the Mesozoic rocks of the Holy Cross Mountains and to the south and east by the Neogene of the Carpathian Foredeep. The Ocieseki Formation was studied in a few areas with relatively numerous exposures (Fig. 1), mostly in the hills of the Ocieseki and Orłowińskie ranges in the Ocieseki area, in the Bardo Syncline in the Zbelutka area, and the Zgórskie Range within the Dyminy Anticline in the Kielce area.

The stratigraphy of the Cambrian of the Holy Cross Mountains has been a topic of polemics on several occasions (e.g., Kowalczewski, 1995, 1997; Orłowski and Mizerski, 1995; Orłowski, 1997). In particular, the ages of and relationships between the neighbouring formations have been debated. Generally, the lithostratigraphic scheme of Orłowski (1975) is followed, also taking into account the critiques by Kowalczewski (1990, 1995), Lendzion (2001), Szczepanik *et al*. (2004) and Kowalczewski *et al*. (2006).

The Ocieseki Formation in its lower part contains the trilobites *Holmia marginata* Orłowski, 1974, *H. glabra* Orłowski, 1974, *Kjerulfia orcina* Orłowski 1974, *K. orienta* Orłowski, 1974, *Schmidtiellus panovi* (Samsonowicz, 1959), *S. nodosus* Orłowski, 1985 *Strenuella polonica* Czarnocki, 1926, *S. sandomirensis* Orłowski, 1985 and *S. zbelutkae* Orłowski, 1985, which date this part of the formation as belonging to the *Schmidtiellus-Holmia* Superzone (Orłowski, 1974, 1985). The upper part of the formation contains the trilobites *Kingaspidoides santacrusensis* (Samsonowicz, 1959) and *Issafeniella orlowinensis* (Samsonowicz, 1959), which point to the *Protolenus-Issafeniella* Zone (Orłowski, 1985; Mizerski *et al*., 1986; Geyer, 1990; Żylińska and Masiak, 2007). The presence of the trilobites *Ornamentapsis guerichi* (Orłowski, 1959), *O. opatowi* (Orłowski, 1985), *O. puschi* (Orłowski, 1985) and *Orodes usarzowi* (Orłowski, 1985) indicates the *Paradoxides insularis* Zone of the Cambrian Series 3 (formerly the middle Cambrian), in the uppermost part of the Ocieseki Formation (Mizerski *et al*., 1986; Żylińska, 2013). The Ocieseki Formation underlies the Słowiec Formation, which belongs to the *Paradoxides insularis* Zone (Orłowski, 1975, 1985; Orłowski and Mizerski, 1995). This is curious, because of the erosional contact between these two formations of the same

Table 1

Outcrops in the study area. *S-H* = *Schmidtiellus-Holmia*, *P-I* = *Protolenus-Issafeniella*

Ocieseki area		
Outcrop, GPS coordinates, location	Lithology, facies, body fossils (if any)	Zone
Sterczyna East, N50°43′24.7″; E020°58′44.2″. Pit on the E slope of Sterczyna Hill on the edge of the forest and cropland, by the yellow hiking trail, 200 m to the S from the Sterczyna hamlet (Fig. 2).	1.6 m thick section of yellow-brown wackes with isolated beds of grey quartz arenite and thin layers of siltstone (Fig. 3). Beds gently dip to NE. Beds of non-bioturbated and cross laminated arenites with sharp soles and tops (Stachacz, 2013, fig. 5B), wackes totally bioturbated (Fig. 3).	*S-H*
Sterczyna Quarry, N50°43′45.2″; E020°58′15.5″. Small, inactive quarry at the top of Sterczyna Hill, near the road from Sterczyna hamlet to the school at Ocieseki (Fig. 2).	> 4 m thick, almost horizontal, thin to medium beds of yellowish quartz arenites and wackes, rarely interbedded with silty shales (Fig. 4A), mostly totally bioturbated, (Fig 4A), except for some beds of arenites with relics of horizontal layering or ripple cross-lamination (Stachacz, 2013, fig. 5A). Body fossils: trilobites *Berabichia oratrix* (Orłowski, 1985), *Strenuella polonica* Czarnocki, 1926. Most of complete trilobites preserved as enrolled specimens within the thickest beds (Stachacz, 2013, fig. 4).	*S-H*
Jaźwina Hill. Natural exposure in riverbed of the Grodno Stream, at foot of the western slope of Jaźwina Hill (Fig. 2). Also loose sandstone slabs near the top of Jaźwina Hill.	About 3 m thick section of thin- to thick-bedded arenites and wackes (Fig. 4B). Thin beds partly amalgamated. Degree of bioturbation varies, also within the amalgamated beds. Relicts of horizontal and ripple cross lamination (Fig. 4B) in some beds.	*S-H*

Ocieseki area		
Outcrop, GPS coordinates, location	Lithology, facies, body fossils (if any)	Zone
Igrzyczna North, N50°44′39.0″; E020°57′07.4″, Artificial slope undercut in a small hill at the foot of the larger Igrzyczna Hill, by the road from Ociesęki to Daleszyce, about 2 km to the north from the school in Ociesęki (Fig. 2).	Normally oriented 110°/16°, about 1.5 m thick of thin-bedded wackes intercalated by uncommon, thin beds of quartz arenites and siltstones (Fig. 5A). The wackes and siltstones usually totally bioturbated (Fig. 5A), in some places relics of horizontal lamination. The arenites bioturbated in varies degree. Unbioturbated ripple laminated beds (M. Stachacz, unpubl. data, 2011, fig. 22A, B). Body fossils: trilobites *Strenuella polonica*, *Berabichia oratrix*.	*S-H*
Igrzyczna South, N50°44′13.9″; E020°56′44.0″, natural exposure in the steep ravine of an ephemeral stream, southern slope of Igrzyczna Hill, near Igrzyczna village (Fig. 2).	Normally oriented, arranged 110°/16°, about 3 m thick section of thin to medium beds of arenites and wackes interbedded by uncommon, thin layers of silty shales (Fig. 5B). The wackes and arenites strongly bioturbated, except for some horizons with horizontal and ripple cross-lamination.	*S-H*
Leśniakowa Dębina Hill, N50°44′20″; E020°58′22″, loose sandstone slabs on the territory of a former, small quarry, on the edge of a forest and a cropland (Fig. 2).	Grey and yellow-grey quartz arenite in loose blocks. Body fossils: trilobites *Strenuella polonica*, *Berabichia oratrix*, rarely *Holmia* sp.	*S-H*
Zamczysko, inactive quarry at the top of Zamczysko Hill, near the large wooden cross by the blue hiking trail (Fig. 2). Loose slabs of the same lithology scattered on the whole Zamczysko Hill.	Medium beds of light-grey or brown quartz arenites without primary sedimentary structures.	*P-I*
Łapigrosz, N50°45′30.7″; E020°56′39.6″, old, exploratory pits at the western foot of the Zamczysko Hill by the blue hiking trail (Fig. 2). The same rocks at the top of the hill.	Medium beds of light-grey or brown quartz arenites without primary sedimentary structures.	*P-I*
Wysokówka Hill: Numerous loose blocks and slabs on a forested hill to the north from Nowa Huta village (Fig. 2).	The blocks of medium beds of white or yellow quartz arenites locally with small silty clasts. Ripple cross-, low angle cross- or hummocky cross-laminated beds (M. Stachacz, unpubl. data, 2011, fig. 41B). Some parts of the beds totally bioturbated. Body fossils: trilobites *Issafeniella ?orlowinensis*.	*P-I*
Zamczysko Reserve vicinity, N50°47′03.5″; E020°57′07.1″, East from the Wysokówka Hill, in the ravine by the neighbouring hill, by the western border of the Zamczysko Natural Reserve (Fig. 2).	Almost horizontal, about 2 m thick section and loose slabs. Thick beds of quartz arenites, some rippled at the top.	*P-I*
Koziel pit, N50°45′14.7″; E020°58′32.5″, old pit in the forest on the periphery of Koziel village (Fig. 2).	Normally oriented, 9°/42°, thin to medium beds of arenite. Beds totally bioturbated, without primary sedimentary structures (Fig. 6).	*P-I*
Zbelutka area		
Zbelutka Quarry, N50°43′04.8″; E021°09′33.6″, abandoned quarry south of Zbelutka Nowa village, by foot of the steep, southern slope of an unnamed hill (Fig. 7).	A few metres thick series of thin- to medium-bedded wackes and quartz arenites. Arenite and wacke beds bioturbated to varying degrees. Unbioturbated beds in the upper part of the section distinctly horizontally laminated and very low-angle cross-laminated. Other beds bioturbated, with relics of horizontal lamination some places and, rarely ripple laminated (Fig. 8).	*P-I*
Chojnów Dół ravine, N50°42′47.8″; E021°07′19.1″, a natural exposure in a deep ravine south of Zbelutka-Kędziorka village (Fig. 7).	Vertical to sub-vertical, several metres thick but further researches were halted because of the owner´s opposition. One of the sandstone bed amalgamated, totally bioturbated in the lower part and unbioturbated, low-angle cross-laminated in its upper part.	*P-I*
Łagowica Road, N50°42′40.5″; E021°10′01.9″, roadcut from Pipała to Nowa Łagowica, east of the road (Fig. 7).	About one metre thick series of thin beds of quartz arenites and wackes normally inclined, almost horizontal, mostly totally bioturbated, rarely horizontally laminated.	*P-I*
Kielce area		
Zagrody, N50°49′53.3″; E020°32′06.8″. Steep, high wall in slope undercuts of hills in Zagrody, near the railway station (Fig. 9).	Normally, sub-vertically arranged, thin- to medium-bedded quartz arenites and wackes interbedded by uncommon siltstone beds.	*P-I*
Zgórskie Range, N50°50′33.3″; E020°29′29.9″. A steep wall on the western side of the crosscut road of road E 77 near Szewce village (Fig. 9).	Folded, inclined at diverse angles, locally inverted, thin-bedded wackes and thin- to medium-bedded quartz arenites intercalated with thin layers of siltstones. Beds of arenites and wackes totally bioturbated, but thin layers of siltstones are horizontally laminated (Fig. 10).	*P-I*
Plebańska Góra, N50°51′25.3″; E020°27′27.8″. Inactive quarry on the slope of Plebańska Hill, south of Jaworznia (Fig. 9).	Medium beds of reddish quartz arenite, rarely wackes and siltstones, steeply inclined to the north. The arenite and wacke beds strongly bioturbated. Trace fossils are blurred by almost total bioturbation.	*P-I*

age. A discussion of the age of the uppermost part of the Ociesęki Formation and the Słowiec Formation is provided by Kowalczewski (1995). The thickness of the Ociesęki Formation is a matter of controversy. Kowalczewski (1990) estimated it as 350–800 m, but, according to tectonic research in the Ociesęki Range and the Zamczysko Range, in the stratotype area of this formation, its thickness at least exceeds 1,200 m (Mizerski *et al*., 1986).

OUTCROPS STUDIED

The field studies were conducted on natural and artificial exposures in the southern part of the Holy Cross Mountains (Table 1). Sandstones of the Ociesęki Formation were mostly studied in the axial part of the Chęciny-Klimontów Anticlinorium: in the Ociesęki Range in the vicinity of Ociesęki, in the Zgórskie Range in the vicinity of Kielce

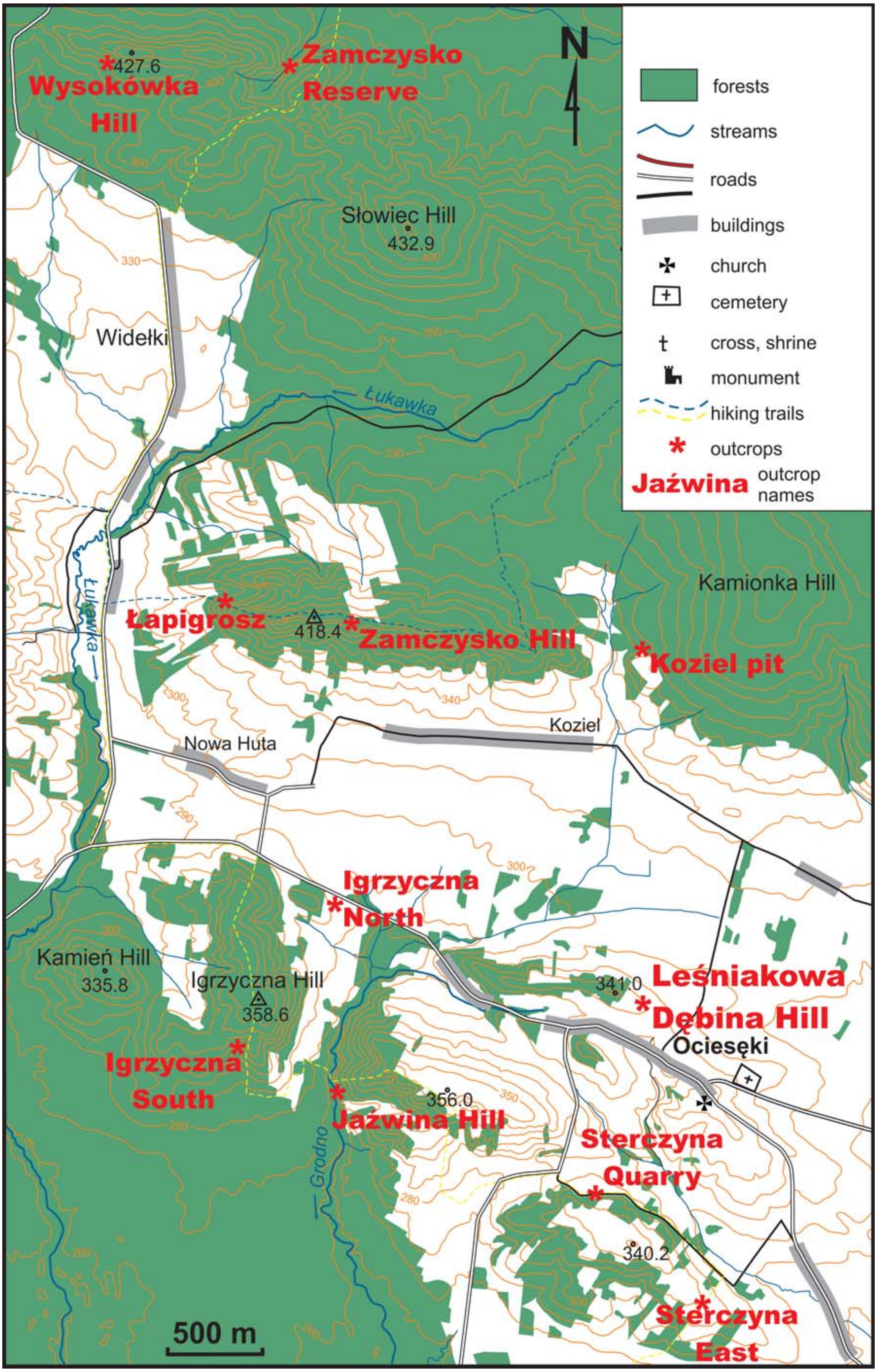


Fig. 2. Map of the Ocieseki area with location of outcrops studied.

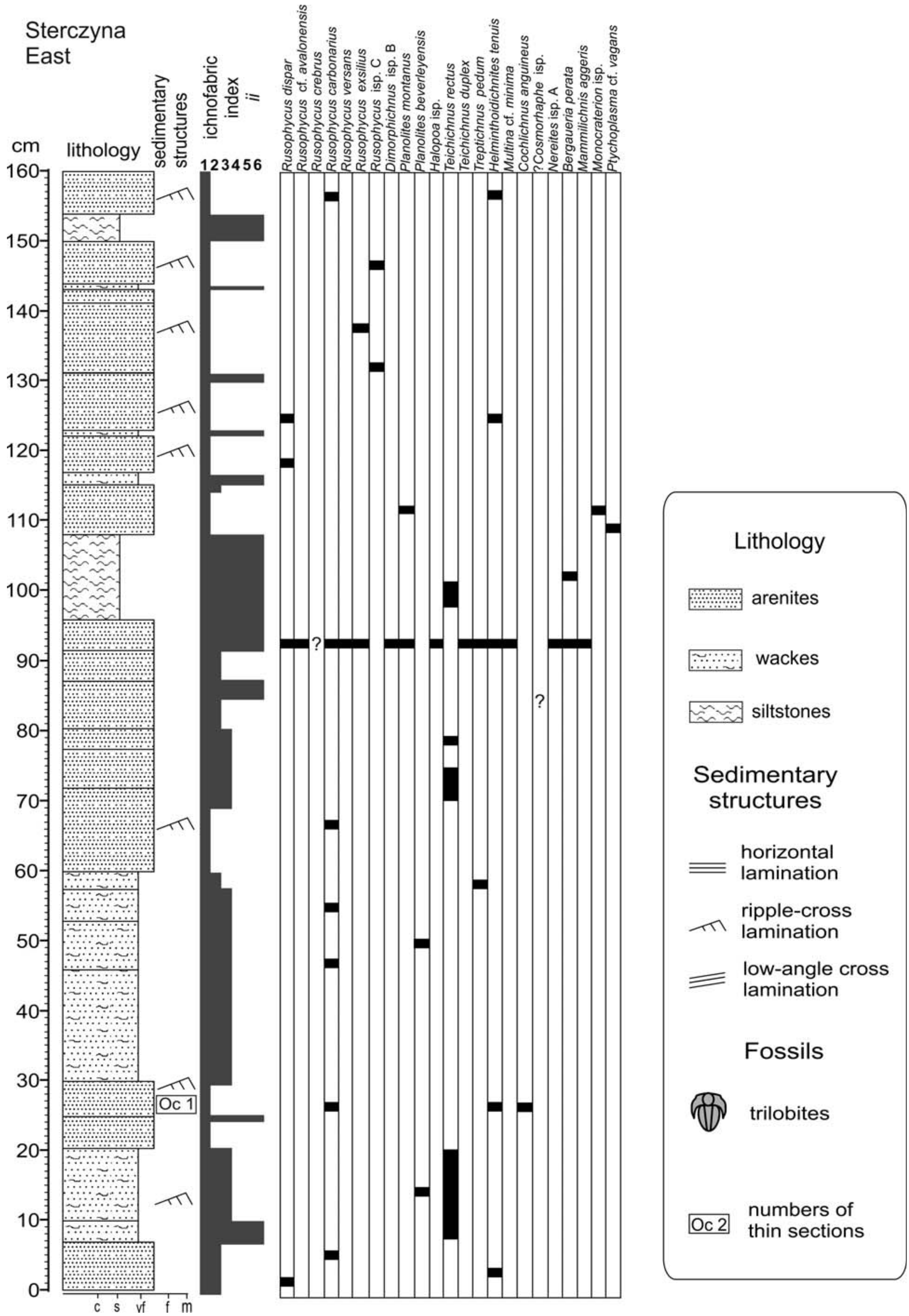


Fig. 3. Sterczyna East stratigraphic log. Ichnofabric index (see Droser and Bottjer, 1986) indicated. Lithology after Stachacz (2013).

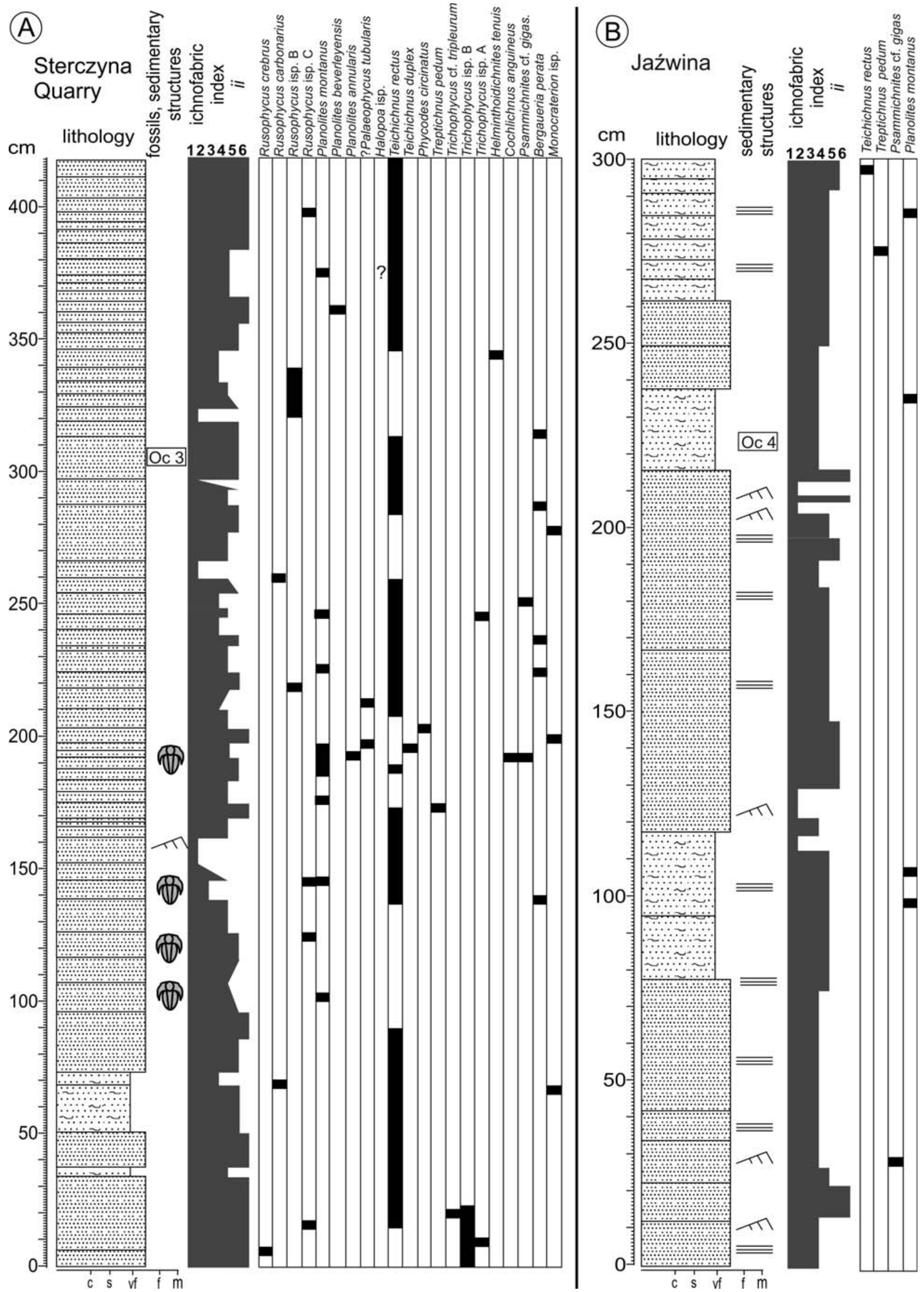


Fig. 4. Stratigraphic logs of sections studied. **A.** Sterczyna Quarry. **B.** Jaźwina. Legend as in Fig. 3. Ichnofabric index (see Droser and Bottjer, 1986) indicated. Lithology after Stachacz (2013).

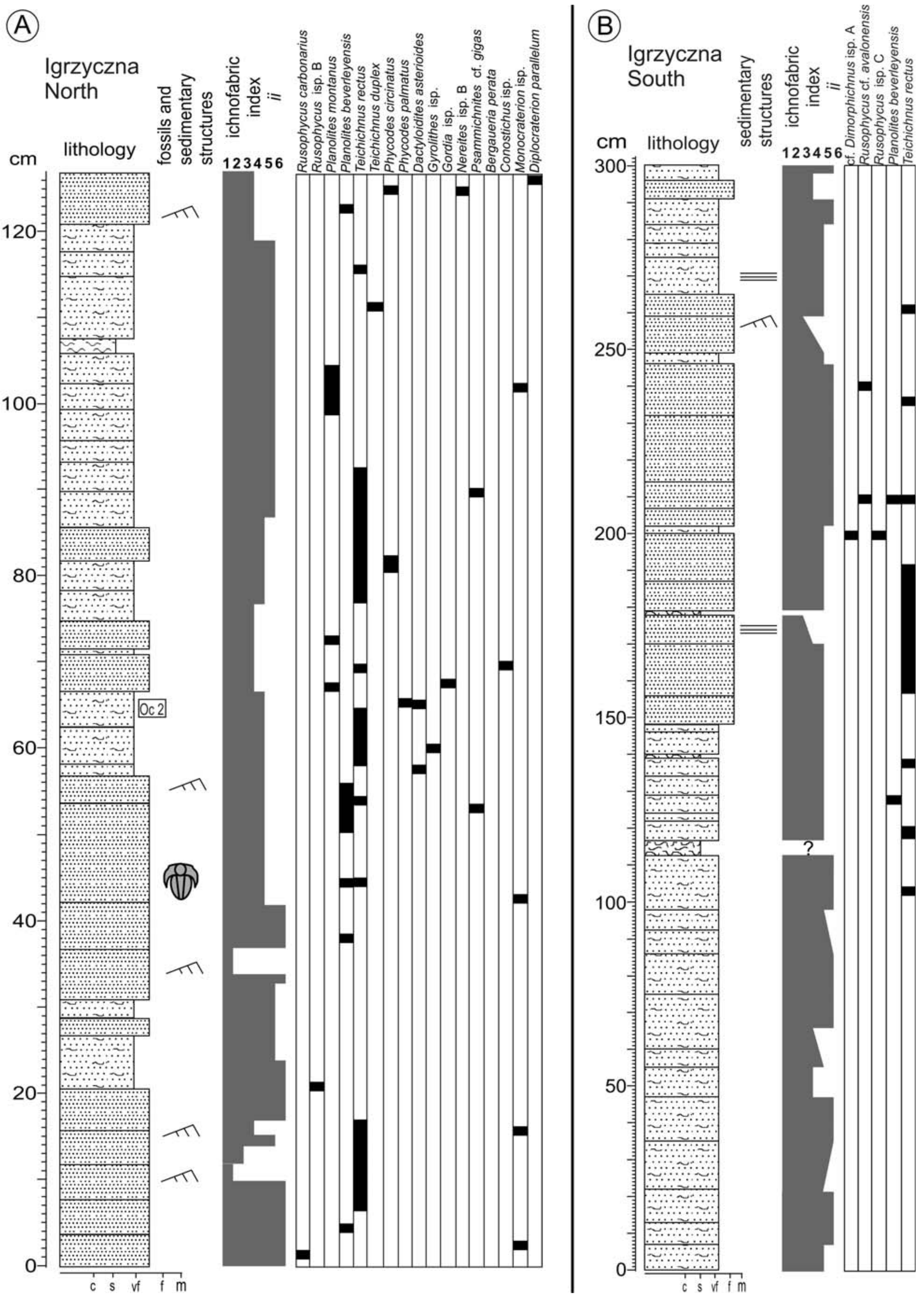


Fig. 5. Stratigraphic logs of sections studied. **A.** Igrzyczna North, **B.** Igrzyczna South. Legend as in Fig. 3. Ichnofabric index (see Droser and Bottjer, 1986) indicated. Lithology after Stachacz (2013).

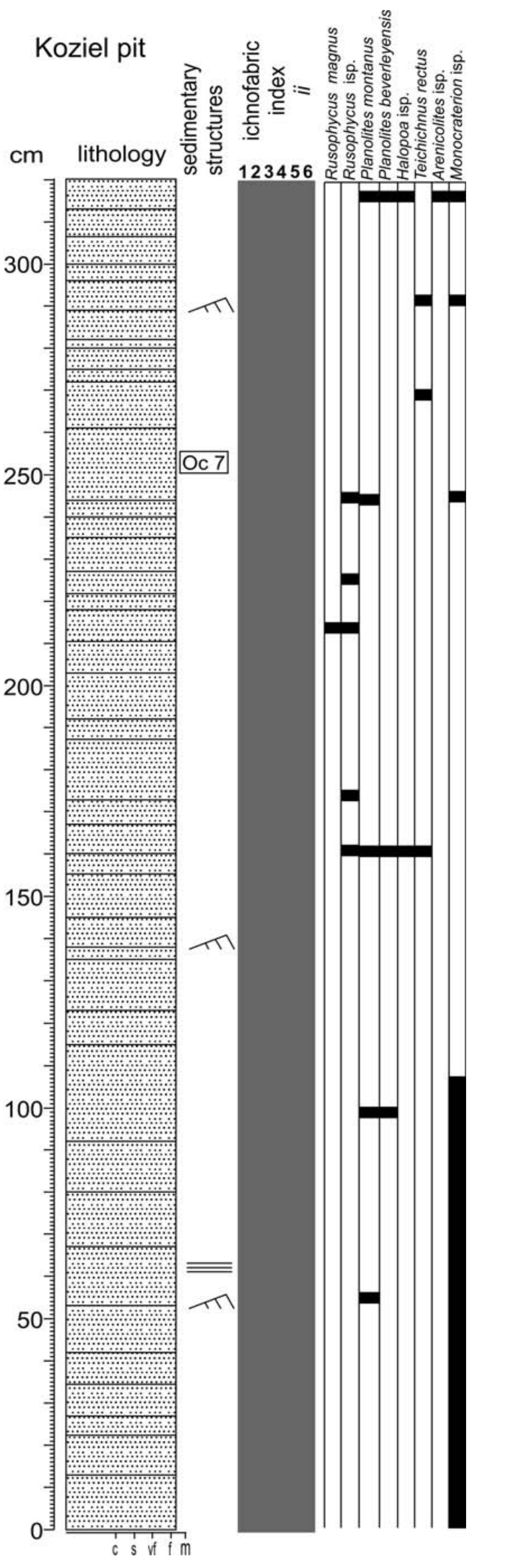


Fig. 6. Stratigraphic log of Koziel pit. Legend as in Fig. 3. Ichnofabric index (see Droser and Bottjer, 1986) indicated.

and in the Bardo Syncline in the Zbelutka region. The Cambrian of the Ociesęki Formation is poorly exposed and only small exposures and outcrops 1.3–8 m high were examined. Natural exposures are mostly in riverbeds and steep ravines. Several pits were made in the slopes of hills. All of the sections studied are made up of arenites and wackes, composed mostly of angular, fine grains of quartz, rarely mica flakes and other minerals.

Moreover, one drill-core from the Szewce IG-1 borehole, housed at the archive of the Polish Geological Institute in Kielce, was examined. Bioturbated, almost vertically oriented sandstone-siltstone heterolithic beds occur there at a depth of 16–48 m. The core shows relicts of horizontal lamination and the trace fossils *Planolites* isp., *Teichichnus* isp. and small, undetermined vertical burrows.

SYSTEMATIC DESCRIPTIONS

Trace fossils have been grouped into the morphological groups, proposed by Książkiewicz (1977) and modified by Uchman (1995, 1998), distinguishing between the horizontal and vertical structures proposed by Schlirf (2000) and representing differences in the behaviour of organisms (see Uchman, 1998). Shortened synonymies with special attention to the Cambrian trace fossils are given below. Occurrences of ichnotaxa in the Ociesęki Formation are presented; however, some of the trace fossils have wide stratigraphical and geographical distribution. The specimens are housed at the Institute of Geological Sciences, Jagiellonian University, Kraków, and labelled INGUJ214P.

Circular and elliptical structures

Ichnogenus *Mammillichnis* Chamberlain, 1971

Remarks. The taxonomy and origin of *Mammillichnis* are unclear. According to Chamberlain (1971), it could represent a resting or hiding trace or the upper part of a burrow. Chamberlain (1977) stated that *Mammillichnis* is a resting trace or a domichnion of "worms" (for more details see Uchman, 1998).

Mammillichnis aggeris Chamberlain, 1971
Fig. 11A

*1971 *Mammillichnis aggeris* – Chamberlain, p. 238, pl. 30. 6, 7, fig. 7G–J.
1996 *Mammillichnis aggeris* Chamberlain, 1971 – Pacześna, p. 56, pl. 7, figs 1, 2.
v 1998 *Mammillichnis aggeris* Chamberlain, 1971 – Uchman, p. 107, figs 1, 2.

Material. Three sandstone slabs (INGUJ214P/Mr56, /Ig139, /K5) with eight specimens.

Description. Hypichnial convex semirelief visible as a small, smooth swelling, 4.5–6 mm wide, 2–4 mm high, usually with a depression in the apical part, which resembles a mammilla. The apical depression is 1.5–2 mm wide.

Remarks. The specimens discussed are very similar to the specimens of *M. aggeris*, illustrated by Chamberlain (1971), Książkiewicz (1977) and Uchman (1998), but the apical depression is smaller, shallower, or indistinct in some specimens, probably because of taphonomic processes.

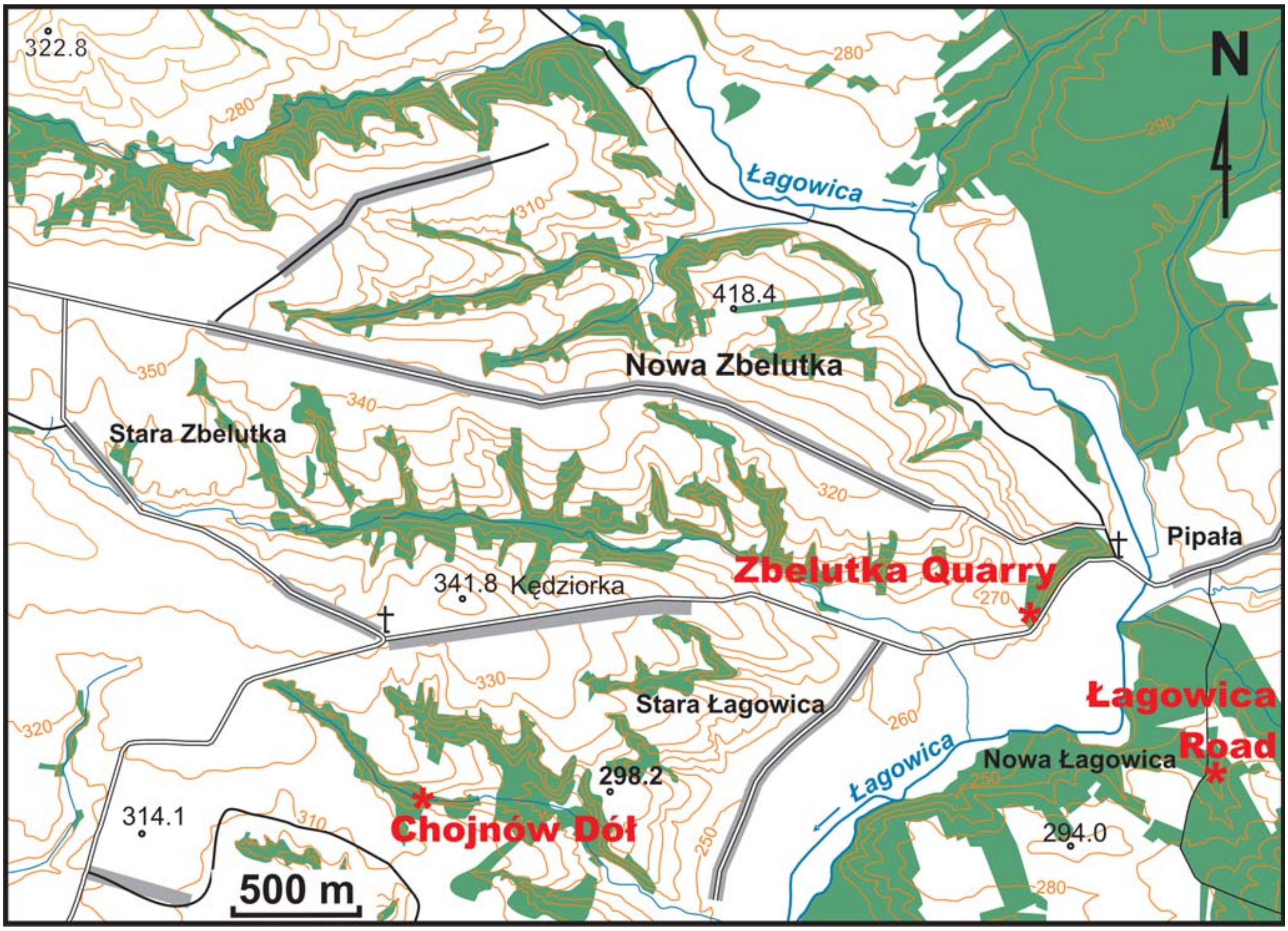


Fig. 7. Map of the Zbelutka area with locations of outcrops studied.

Ichnogenus *Bergaueria* Prantl, 1945

Remarks. According to Pemberton *et al*. (1988), a diameter to height ratio of 2, as well as the cylindrical or semicircular shape and the absence of sculpture are the diagnostic features of this ichnogenus, which allow distinction from the similar *Conostichus* Lesquereux, 1876 and *Astropolichnus* Crimes and Anderson, 1985. *Bergaueria* is commonly interpreted as a trace of anchoring or burial of sea anemones or similar suspension feeders (e.g., Pemberton *at al.*, 1988).

Bergaueria perata Prantl, 1945
Fig. 11B, C

*1945 *Bergaueria perata* n. g. n. sp. – Prantl, p. 51, figs 1, 2, pl. 1.1, 1.2.
1963 *Bergaueria perata* Prantl – Radwański and Roniewicz, p. 271, pl. 9.1–9.3.
1989 *Bergaueria perata* Prantl, 1945 – Orłowski, p. 223, pl. 18.3.
1990 *Bergaueria perata* Prantl, 1945 – Pemberton and Magwood, p. 437, figs 2.1–2.3, 3.3
1996 *Bergaueria perata* Prantl, 1945 – Pacześna, p. 56, pl. 1.6, 1.7.
v 1996 *Bergaueria perata* Prantl, 1945 – Orłowski and Żylińska, p. 403, fig. 11C–F.
2002 *Bergaueria perata* Prantl, 1945 – Orłowski and Żylińska, p. 137, fig. 3A, B.
2006 *Bergaueria perata* Prantl, 1945 – Gámez Vintaned *et al*., p. 452, fig. 6.1–6.4.

Material. Six specimens (INGUJ214P/Ig138–140, /Mr54–56).
Description. Hypichnial, convex hyporelief or endichnial, cylindrical or bulging, with a high tubercle, in most cases with a small, apical depression. The surface of the tubercle is smooth or covered with delicate grooves. The whole structure is 15–45 mm in diameter, 5–20 mm high, with an apical depression 2–4 mm wide.
Remarks. The size, presence/absence of the apical depression are variable, but this falls into the variability of *B. perata* Prantl, 1945 (Pemberton *et al*., 1988). Similar specimens from the Ociesęki Formation have been described by Orłowski and Żylińska (2002), from the Furongian of the Holy Cross Mountains (Radwański and Roniewicz, 1963; Orłowski and Żylińska, 1996) as well as from the Cambrian rocks of the central and western Europe (e.g., Prantl, 1945; Gámez Vintaned *et al*., 2006) and North America (e.g., Pemberton and Magwood, 1990).

Ichnogenus *Conostichus* Lesquereux, 1876

Remarks. According to Pemberton *et al*. (1988), this ichnogenus has conical shape with a sculptured surface and the diameter to height ratio varies. The similar *Bergaueria* differs in the absence of ornamentation. *Conostichus* is commonly interpreted as a trace of sea anemones or similar suspension feeder organisms, anchoring or burying in the sediment (e.g., Pemberton *et al*., 1988).

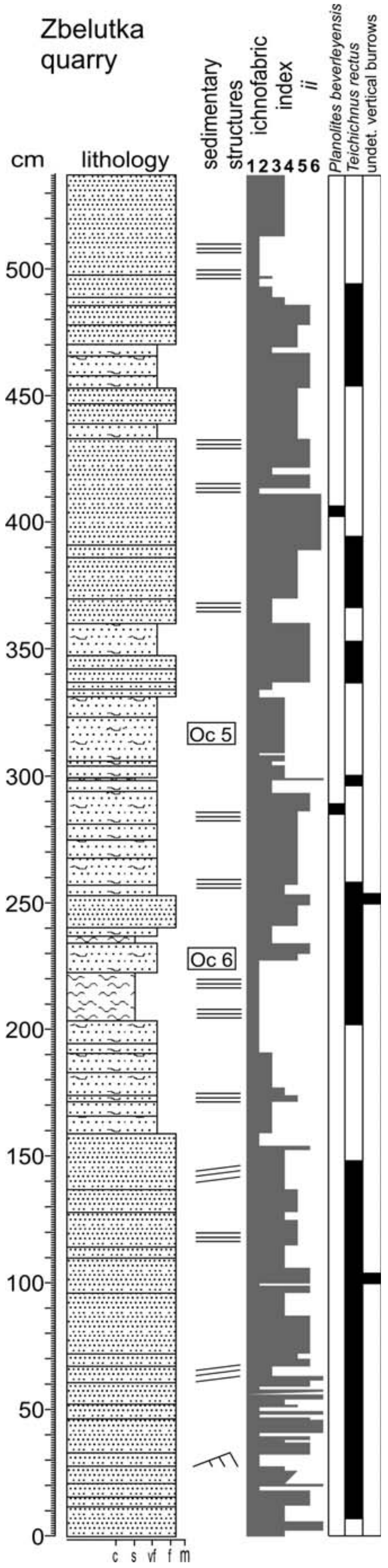


Fig. 8 Stratigraphic log of Zbelutka Quarry. Legend as in. Fig. 3. Ichnofabric index (see Droser and Bottjer, 1986) indicated.

Conostichus isp.
Fig. 11D

Material. Two specimens (INGUJ214P/Ig143, 144).
Description. Endichnial full relief, visible as irregular cone, nearly elliptical cross sections, about 20 mm high. The margin of the cone base is distinctly semi-circular. The surface of the cone is uneven, indistinctly sculptured by several furrows running from the apex to the margin (arrowed in Fig. 11D). The base of the cone is about 28 mm wide.
Remarks. The illustrated specimen is similar to *Bergaueria perata* Prantl, 1945, but it differs in its conical shape and indistinctly sculptured surface that formed vertical furrows. Similar burrows with very indistinct sculpture have been described as *Conostichus* isp. by Pacześna (2010) from the Cambrian of the Upper Silesian Block.

Ichnogenus *Astropolichnus* Crimes and Anderson, 1985

Remarks. *Astropolichnus* Crimes and Anderson, 1985 is similar to *Conostichus* Lesquereux, 1876 and *Bergaueria* Prantl, 1945, but according to Pemberton *et al*. (1988), relatively large diameter to height ratio of >3 and numerous unbranched, radial ridges surrounding the centre are typical features of this ichnogenus. *Astropolichnus* is commonly interpreted as a trace of sea anemones or similar suspension feeding organisms, anchoring or burying themselves (e.g., Pemberton *et al*., 1988). According to Seilacher (2007), *Astropolichnus* could have been produced by actinians with fleshy septa within the gastrocoel.

Astropolichnus hispanicus (Crimes, Legg, Marcos and Arboleya, 1977)
Fig. 11E

*1977 *Astropolithon hispanicus* isp. nov. – Crimes, Legg, Marcos and Arboleya, p. 112, pl. 5.
1985 *Astropolichnus ?hispanicus* (Crimes *at al*., 1977) – Crimes and Anderson, p. 31, pl. 5.1.
2010 *Astropolichnus hispanicus* (Crimes *at al*., 1977) – Jensen *et al*., p. 696, fig. 8a.

Material. One specimen (INGUJ214P/Ig141).
Description. Hypichnial, convex semirelief visible as two elliptical discs. The first disc partly overlaps the other one. One of the discs shows a distinct depression in its central part with radial, indistinct ribs around it. Ribs are not seen on the second disc. Single disc is about 11 mm wide and about 1.5 mm high.
Remarks. The specimen discussed shows traces of either double anchoring of organism and its displacement or resting traces of two neighbouring polyps. The ribs on one of the discs are not preserved through taphonomic processes. The illustrated specimens, preserved in greywacke, slightly differ from typical specimens of *A. hispanicus* (cf. Crimes *et al.*, 1977; Crimes and Anderson, 1985, Pillola *et al.*, 1994) in narrower ridge radiating from the central part. These variations are probably a result of taphonomic processes, which were different in the sandy and silty deposits. Nevertheless, the specimen discussed distinctly shows features typical of *A. hispanicus.* This ichnospecies is typical of the Gondwana and Avalonia palaeocontinents and it corresponds to the trilobite Redlichiid realm (Pillola *et al.*, 1994). The specimen from the Ociesęki Formation described here is the first occurrence of *A. hispanicus* in the Baltica area.

Ichnogenus *Rusophycus* Hall, 1852

Seven ichnospecies of *Rusophycus* have been described from the Ociesęki Formation (Stachacz, 2012a), including *Rusophycus dispar* (Linnarsson, 1871), *Rusophycus* cf. *avalonensis* Crimes

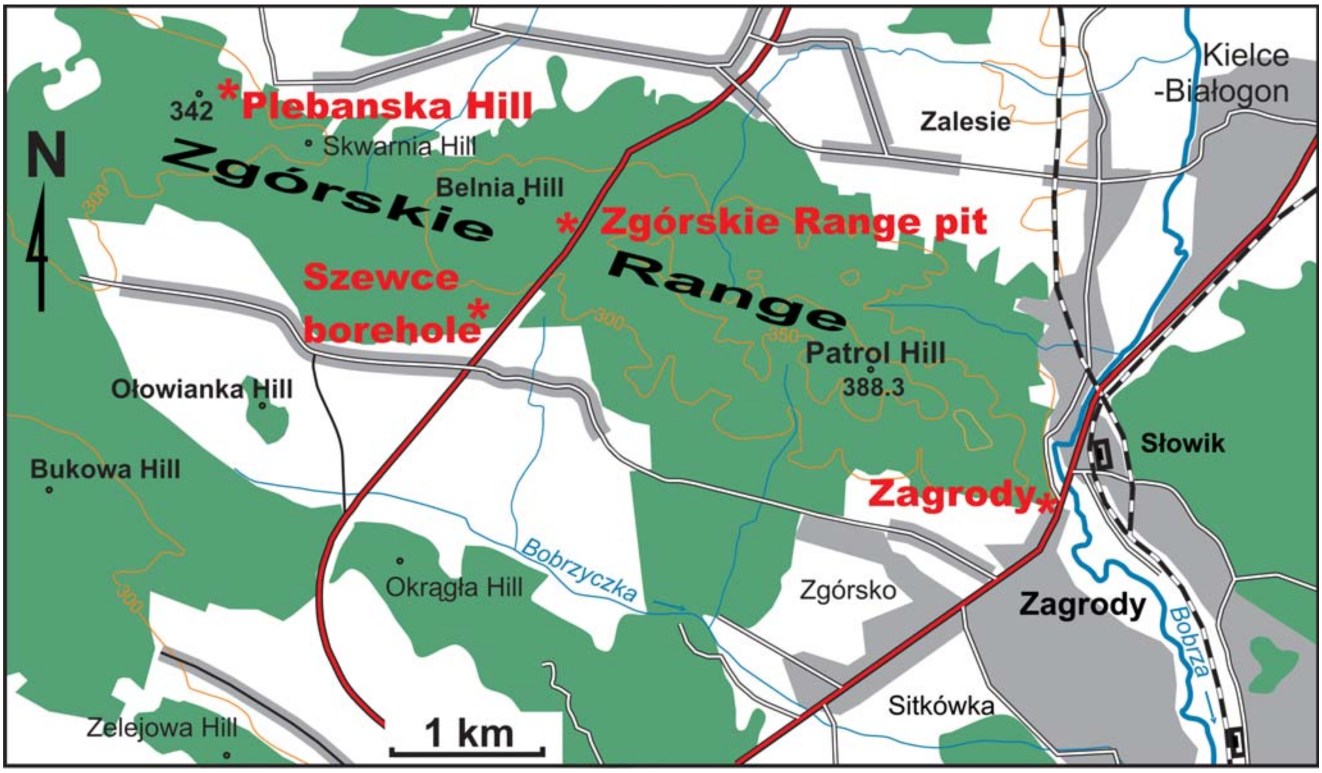


Fig. 9. Map of the Zgórskie Range with location of outcrops studied.

and Anderson, 1985, *Rusophycus crebrus* (Orłowski, 1992b), *Rusophycus magnus* (Orłowski, 1992b), *Rusophycus carbonarius* (Dawson, 1864), *Rusophycus versans* Schlirf and Uchman, 2001, and *Rusophycus exsilius* Stachacz, 2012. Moreover, *Rusophycus* ispp. A, B, C, have been recognized, but are not presented in this paper. Additional remarks on the formation of well preserved *Rusophycus* in storm deposits of the Ocieseki Formation are provided by Stachacz (2013).

Horizontal simple structures

Ichnogenus *Dimorphichnus* Seilacher, 1955

Remarks. *Dimorphichnus* Seilacher, 1955 is commonly interpreted as the scratch traces of arthropods (e.g., Seilacher, 1955; Pickerill and Peel, 1990). A discussion of the morphological similarities and differences between *Dimorphichnus* Seilacher, 1955 and *Diplichnites* Dawson, 1873 was presented by Fillion and Pickerill (1990).

cf. *Dimorphichnus* isp. A
Fig. 12A

Material. One specimen (INGUJ214P/IgS8).
Description. Hypichnial, convex semirelief composed of two sets of slightly curved ridges arranged in different directions, criss-crossing at an angle of 35–40°. Ridges on the first set are generally parallel to one another, while criss-crossing on the second set. On one side, the ridges terminate, where they plunge abruptly into the bed, while on the opposite side the termination is thicker and gently plunge. Individual ridges are 2–3 mm wide, maximally about 70 mm long. Parallel ridges in a single set are 3–4 mm apart.
Remarks. Scratch traces cf. *Dimorphichnus* isp. A differ from cf. *Dimorphichnus* isp. B in distinctly wider and sparsely distributed ridges, which are casts of scratch traces. The specimen described differs from *D. obliquus* Seilacher, 1955 in having shorter, but wider ridges of the same width, while the latter displays two types of ridge with variable width.

cf. *Dimorphichnus* isp. B
Fig. 12B

Material. One specimen (INGUJ214P/Mr45).
Description. Convex, hypichnial semirelief, composed of a set of several (up to 9) parallel ridges. The ridges are wide and sigmoidally curved for a short distance on one side and very narrow and slightly curved on the other. The ridges are semi-circular in cross-section. Their wider terminations abruptly end, plunging into the bed on the thinner termination. The ridges are up to 30 mm long, 2 mm apart, but the thick part is 13–15 mm long, 2 mm thick in the median part, but thinner towards the terminations.
Remarks. Scratch traces cf. *Dimorphichnus* isp. B differ from cf. *Dimorphichnus* isp. A in having distinctly narrower ridges, which are the casts of scratch traces. The illustrated specimen differs from *D. obliquus* Seilacher, 1955 in the presence of only one series of ridges with a highly variable width.

Ichnogenus *Planolites* Nicholson, 1873

Remarks. The distinction between *Planolites* Nicholson, 1873 and the morphologically very similar *Palaeophycus* Hall, 1847 was delineated by Pemberton and Frey (1982), Fillion and Pickerill (1990) and Keighley and Pickerill (1995). The absence of a wall and the presence of an active filling contrasting with the host rock are typical features of *Planolites*. *Planolites* include very common structures, formed by worm-like deposit-feeders in many facies (e.g., Pemberton and Frey, 1982; Fillion and Pickerill, 1990).

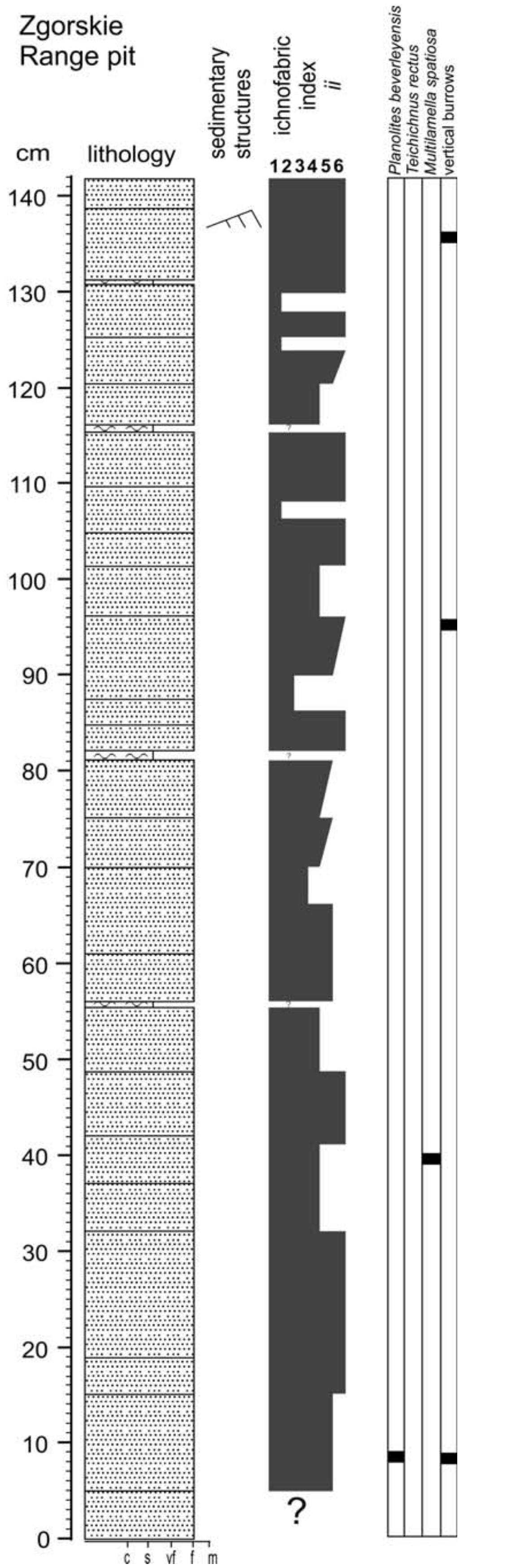


Fig. 10. Stratigraphic log of the Zgórskie Range pit. Legend as in Fig. 3. Ichnofabric index (see Droser and Bottjer, 1986) indicated.

Planolites beverleyensis (Billings, 1862)
Fig. 12C

1982 *Planolites beverleyensis* (Billings, 1862) – Pemberton and Frey, p. 866, pls 1.7, 2.5, 2.8, 2.9, 5.8, 5.9, 3.1, 3.2, 3.7, 3.8; 5.1, 5.2 (cum. syn.).
v1989 *Planolites beverleyensis* (Billings, 1862) – Orłowski, p. 216, pl. 13.3, 13.4.
1989 *Planolites beverleyensis* (Billings, 1862) – Walter *et al.*, p. 61, pls 15.2–15.6, 16.1–16.6.
1996 *Planolites beverleyensis* (Billings, 1862) – Paczeŝna, p. 235, fig. 10E, I.
1999 *Planolites beverleyensis* (Billings, 1862) – Mizerski *et al.*, p. 354, pl. 1.1a, 5a.

Material. Eighteen specimens (INGUJ214P/St101–104, /Mr/107–110, /Ig121, /Js29–37), numerous specimens observed in the field.
Description. Horizontal, hypichnial, convex semirelief or endichnial full relief preserved as straight or slightly curved, semicircular or semi-elliptical ridges with smooth surface. The ridges are 3–10 mm wide, uniformly through the whole length, which may rich several tens of millimetres. The ridges are infilled by sandy material, differing slightly in texture from the host rock.
Remarks. Some specimens are difficult to distinguish from *Palaeophycus tubularis* Hall, 1847 because of indistinct textural differences between the sandy infilling and sandy-silty host rock.

Planolites montanus Richter, 1937
Fig. 12D

*1937 *Planolites montanus* sp. nov. – Richter, p. 151, figs 1–5.
1970 *Planolites ballandus* sp. nov. – Webby, p. 95, fig. 14A–C.
1982 *Planolites montanus* Richter – Pemberton and Frey, p. 869, pls 2.4, 2.7, 3.9 (cum. syn.).
1987 *Planolites nematus* isp. nov. – Kowalski, p. 25, pls 2.1, 2.3, 5.3, 6.1, 6.2.
1987 *Planolites ballandus* Webby, 1970 – Kowalski, p. 25, pls 2.3, 3.1, 3.4, 4.1, 5.4, 6.1, 6.3.
1987 *Planolites montanus* Richter – Kowalski, p. 25, pl. 4.1.
v 1989 *Planolites montanus* Richter, 1937 – Orłowski, p. 216, pl. 13.1–13.2.
1989 *Planolites ballandus* Webby, 1970 – Walter *et al.*, p. 235, fig. 10D, F.
1999 *Planolites montanus* Richter, 1937 – Mizerski *et al.*, p. 354, pl. 1.5a.
1999 *Planolites montanus* – MacNaughton and Narbonne, p. 108, fig. 7A.
2006 *Planolites montanus* Richter, 1937 – Gámez Vintaned *et al.*, p. 462, fig. 10.3a, b.

Material. One sandstone slab with numerous specimens (ING UJ214P/LD1), numerous specimens observed in the field.
Description. Hypichnial, convex full relief or semirelief curved ridges. The ridges are semicircular or semi-elliptical in cross-section. The ridges are smooth, 1–5 mm wide along the entire length, a few over a dozen millimetres long. They may be abundant and densely cover the soles of beds.
Remarks. Some specimens are difficult to distinguish from small specimens of *Palaeophycus tubularis* Hall, 1847 because of indistinct textural differences between the sandy infilling and sandy-silty host rock.

Planolites annularis Walcott, 1890
Fig. 12E

*1890 *Planolites annularis* sp. nov. – Walcott, p. 602, pl. 60.5.
1982 *Planolites annularis* Walcott, 1890 – Pemberton and Frey, p. 869, pl. 1.19 (cum. syn.).

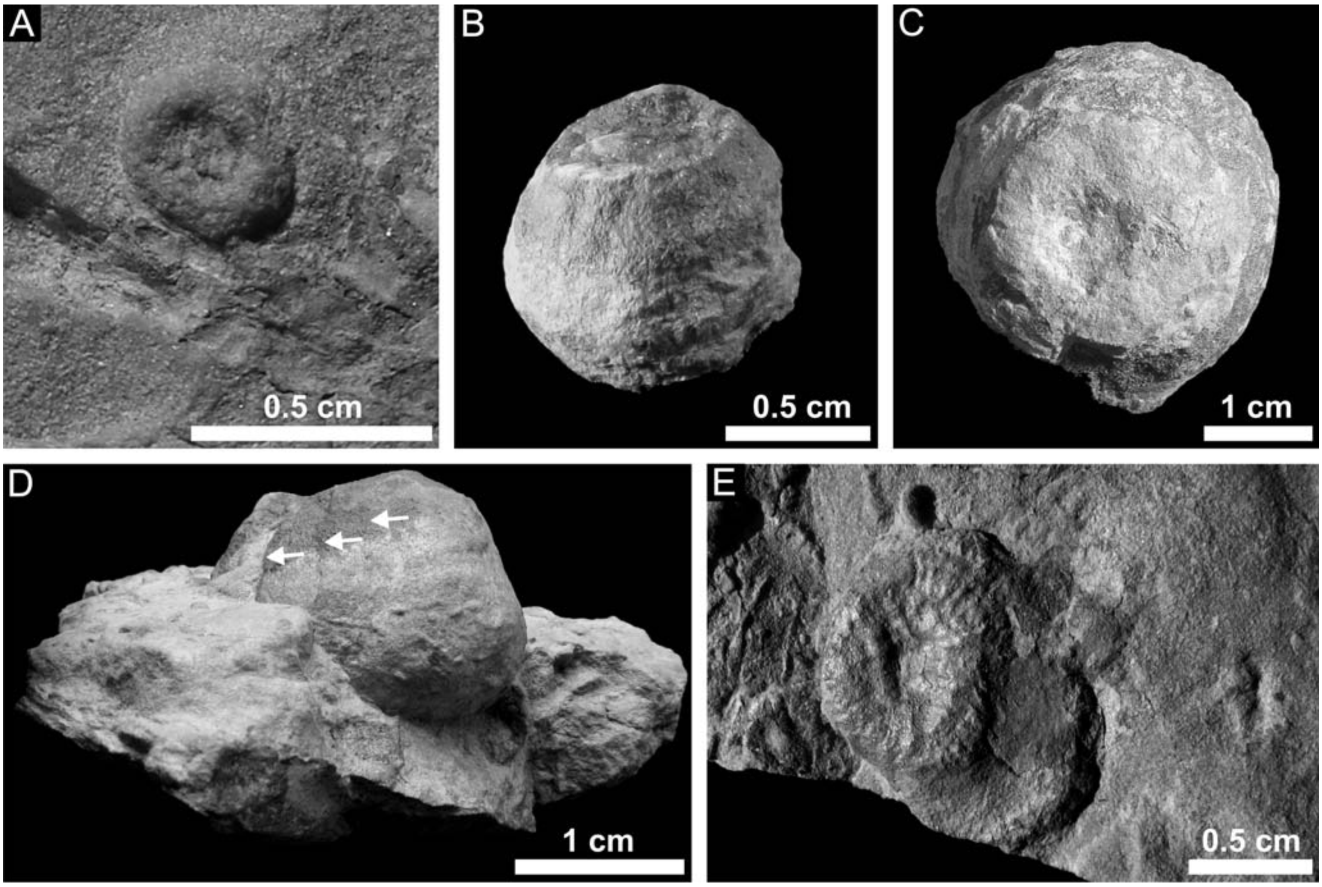


Fig. 11. Circular and elliptical structures from the Ociesęki Formation. **A.** *Mammillichnis aggeris* Chamberlain, 1971, hypichnion in thin quartz arenite bed, INGUJ214P/Mr56; *Schmidtiellus-Holmia* Superzone, Sterczyna East. **B, C**. *Bergaueria perata* Prantl, 1945, endichnia from thin wacke beds; B – INGUJ214P/Mr54, *Schmidtiellus-Holmia* Superzone, Sterczyna East; C – INGUJ214P/NLd1, *Protolenus-Issafeniella* Zone, Łagowica Road. **D.** *Conostichus* isp., endichnion in thin wacke bed, vertical furrows are arrowed, INGUJ214P/Ig143; *Schmidtiellus-Holmia* Superzone, Igrzyczna North. **E.** *Astropolichnus hispanicus* (Crimes *at al*., 1977), hypichnial convex semirelief in thin wacke bed, INGUJ214P/Ig141; *Schmidtiellus-Holmia* Superzone, Igrzyczna Hill.

1987 *Planolites annularius* Walcott, 1890 – Kowalski, p. 25, pl. 5.2.
1989 *Planolites annularis* Walcott, 1890 – Orłowski, p. 217, pl. 13.5, 13.6.
1990 *Planolites annularis* Walcott, 1890 – Fillion and Pickerill, p. 49, pls 10.11, 15, 12.4, 12.5.
1996 *Planolites annularis* Walcott, 1890 – Pacześna, p. 61, pl. 15.1.
1999 *Planolites annularis* Walcott, 1890 – Mizerski *et al*., p. 354, pl. 1.1b.
2006 *Planolites annularis* Walcott, 1890 – Gámez Vintaned *et al*., p. 461, fig. 10.1c.

Material. Four sandstone slabs (INGUJ214P/St106–108, /Mr/111) with six specimens.
Description. Horizontal, hypichnial, convex semirelief visible as straight or slightly curved ridges. The ridges are semicircular or semi-elliptical in cross-section. The ridges are about 2 mm wide uniformly throughout their length. The surfaces of the ridges are annulated. Individual burrows are up to 20 mm long. Individual annuli are about 1 mm wide.
Remarks. The specimens described display the typical annulation, which is a diagnostic feature of *P. annularis* (cf. Pemberton and Frey, 1982; Kowalski, 1987; Orłowski, 1989), but are smaller in size.

Ichnogenus *Palaeophycus* Hall, 1847

Remarks. See remarks on *Planolites*. *Palaeophycus* is interpreted as a structure formed by predators, moving mainly along the sediment interface (e.g., Pemberton and Frey, 1982).

?*Palaeophycus tubularis* Hall, 1847
Fig. 12F

Material. Two specimens (INGUJ214P/St111, 112).
Description. Endichnial, straight or slightly curved tubes, circular or oval in the cross-section, unbranched, with a smooth, very distinct lining, with a constant width of about 7 mm, up to 100 mm long. The tubes are infilled with the same sand as the host rock.
Remarks. The specimens observed are only fragments of larger trace fossils, the complete morphology of which, e.g. the presence or absence of branching, is uncertain.

Ichnogenus *Halopoa* Torell, 1870

Remarks. *Halopoa* Torell, 1870 differs from *Teichichnus* Seilacher, 1955 in its much more elongated shape, external sculpture and smaller vertical extension (Uchman, 1998). Jensen (1997) considered *Halopoa* as a synonym of *Palaeophycus*

Hall, 1847. *Halopoa* probably was formed by organisms systematically reworking sand (Uchman, 1998).

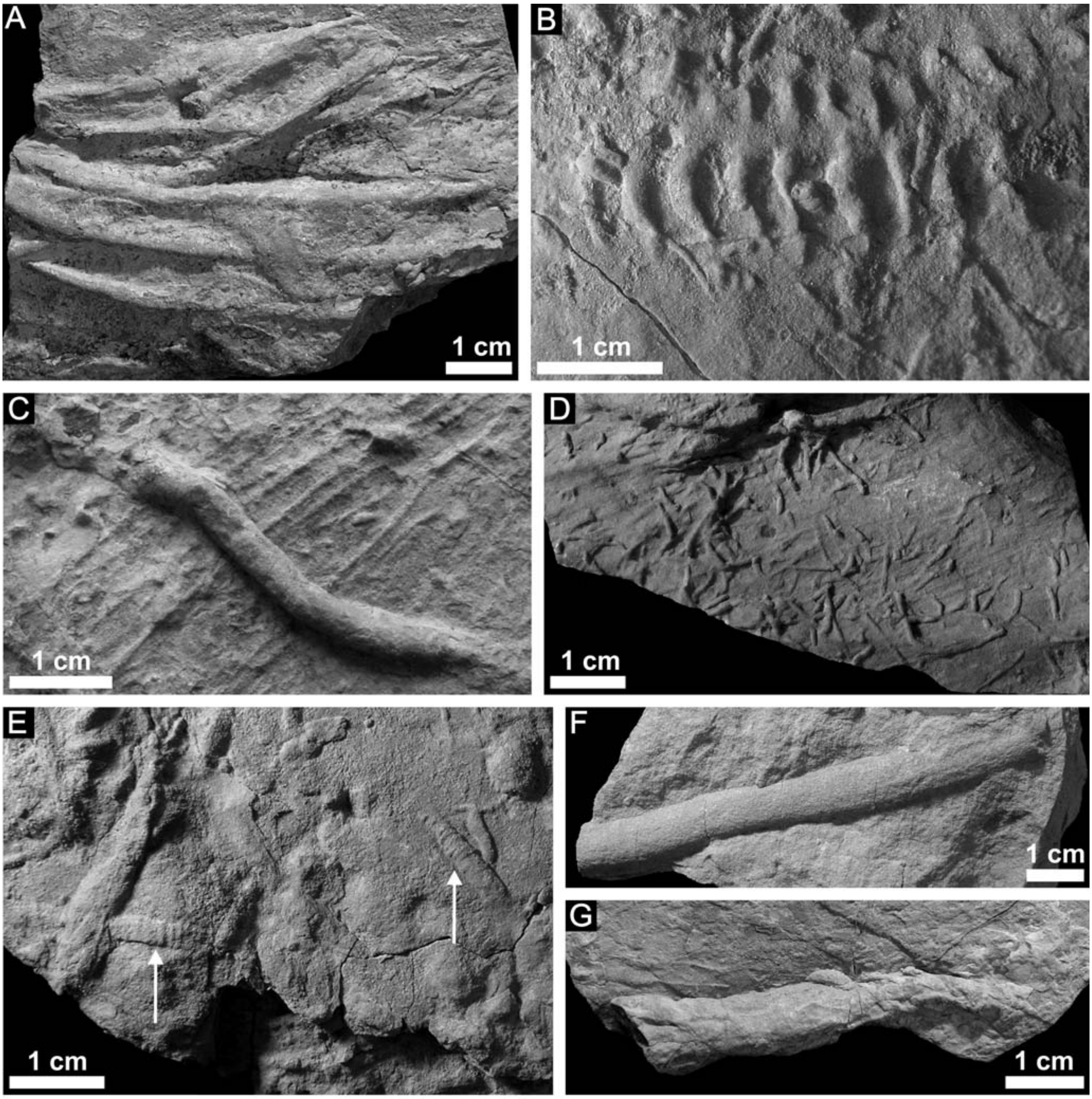


Fig. 12. Horizontal simple structures from the Ociesęki Formation, *Schmidtiellus-Holmia* Superzone. **A.** cf. *Dimorphichnus* isp. A, hypichnion in thin quartz arenite bed, INGUJ214P/IgS8; Igrzyczna South. **B.** cf. *Dimorphichnus* isp. B, hypichnion in thin quartz arenite bed, INGUJ214P/Mr45; Sterczyna East. **C.** *Planolites beverleyensis* (Billings, 1862), hypichnion in thin quartz arenite bed, INGUJ214P/Ig122; Igrzyczna Hill. **D.** *Planolites montanus* Richter, 1937, hypichnia in thin quartz arenite bed, INGUJ214P/LD1; Leśniakowa Dębina Hill. **E.** *Planolites annularis* Walcott, 1890 (arrowed), hypichnia in thin quartz arenite bed, INGUJ214P/St108; Sterczyna. **F.** ?*Palaeophycus tubularis* Hall, 1847, endichnion in medium quartz arenite bed, INGUJ214P/St111; Sterczyna. **G.** *Halopoa* isp., hypichnion in thin quartz arenite bed, INGUJ214P/Mr92; Sterczyna.

Halopoa isp.
Fig. 12G

Material. Four specimens (INGUJ214P/Mr92, /Mr115, /St146, /K4).
Description. Hypichnial, full-relief ridges of inconstant width, 60–95 mm long. Surface of the ridges is irregular and wrinkled. The ridges are irregular, nearly oval in cross-section, 4–20 mm wide.

Remarks. The discussed specimens differs from *H. imbricata* Torell, 1870 (e.g., Uchman, 1998; Orłowski and Żylińska, 2002; Leszczyński, 2004) by the presence of loosely arranged, indistinct, short and wrinkled furrows on the surface, instead of densely packed, long ridges and furrows.

Simple vertical structures

Ichnogenus *Cylindrichnus* Toots in Howard, 1966

Remarks. This ichnogenus includes gently curved, unbranched, slightly conical burrows, circular in cross-section, which taper downward, with concentric linings (Frey and Howard, 1985; Ekdale and Harding, 2015). The type ichnospecies, *C. concentricus* Toots in Howard, 1966 is an arcuate U-shaped structure (Ekdale and Harding, 2015). However, other ichnospecies included in *Cylindrichnus* are observed as mostly single, vertical structures tapering downward (Howard and Frey, 1984; Uchman and Krenmayr, 1995). Taxonomic details of this ichnogenus have been presented by Fürsich (1974), Howard and Frey (1984), Frey and Bromley (1985), Frey and Howard (1990), D'Alessandro and Bromley (1986) and Uchman and Krenmayr (1995) and most recently revised by Ekdale and Harding (2015).

Cylindrichnus operosus Orłowski, 1989
Fig. 13A, B

* v 1989 *Cylindrichnus operosus* isp. nov. – Orłowski, p. 218, pl. 15.1–15.3.
v 2008 *Cylindrichnus operosus* Orłowski, 1989 – Pacześna and Żylińska, p. 11, fig. 12.

Material. Two slabs of fine-grained quartz arenite (INGUJ214P/W5, INGUJ214P/St145) with three specimens and four specimens in the collection of Prof. Orłowski at Warsaw University.
Description. Vertical or oblique, concentrically laminated pipe, tapering downwardly and forming a funnel in its upper part. The surface of the burrow is smooth. The concentric laminae repeat the outer shape of the burrow around the central tunnel. The pipe is about 60 mm long and 10–20 mm in diameter in the widest part of the funnel. Beyond the funnel, the diameter of the central tunnel is smaller, 2–8 mm.
Remarks. The specimen illustrated in Figure 46A is only a small fragment of the top part of the whole structure, but it shows well the diagnostic features of *C. operosus* Orłowski, 1989, especially the extension of the upper part into the short and wide funnel and the concentric lamination following the burrow outline. The specimens described are partly similar to *Cylindrichnus concentricus* Toots in Howard, 1966. However, the latter taxon is a U-shaped burrow (Ekdale and Harding, 2015).

Ichnogenus *Monocraterion* Torell, 1870

Remarks. The similarity of *Monocraterion* Torell, 1870 and *Skolithos* Haldeman, 1840 has been a matter of debate (see Schlirf and Uchman, 2005). According to authors cited, *Monocraterion* essentially is a funnel-shaped shaft, while *Skolithos* may have been formed as only a straight pipe, without any funnel in its top part. *Monocraterion* is interpreted as a dwelling burrow of a deposit-feeder, living inside a shaft (Jensen, 1997).

Monocraterion isp.
Fig. 13C–E

Material. Fourteen sandstone slabs (INGUJ214P/Ig108–110, /St125–130, /Mr113, 114, /W1, 2, /W4), with about thirty specimens; numerous specimens observed in the field.
Description. Vertical, endichnial, straight or slightly curved cylinder with funnel at the top. The cylinder is 4–15 mm in diameter; the funnel observed is 5–25 mm in diameter and 4–10 mm deep. However, the observed lengths of the burrows are usually incomplete.
Remarks. According to the diagnosis of *M. tentaculatum*, the presence of numerous, small, horizontal, slightly curved, tubular full-relief structures going from the raised, central knob is a typical feature of this ichnogenus (Jensen, 1997; see also Schlirf and Uchman, 2005). Most of the specimens studied here do not show these features and there is no certainty that all the specimens discussed represent this ichnospecies.

Ichnogenus *Skolithos* Haldeman, 1840

Remarks. *Skolithos* is interpreted as a dwelling structure of suspension feeders. For debates on its similarity to *Monocraterion* Torell, 1870 and its ethology see Schlirf and Uchman (2005).

Skolithos isp.
Fig. 13F–H

Material. Two sandstone slabs (INGUJ214P/W6, 7) with a few specimens.
Description. Single, vertical, straight or curved shaft without a funnel, circular in cross-section. The pipe is smooth or slightly rough, 2–4 mm in diameter, 70–300 mm long. It usually occurs abundantly, densely crossing sandstone beds.
Remarks. The specimens described occur in medium or thick beds of quartz arenite, where they formed monoichnospecific assemblages.

Branched structures

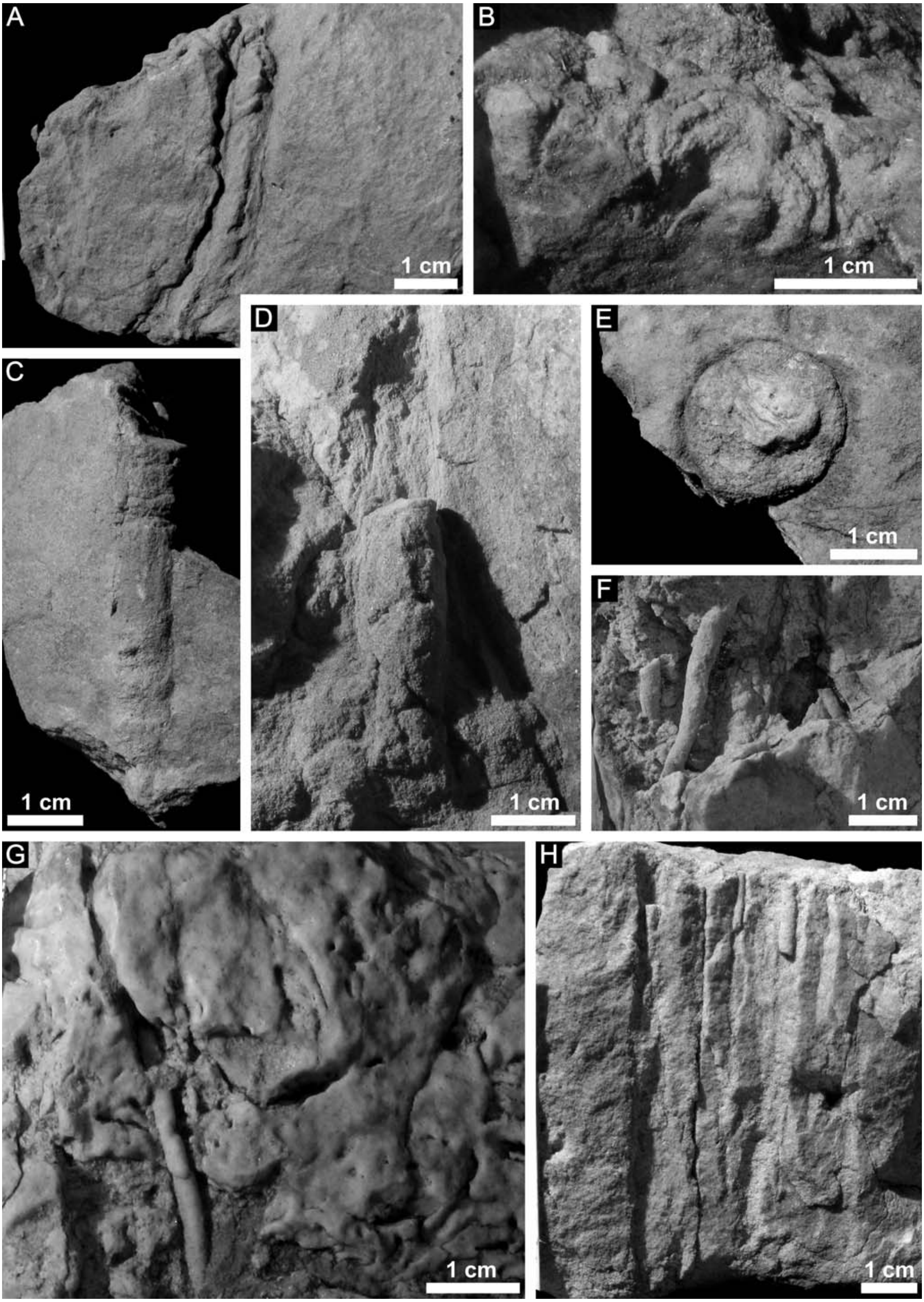
Ichnogenus *Phycodes* Richter, 1850

Remarks. Ichnotaxonomy details of *Phycodes* and its interpretation are provided e.g. by Seilacher (1955), Osgood (1970) and Fillion and Pickerill (1990). *Phycodes* is a dwelling-feeding structure of worms, feeding on organic-rich sediments (Fillion and Pickerill, 1990). *Phycodes* is very similar to *Arthrophycus* and, according to Seilacher (2007), the main distinction between them is based on the size of these structures, the latter being distinctly larger. Moreover, according to this author, these taxa are separated in time, so that *Phycodes* appears to be restricted to the Ordovician and *Arthrophycus* occurs in the Silurian. Nevertheless, *Arthrophycus* occurs in the rocks since the Cambrian up to the Carboniferous (Rindsberg and Martin, 2003). Additionally, both the size and the age are rejected as ichnotaxobases (Bertling *et al.*, 2006). A more important feature that makes *Phycodes* different from *Arthrophycus* is the absence of annulation or its poor preservation (cf. Seilacher, 2007). Additionally, some ichnospecies of *Arthrophycus* are unbranched, while *Phycodes* is essentially a branched form (Bromley, 1996).

Phycodes circinatus Richter, 1853
Fig. 14A, B

1934 *Phycodes circinatum* Reinh. Richter – Mägdefrau, p. 259, figs 3, 5, 6, pl. 10.1–3, 11. 1–4.
1990 *Phycodes circinatus* Richter, 1853 – Fillion and Pickerill, p. 46, pl. 11.4, 11.9, 11.10.
1991 *Phycodes circinatum* Richter, 1853 – Yang and Wang, p. 84, pl. 2.1.
2000 *Phycodes circinatum* Richter – Seilacher, p. 253, fig. 14 (cum. syn.).

Material. Fifteen specimens (INGUJ214P/Ig71–80, INGUJ214P/Mr81, 82, INGUJ214P/NLj7–9). As well, specimens were observed in the field.
Description. Hypichnial semirelief, generally horizontal, branching ridges meet in the same point. Usually, a few to over a dozen smaller branches diverge from a common stem. The branches are closely spaced, almost parallel to one another. The branches are


A
1 cm
B
1 cm
C
1 cm
D
1 cm
E
1 cm
F
1 cm
G
1 cm
H
1 cm

straight or slightly J-shaped. Some of them have a indistinct, narrow median furrow. The branches are oval or semioval in cross-section, 2–5 mm wide, 30–70 mm long, but some of them are much longer than others. Their surface is smooth, even or indistinctly undulating.

Remarks. *Phycodes circinatus* described here (especially specimen INGUJ214P/Ig76, Fig. 14B) is in part similar to *P. palmatus* (Hall, 1852) in having single larger and isolated branches. The latter, however, differs in the distinctly larger diameter of the branches and their palmate or digitate, looser arrangement (Fillion and Pickerill, 1990). *Phycodes circinatus* is also similar to a larger trace fossils *Arthrophycus alleghaniensis* (see remarks on the ichnogenus *Phycodes*), but commonly has an almost smooth surface, while the latter shows more or less distinct annulation. Moreover, *P. circinatus* has a looser arrangement of branches that can be separated in the distal part of the structure (Seilacher, 2000). According to diagnosis of Fillion and Pickerill (1990), *P. circinatus* formed fasciculate not flabellate pattern. Nevertheless, their figured material (Fillion and Pickerill, 1990, pl. 11., figs 9, 10), as well as specimens of *P. circinatus* illustrated by Häntzschel (1975) and Seilacher (2000) display flabellate-like structures. As well, according to the diagnosis of Seilacher (2000), *P. circinatus* formed tightly arranged bundles, spread and curved in a palmate pattern. The presence of *P. circinatus* in the Ociesęki Formation expands its stratigraphical range to the Cambrian Series 2. The oldest previously known specimens of *P. circinatus* were from the middle Cambrian (Yang and Wang, 1991).

Phycodes cf. *flabellum* (Miller and Dyer, 1878)
Fig. 14C

Material. One sandstone slab with three specimens (INGUJ214P/Mr98).

Description. Hypichnial semirelief, composed of a main ridge and six to eight smaller ridges, branching from one side. The main ridge is straight. The branching points are distributed along the main ridge, densely packed, in contact, almost parallel to each other, slightly parted in their distal part. The surface of the ridges is smooth or rough. The ridges are semicircular in cross-section. The main ridge is 35–50 mm long and side ridges are 10–20 mm long.

Remarks. The specimen described is similar to *Phycodes flabellum* (Miller and Dyer, 1878) (see Seilacher, 2000, fig. 14) but differs by the absence of corrugation.

Phycodes palmatus (Hall, 1852)
Fig. 14D

*1852 *Buthotrephis palmata* n. sp. – Hall, p. 20, pls 3.1, 7.1.
?1955 *Phycodes palmatum* Hall (1852) – Seilacher, p. 127, fig. 3A, pl. 23.3, 5.
1989 *Phycodes palmatum* Hall, 1852 – Orłowski, p. 220, pl. 16.2.
1990 *Phycodes palmatus* (Hall, 1852) – Fillion and Pickerill, p. 47, pl. 11, figs 11, 14.
1990 *Phycodes palmatum* (Hall, 1852) – Pickerill and Peel, p. 22, fig. 9d.
1999 *Phycodes palmatum* (Hall, 1852) – Mizerski *et al.,* p. 359, pl. 1.4.
2004 *Phycodes palmatus* (Hall, 1852) – Knaust, p. 13, fig. 7.3.

Material. Two specimens (INGUJ214P/Ig93, 94), specimens observed in the field.

Description. Hypichnial or endichnial, horizontal initial stem subdivided into 3–5 smooth, cylindrical branches diverging from the same point. The common stem is 20–30 mm wide; the diverging branches are 10–15 mm wide and 10–25 cm long.

Remarks. This ichnospecies was created as *Buthotrephis palmata* (Hall, 1852) and was included in *Phycodes* Richter, 1850 by Seilacher (1955). *Phycodes palmatus* differs from *P. circinatus* (Richter, 1853) in having smaller numbers of branches and in their larger width and palmate arrangement. The absence of a nodular wall with knobs distinguishes *P. palmatus* from *P. bilix* (Książkiewicz) (Uchman, 1998).

Ichnogenus *Treptichnus* Miller, 1889

Remarks. Discussions on details of taxonomy of *Treptichnus* and the similar ichnotaxa, including *Trichophycus* and *Phycodes*, have been presented in many papers (e.g., Buatois and Mángano, 1993; Geyer and Uchman, 1995; Jensen, 1997 and Schlirf, 2000). *Treptichnus* is usually interpreted as feeding or agrichnial structures, formed by worm-like organisms (e.g., Buatois and Mángano, 1993).

Treptichnus pedum (Seilacher, 1955)
Fig. 14E

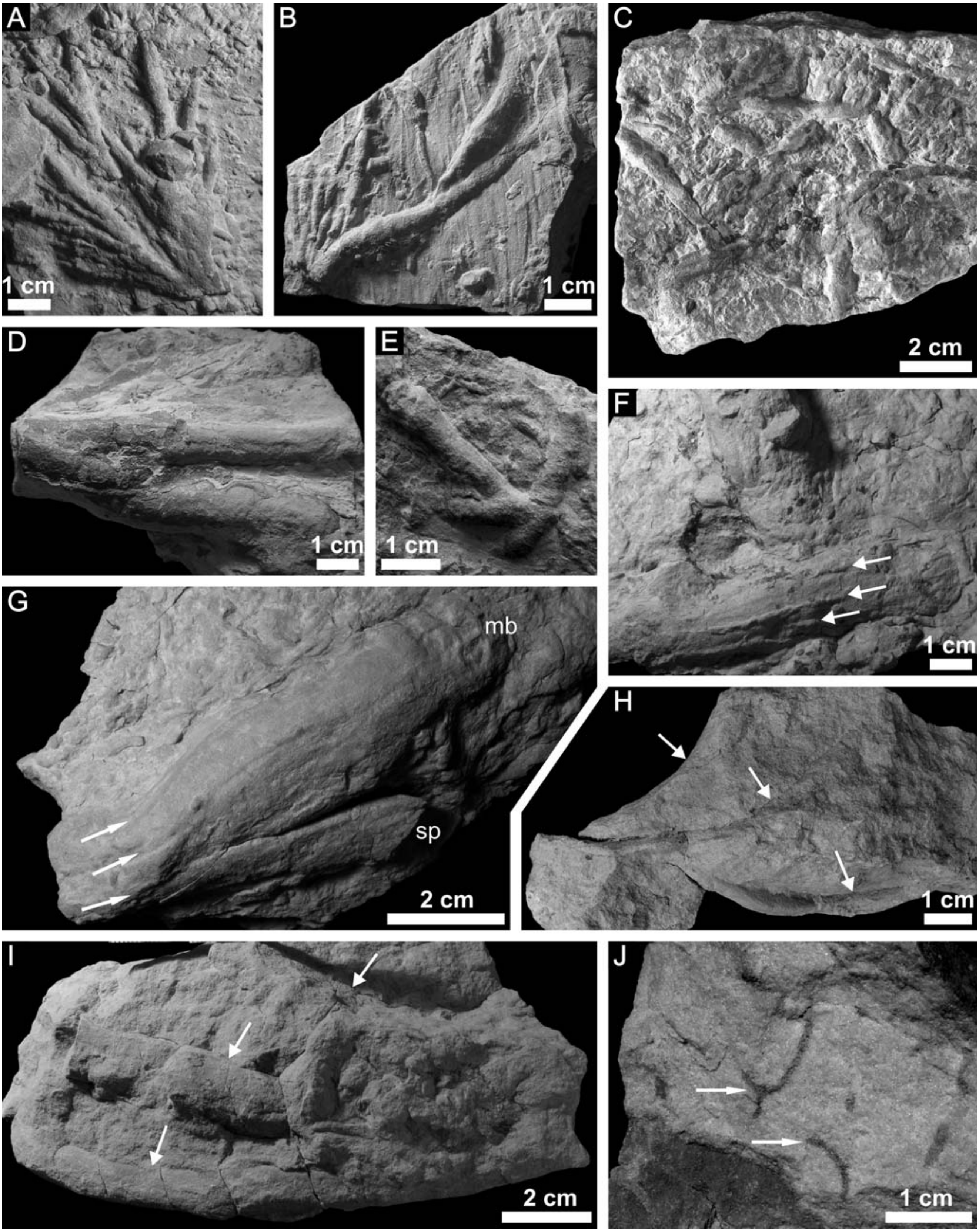
*1955 *Phycodes pedum* n. sp. – Seilacher, p. 386, figs 4–5.13, pl. 23.6–23.7, 25.3.
1987 *Phycodes pedum* Seilacher, 1955 – Kowalski, p. 24, pl. 2.2.
v 1989 *Phycodes pedum* Seilacher, 1955 – Orłowski, p. 219, pl. 15.4, 5.
1989 *Phycodes pedum* Seilacher, 1955 – Walter *et al*., p. 236, fig. 9C (cum. syn.).
1995 *Trichophycus pedum* (Seilacher, 1955) – Geyer and Uchman, p. 185, figs 5.3–5.5, 7.1–7.9 (cum. syn.).
1997 *Treptichnus pedum* (Seilacher, 1955) – Jensen, p. 91, fig. 62B.
1999 *Treptichnus* (*Phycodes*) *pedum* – MacNaughton and Narbonne, p. 106, fig. 8 [marked as „Tp”].

Material. Nine specimens (INGUJ214P/Ja5–7, INGUJ214P/Mr/95–99, INGUJ214P/Mr/116) and specimens observed in the field.

Description. Hypichnial full relief, composed of one main, straight or arcuate ridge, 30–100 mm long, with branches up to 20 mm long. The branches are short, smooth, circular or oval in cross-section, about 5 mm wide and partly plunging into the bed.

Remarks. Seilacher (1955) included this ichnospecies in *Phycodes* Richter, 1850, which distinctly differs in having branches that diverge from the same point of the initial burrow. Geyer and

Fig. 13. Vertical simple structures from the Ociesęki Formation. **A, B.** *Cylindrichnus operosus* Orłowski, 1989; A – endichnion in thin quartz arenite bed, side view, INGUJ214P/St145; *Schmidtiellus-Holmia* Superzone, Sterczyna; B – endichnion in medium quartz arenite bed, oblique view, INGUJ214P/W5; *Protolenus-Issafeniella* Zone, Wysokówka. **C–E.** *Monocraterion* isp., endichnia in medium quartz arenite bed, *Protolenus-Issafeniella* Zone, Wysokówka; C – INGUJ214P/W3, D – INGUJ214P/W1, E – INGUJ214P/W4; C, D – side views, E – view from the top of bed. **F–H.** *Skolithos* isp., endichnia in thin quartz arenite bed, side views, *Protolenus-Issafeniella* Zone; F, G – INGUJ214P/K6–7, Koziel; H – INGUJ214P/W7, vicinity of the Zamczysko Reserve.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Uchman (1995) included the ichnospecies discussed in the ichnogenus *Trichophycus* Miller and Dyer, 1878. However, *Trichophycus* differs in having rare, irregular probes, which do not form regular branches (see Fillion and Pickerill, 1990). More discussions on *Treptichnus pedum* are presented by Buatois and Mángano, (1993), Geyer and Uchman (1995) and Jensen (1997). According to Dzik (2005) and Vannier *et al.* (2010), this ichnospecies was formed by priapulids.

Ichnogenus *Trichophycus* Miller and Dyer, 1878

Remarks. *Trichophycus* Miller and Dyer, 1878 is similar to *Treptichnus* Miller, 1889 (see remarks for ichnogenus *Treptichnus*). *Trichophycus* is usually interpreted as spreite structures, formed by worm-like deposit-feeders; however, the possibility of formation by arthropods including trilobites has been discussed (Seilacher and Crimes, 1969; Seilacher, 1983; Geyer and Uchman, 1995).

Trichophycus cf. *tripleurum* Geyer and Uchman, 1995
Fig. 14F, G

?*1995 *Trichophycus tripleurum* isp. nov. – Geyer and Uchman, p. 191, fig. 8.1–8.3 (cum. syn.).

Material. Three specimens catalogued (INGUJ214P/St84–86), over a dozen fragmentary specimens observed in the field, all in beds of quartz arenite or wacke.

Description. Hypichnial convex full relief, composed of a main, winding or slightly curved ridge and arcuate curved branches. The ridge has a curved, herring-bonelike structure, but branches are less regular. The branches are usually much narrower than the main ridge. The main ridges display two small, indistinct, longitudinal ridges on their surfaces. The observed fragments of burrows are 11–22 mm wide and 40–150 mm.

Remarks. The upward-branching probes typical of *Trichophycus* are difficult to observe, but mostly horizontal branches are present. Moreover, the trilobate surface typical of *T. tripleurum* in the specimens discussed is very indistinct.

Trichophycus isp. A
Fig. 14H

Material. One catalogued specimen (INGUJ214P/St89); over a dozen fragmentary specimens observed in the field.

Description. Endichnial tube, composed of alternating, paired, V-shaped, curved branches, arches of which are directed toward the sole of the bed. The tubes are close to triangular or trapezoid in cross section. The surface of the burrow is smooth, rarely irregular. The specimens described have branches that strongly penetrate the deposit upward, but they are poorly developed in the horizontal plane. Individual branches are 5–15 mm wide, 30–70 mm long, with the angle between individual branches amounting to about 30°.

Remarks. *Trichophycus* isp. A differs from *Trichophycus* isp. B in its distinctly smaller size and regular, V-shaped probes.

Trichophycus isp. B
Fig. 14I

Material. Eight specimens (INGUJ214P/St88, /St90–96), specimens observed in the field.

Description. Endichnial, arcuate main tube and secondary branching, banana-like tubes, the convex side of which is directed toward the sole of the bed. Some specimens are composed of very indistinct main tubes and branches of the same width. The branches are inclined and strongly penetrate the sediment upward. Some of the specimens have single, side tubes. The tubes are circular, close to triangular or trapezoid in the cross-section. The surface of the tubes is smooth or irregular, in some places covered by irregular furrows. Individual branches are 5–15 mm wide, 30–70 mm long.

Remarks. *Trichophycus* isp. B differs from *Trichophycus* isp. A in having a distinctly larger size of the irregularly arranged branches.

Ichnogenus *Polykladichnus* Fürsich, 1981

Remarks. *Polykladichnus* Fürsich, 1981 differs from *Skolithos* Haldeman, 1840 in the branching of its vertical shafts. Details on its taxonomy and the differences between *Polykladichnus*, *Skolithos* and other vertical burrows are presented by Schlirf and Uchman (2005).

Polykladichnus cf. *aragonensis* Uchman and Álvaro, 2000
Fig. 14J

*2000 *Polykladichnus aragonensis* isp. nov. – Uchman and Álvaro, p. 214, figs 1–8.

2005 *Polykladichnus aragonensis* Uchman and Álvaro, 2000; Schlirf and Uchman, p. 117, figs 1A, C–E, 2A, B, 3A, B, 4, 5, 8.

Material. One sandstone slab (INGUJ214P/W15) with several specimens.

Description. Endichnial, vertical pipe, branching in the upper part, filled with silty material. The branches are U-shaped. They resemble an upside-down gothic arch with a slightly rounded top. The pipes are circular in the cross-section, about 1 mm in diameter. The branches are about 10 mm long, 7–10 mm wide.

Remarks. The specimens discussed show branching of the vertical pipe, which is the diagnostic feature of *P. aragonensis* Uchman and Álvaro (2000); however, these features are only partly visible. Moreover, the specimens are much smaller than *P. aragonensis* (cf. Uchman and Álvaro 2000; Schlirf and Uchman, 2005).

◄

Fig. 14. Branched structures from the Ociesęki Formation. **A, B.** *Phycodes circinatus* Richter, (1853); hypichnial convex semirelief in thin quartz arenite bed, *Schmidtiellus-Holmia* Superzone, Igrzyczna; A – INGUJ214P/Ig71, B – INGUJ214P/Ig76. **C.** *Phycodes* cf. *flabellum* (Miller and Dyer, 1878), hypichnial convex semirelief in thin wacke beds, INGUJ214P/Mr98, *Schmidtiellus-Holmia* Superzone, Sterczyna East. **D.** *Phycodes palmatus* Hall, 1852, hypichnial convex semirelief in thin wacke beds, INGUJ214P/Ig94; *Schmidtiellus-Holmia* Superzone, Igrzyczna. **E.** *Treptichnus pedum* (Seilacher, 1955), hypichnial convex semirelief in thin wacke beds, INGUJ214P/Mr96; *Schmidtiellus-Holmia* Superzone, Sterczyna East. **F, G.** *Trichophycus* cf. *tripleurum* Geyer and Uchman, 1995, hypichnial convex semireliefs in thin quartz arenite beds, *Schmidtiellus-Holmia* Superzone, Sterczyna; F – individual probe, three ridges on the surface of hypichnion are arrowed, INGUJ214P/St85, G – three ridges are arrowed, mb – main burrow, sp – secondary probe, INGUJ214P/St84. **H.** *Trichophycus* isp. A, endichnion in medium quartz arenite bed, side view, INGUJ214P/St89; *Schmidtiellus-Holmia* Superzone, Sterczyna. **I.** *Trichophycus* isp. B, endichnion in medium quartz arenite bed, side view, slightly oblique view from the sole of bed, INGUJ214P/St92; *Schmidtiellus-Holmia* Superzone, Sterczyna. **J.** *Polykladichnus* cf. *aragonensis* Uchman and Álvaro, 2000, endichnia in medium quartz arenite bed, view of the vertically fractured slab, INGUJ214P/W15; *Protolenus-Issafeniella* Zone, Wysokówka Hill.

Radial structures

Ichnogenus *Dactyloidites* Hall, 1886

Remarks. *Dactyloidites* Hall, 1886 was revised by Fürsich and Bromley (1985), who included *Brooksella* Walcott, 1896 and *Haentzschelina* Vialov, 1964 in this ichnogenus. However, some authors (e.g., Gámez Vintaned *et al*., 2006; Schwimmer, 2012) have excluded *Brooksella* from *Dactyloidites*. *Dactyloidites* is interpreted as a structure, produced by worm-like organisms, reworking sediment around the central shaft (Fürsich and Bromley, 1985). Individual ichnospecies of *Dactyloidites* distinctly show two different morphotypes: the star-like morphotype, typical of the Palaeozoic ichnospecies (Meléndez in Cabanás, 1966), and the leaf-like morphotype, typical of the Cenozoic ichnospecies (e.g., Uchman and Pervesler, 2007). Comments on the taxonomy of *Dactyloidites* were provided by, e.g. Uchman and Pervesler (2007) and Wilmsen and Niebuhr (2014).

Dactyloidites asterioides (Fitch, 1850)
Fig. 15A

1850 ? *Buthotrephis asterioides*, new species – Fitch, p. 863, unnumbered fig.
1898 *Dactyloidites asteroides* Fitch – Walcott, p. 41, pls 24–28.
1965 *Volkichnium volki* n. gen. and n. sp. – Pfeiffer, p. 1266, figs 1, 2.
?1966 *Anthoichnites cabanasi* nov. gen. (parataxon), n. sp. – Meléndez in Cabanás, p. 79, figs 1–3.
v1996 *Volkichnium volki* Pfeiffer, 1965 – Orłowski and Żylińska, p. 400, fig. 9.
?2006 *Dactyloidites cabanasi* Hall 1886 – Gámez Vintaned *et al*., p. 453, figs 8: 7.1–7.5, 8d; p. 460, fig. 10.1b.
2002 ? *Asterophycus* isp. – Orłowski and Żylińska, p. 140, fig. 5d.
2010 *Dactyloidites* isp. – Jensen *et al*., p. 695, fig. 7.

Material. Six specimens (INGUJ214P/Ig101–106).

Description. Hypichnial, full relief, star-shaped structure, composed of 4–6 regularly arranged ridges (arms), radiating from the central part. The ridges are fusiform, circular or oval in cross-section. The central part of the burrow, where the ridges meet, does not display any swelling, but a small depression. One of the specimens discussed shows an indistinctly visible, circular shaft in the central part. The specimens preserved in the sandstone beds show only very indistinct spreites within the arms. Individual arms are 10–20 mm long, 4–9 mm wide. The whole structure is 30–43 mm wide.

Remarks. The specimens discussed are very similar to *Dactyloidites cabanasi*, described by Meléndez in Cabanás (1966) and Gámez Vintaned *et al*. (2006), but differ in their distinctly thinner arms of different shape. According to Meléndez in Cabanás (1966), *D. cabanasi* shows arms that coalesce at the half the length, while specimens illustrated here show only separated arms. However, the shape of the arms of the ichnospecies discussed is the less important diagnostic feature (cf. Jensen *et al*., 2010). The specimens discussed here are also similar to the specimen, illustrated by Orłowski and Żylińska (2002) and described as ?*Asterophycus* isp. from the Ociesęki Formation. Moreover, these specimens are very similar (especially INGUJ214P/Ig101, Fig. 15A) to *Volkichnium volki* Pfeiffer, 1965 (compare: Pfeiffer, 1965, figs 1, 2) from the Ordovician Phycoden-Schichten of Thuringia and also to that described from the Cambrian Wiśniówka Formation in Poland (Orłowski and Żylińska, 1996) and *Dactyloidites* isp., described by Jensen *et al*. (2010). It is possible that *Volkichnium volki* and *D. cabanasi* could be included in *D. asterioides* as synonyms. Nevertheless, *D. cabanasi* is much better documented as a trace fossil (e.g., Gámez Vintaned *et al*., 2006). *Dactyloidites asterioides*, which is the typical ichnospecies of *Dactyloidites*, is very similar to *D. cabanasi,* however, according to Jensen *et al*. (2010), probably they are differentiated by protrusive spreites in *D. cabanasi* and retrusive spreites in *D. asterioides*. *D. asterioides* was formerly interpreted as plant remains (Fitch, 1850) or medusae (Walcott, 1898). Probably some of the specimens included in this ichnospecies could be body fossils, but other specimens (e.g., Walcott, 1898, pl. 25, fig. 3) that show a distinct spreite could be trace fossils.

Spiral structures

Ichnogenus *Gyrolithes* Saporta, 1884

Remarks. *Gyrolithes* Saporta, 1884 is assumed as a younger synonym of *Spiroscolex* Torell, 1870 (e.g., Jensen, 1997). Remarks on the taxonomic details of this ichnogenus and similar taxa are provided by, e.g., Bromley and Frey (1974), Jensen (1997), Uchman and Hanken (2013) and Stachacz (2012b). *Gyrolithes* is probably a dwelling-feeding burrow, connecting the sediment surface of the food-rich sediment layers (Jensen, 1997).

Gyrolithes isp.
Fig. 15B

Material. One specimen (INGUJ214P/Ig96).

Description. A fragment of an endichnial, spiral tube (slightly more than a one full whorl, about 50 mm in diameter) coiled around the axis, perpendicular to the bedding surface. The tube, about 3 mm wide, is filled with material, similar to the host rock. Its surface is smooth.

Remarks. The illustrated specimen differs distinctly from the common Cambrian *Gyrolithes polonicus* Fedonkin, 1982 in having a much larger size and a relatively large radius of the spiral (cf. Jensen, 1997; Stachacz, 2012b).

Spreite structures

Ichnogenus *Teichichnus* Seilacher, 1955

Remarks. This ichnogenus embraces vertical spreite, "wall"-like dwelling-feeding structures, which display parallel spreite laminae formed by deposit-feeder organisms, moving in the vertical plane.

Teichichnus rectus Seilacher, 1955
Fig. 15C–H

*1955 *Teichichnus rectus* n. gen. n. sp. – Seilacher, p. 378, pl. 24.1
1985 *Teichichnus rectus* Seilacher, 1955 – Frey and Bromley, p. 812, figs 7B, 16A–C, 18C.
1989 *Teichichnus rectus* Seilacher, 1955 – Orłowski, p. 222, pl. 17.1–17.4.
1996 *Teichichnus rectus* Seilacher, 1955 – Pacześna, p. 62, pls 18.6, 18.7, 19.1–19.9, 20.1, 20.2.

More synonyms in: Schlirf (2000).

Material. One hundred and seventy specimens (INGUJ214P/ Ig1–44, /Ig55–63, /St1–61–64, /St140, /Mr83–88, /Zbł/1–16, /Js22–24, /ZbP9–34, in addition to numerous specimens observed in the field.

Description. Endichnial or hypichnial, convex, full relief structure, forming a "wall" that shows a banana- or wedge-like shape in longitudinal section. A distinct U-shaped, downward-directed

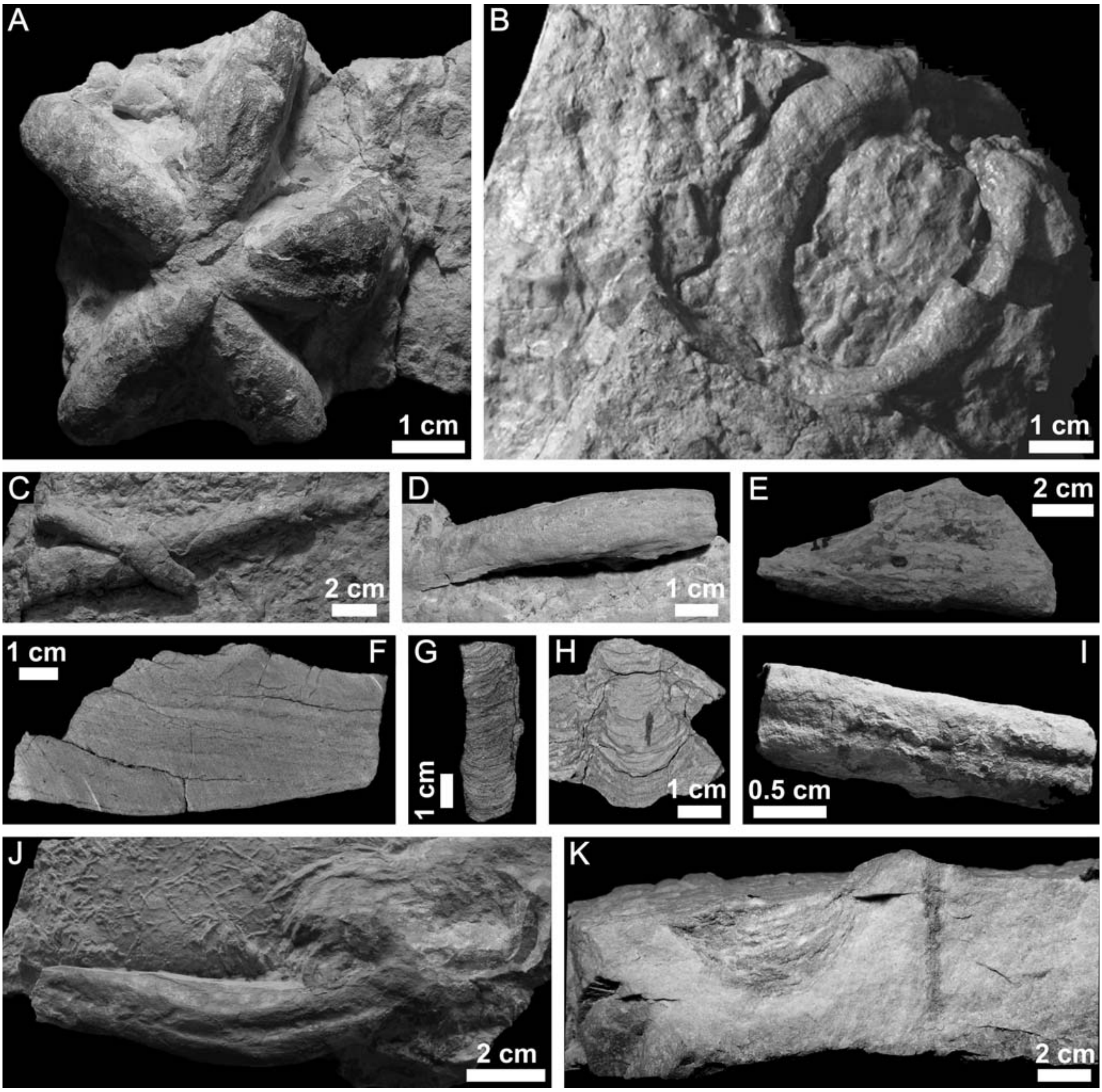
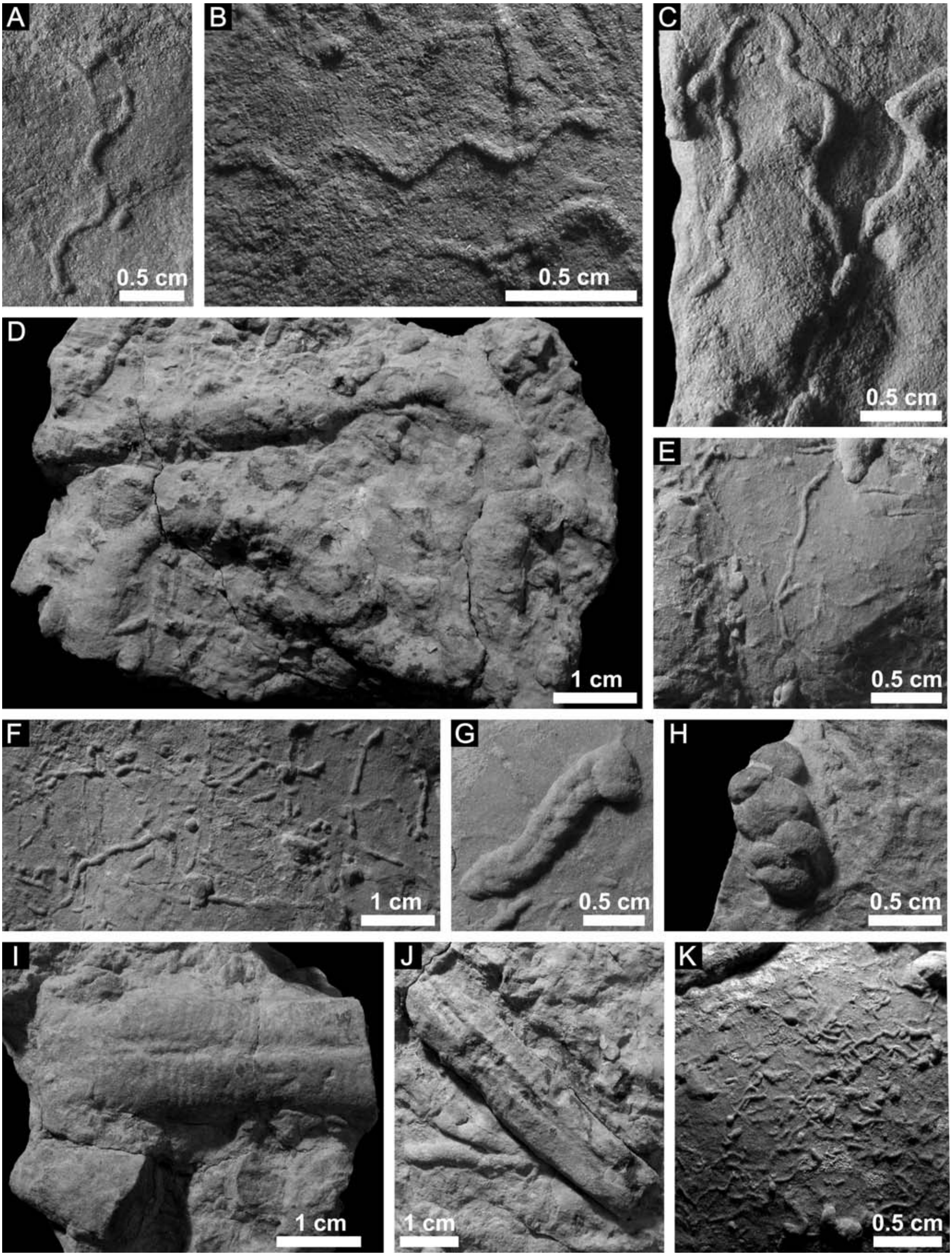


Fig. 15. Radial, spiral and spreite structures from the Ociesęki Formation. **A.** *Dactyloidites asterioides* (Fitch, 1850), Hypichnial convex relief in thin wacke bed, INGUJ214P/Ig101; *Schmidtiellus-Holmia* Superzone, Igrzyczna. **B.** *Gyrolithes* isp., endichnion in thin wacke bed, INGUJ214P/Ig96; *Schmidtiellus-Holmia* Superzone, Igrzyczna Hill. **C–H.** *Teichichnus rectus* Seilacher, 1955, *Schmidtiellus-Holmia* Superzone; C – hypichnia in thin, bioturbated quartz arenite bed, two overcrossing specimens, INGUJ214P/St61, Sterczyna; D – hypichnion in thin quartz arenite bed, INGUJ214P/St2, Sterczyna; E – endichnion, side view, INGUJ214P/St1, Sterczyna; F – endichnion, cut surface parallel to axis of burrow and bedding plane, INGUJ214P/Ig3, Igrzyczna; G – endichnion, cut surface perpendicular to the axis of burrow and bedding plane, INGUJ214P/St1a, Sterczyna; H – endichnion, cut surface perpendicular to the axis of burrow and bedding plane, INGUJ214P/Ig5, Igrzyczna. **I, J.** *Teichichnus duplex* Schlirf and Bromley, 2007, *Schmidtiellus-Holmia* Superzone; I – endichnion in thin wacke bed, INGUJ214P/Ig45, Igrzyczna Hill; J – hypichnial full relief in thin quartz arenite bed, on the right side fragment of *Cruziana dispar*, INGUJ214P/Mr90, Igrzyczna Hill. **K.** *Diplocraterion parallelum* Torell, 1870, endichnion in thin quartz arenite bed, INGUJ214P/Ig130, *Schmidtiellus-Holmia* Superzone, Igrzyczna Hill.

spreite is visible in cross-section. The structure is a few to tens of millimetres wide, 10–50 mm high. Individual spreite laminae are 0.5–2 mm thick. The usual length is 50–100 mm; however, some individual specimens observed in the field are up to 300 mm long.

Remarks. The specimens analysed are diversified in shape and size. A few morphogroups are visible: banana-shaped, wedge-shaped and almost rectangular in the longitudinal section. The shape can be deformed by neighbouring specimens, most of which show phobotaxis and rarely overcrossings. Large differences in size are distinctly visible between individual outcrops. The largest specimens, 200–300 mm long occur abundantly in the sandy-silty facies transition of the Ociesęki and Kamieniec formations at Zbelutka, where *Teichichnus* forms an almost monoichnospecific assemblage.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Teichichnus duplex Schlirf and Bromley, 2007
Fig. 15I, J

?1989 *Scolicia* sp. – Orłowski, p. 221, pl. 14.4.
2002 *Teichichnus* isp. (?isp. nov.) – Mikuláš *et al*., p. 56, pl. 1.1, 1.2.
*2007 *Teichichnus duplex* isp. nov. – Schlirf and Bromley, p. 135, figs 4–8.

Material. Twenty-three specimens (INGUJ214P/St66–82, /Mr/90, /Ig44–50).
Description. Endichnial, elongated, flattened ridge or a "wall" structure in sandstone or siltstone beds. It is wedge-shaped in longitudinal section, 30–100 mm long, 9–12 mm wide and about 30 mm high. The surface of the ridge displays two ridge-like lobes, separated by a more or less distinct furrow. Cross-section shows a distinct spreite visible as U-shaped laminae, parallel in the upper part, and doubly gutter-shaped in the lower part of the burrow.
Remarks. The outer morphology of *Teichichnus duplex* is close to that of *Scolicia*, which has been produced by irregular echinoids (see Uchman, 1995) since the Jurassic. Possible Cambrian trace makers of *T. duplex* were arthropods (Schlirf and Bromley, 2007). The occurrence of *T. duplex* in the Ociesęki Formation extends its stratigraphical range to the Cambrian Series 2, because it was previously known from the Cambrian Series 3 and the Upper Triassic (Schlirf and Bromley, 2007).

Ichnogenus *Diplocraterion* Torell, 1870

Remarks. *Diplocraterion* is a dwelling burrow (domichnia) (Bromley, 1996), produced by suspension-feeder or benthic predators (Fürsich, 1975). Remarks on its taxonomy and origin are also presented by Fillion and Pickerill (1990).

Diplocraterion parallelum Torell, 1870
Fig. 15K

*1870 *Diplocraterion parallelum* n. g. n. sp. – Torell, p. 13, without fig.
v1989 *Diplocraterion parallelum* Torell, 1870 – Orłowski, p. 223, pl. 18.6.
1989 *Diplocraterion parallelum* Torell, 1870 – Walter *et al*., p. 245, fig. 14C.
1996 *Diplocraterion parallelum* Torell, 1870 – Orłowski and Żylińska, p. 401, fig. 10A–C.
1997 *Diplocraterion parallelum* Torell, 1870 – Jensen, p. 48, figs 7A, 10A, 33A.
More synonyms in: Fürsich (1974a), Schlirf (2000).

Material. Two specimens (INGUJ214P/Ig130, /Za1) in fine-grained quartz arenite.
Description. U-shaped, vertical structure, composed of a marginal tunnel with a spreite between the limbs, which are perpendicular to the top of bed. The whole structure is 25–40 mm high and about 40 mm wide. The marginal tunnel is 3–4 mm in diameter. The specimen INGUJ214P/Ig130 (Fig. 15K) does not show a distinct marginal tunnel, but only fragment of a tube.
Remarks. The specimen without a distinct marginal tunnel shows the general shape of *D. parallelum* with a distinct marginal tunnel.

Winding and meandering structures

Ichnogenus *Cochlichnus* Hitchcock, 1858

Remarks. *Cochlichnus* Hitchcock, 1858 is usually interpreted as a surface or shallow subsurface trail, produced by worms with poorly developed parapodia or in continental deposits, by the larvae of insects and nematodes (e.g., Hitchcock, 1858; Hakes, 1977; Uchman *et al.*, 2004). Głuszek (1995) suggested that *Cochlichnus* is a trace of predators, penetrating muddy sediment directly below the sandy layer. Subsurface forms of *Cochlichnus* have been described by Rindsberg (1994) under *Cymatulus*, but Stanley and Pickerill (1998) included the latter taxon as a synonym of *Cochlichnus* because of the very subtle distinction between them.

Cochlichnus anguineus Hitchcock, 1858
Fig. 16A, B

1998 *Cochlichnus anguineus* Hitchcock, 1858 – Buatois and Mángano, p. 373, fig. 4F.
1990 *Cochlichnus anguineus* Hitchcock, 1858 – Fillion and Pickerill, p. 23, pl. 3.3.
2000 *Cochlichnus anguineus* Hitchcock, 1858 – Schlirf, p. 176, pl. 8.9–8.11, fig. 27.
2006 *Cochlichnus anguineus* Hitchcock, 1858 – Gámez Vintaned *et al*., p. 456, figs 8.9d, 9.9b.
More synonyms in: Schlirf (2000).

Material. Two specimens (INGUJ214P/ST115, /Mr59).
Description. Hypichnial, convex, thin, meandering ridges with smooth surfaces. The meanders are regularly sinusoidal. The observed fragments of the ridges are about 0.8 mm wide, about 0.5 mm high, 20–30 mm long, with the amplitude of sinusoid meanders about 2–3 mm, and wavelength about 4 mm.
Remarks. Details on the taxonomy and origin of *C. anguineus* were provided by Głuszek (1995).

Ichnogenus *Cosmorhaphe* Fuchs, 1895

Remarks. *Cosmorhaphe* is interpreted as a trap-burrow for microorganisms (Seilacher, 1977). *Cosmorhaphe* differs from *Helminthopsis* Heer, 1877 by the presence of two orders of meanders (Uchman, 1998).

◄

Fig. 16. Winding and meandering structures from the Ociesęki Formation. A, B. *Cochlichnus anguineus* Hitchcock, 1858, hypichnial convex semireliefs in thin quartz arenite beds; *Schmidtiellus-Holmia* Superzone, Sterczyna; A – INGUJ214P/St115, B – INGUJ214P/Mr59. C. ?*Cosmorhaphe* isp., hypichnial convex semirelief in thin quartz arenite bed, INGUJ214P/STMr61; *Schmidtiellus-Holmia* Superzone, Sterczyna East. D. *Gordia* isp., hypichnial convex semirelief in thin wacke bed, INGUJ214P/Ig132; *Schmidtiellus-Holmia* Superzone, Igrzyczna. E, F. *Helminthoidichnites tenuis* Fitch, 1850, hypichnial convex semireliefs in thin quartz arenite beds, *Schmidtiellus-Holmia* Superzone, Sterczyna East; E – INGUJ214P/Mr68, F – INGUJ214P/Mr48. G. *Nereites* isp. A, hypichnial convex semirelief in thin quartz arenite bed, INGUJ214P/Mr79; *Schmidtiellus-Holmia* Superzone, Sterczyna East. H. *Nereites* isp. B, hypichnial convex semirelief in thin quartz arenite bed, INGUJ214P/Ig113; *Schmidtiellus-Holmia* Superzone, Igrzyczna Hill. I, J. *Psammichnites* cf. *gigas* Torell, 1870, hypichnial full reliefs n thin quartz arenite beds, *Schmidtiellus-Holmia* Superzone; I – INGUJ214P/Ig98, Igrzyczna; J – INGUJ214P/St114, Sterczyna hill. K. *Multina* cf. *minima*, hypichnial full relief or convex semirelief in thin quartz arenite bed, INGUJ214P/Mr64; *Schmidtiellus-Holmia* Superzone, Sterczyna East.

?*Cosmorhaphe* isp.
Fig. 16C

Material. One specimen (INGUJ214P/Mr61).
Description. Hypichnial thin ridge and seven second-order meanders within one distinct first-order meander, circular in cross-section, smooth, about 1 mm high, and preserved in full relief. The second-order meanders are irregular, 3–5 mm wide, with diverse amplitudes. The ridge surface is smooth. The first-order meander is about 30 mm deep and 1.5 mm wide.
Remarks. The specimen described is only a fragment of a larger structure. It shows only one first-order meander; however, the second-order meanders within it are typical of *Cosmorhaphe*. *Helminthopsis tenuis* Książkiewicz, 1968, is somewhat similar, but it displays only one order of meanders.

Ichnogenus *Gordia* Emmons, 1844

Remarks. *Gordia* differs from *Helminthoidichnites* Fitch, 1850 in the occurrence of much more winding, symmetric meanders and the presence of self overcrossing (Hofmann and Patel, 1989; Pickerill and Peel, 1990). *Gordia* can be produced by different organisms, mostly arthropods including insect larvae and "worms" (Uchman *et al*., 2009).

Gordia isp.
Fig. 16D

Material. Three specimens (INGUJ214P/Ig132–134).
Description. Long, hypichnial, ridge, forming elongated, complete or almost closed loops or wide horseshoe-shaped meanders. The ridge is 4–8 mm wide. The loops are 10–25 mm wide and the meanders are 25–40 mm deep.
Remarks. The specimens described are only fragmentarily preserved as single loops without overcrossing, in slabs of a fragile wacke. The specimens discussed are very similar to *Gordia marina* Emmons, 1844, but fragmentary preservation does not permit closer determination.

Ichnogenus *Helminthoidichnites* Fitch, 1850

Remarks. *Helminthoidichnites* Fitch, 1850 differs from *Gordia* Emmons, 1844 in its distinctly less looping course (Hofmann and Patel, 1989; Pickerill and Peel, 1990). *Helminthoidichnites* is interpreted as a structure, formed by nematodes or insect larvae (Buatois *et al*., 1997), or by other arthropods, as indicated by the presence of transverse striae (Uchman *et al*., 2009).

Helminthoidichnites tenuis Fitch, 1850
Fig. 16E, F

*1850 *Helminthoidichnites tenuis* – Fitch, p. 866, unnumbered fig.
1989 *Helminthoidichnites tenuis* Fitch, 1850 – Hofmann and Patel, p. 141, fig. 2a.
1997 *Helminthoidichnites tenuis* Fitch, 1850 – Jensen, p. 55, fig. 37C.
1999 *Helminthoidichnites tenuis* – MacNaughton and Narbonne, p. 106, fig. 7B.
2009 *Helminthoidichnites tenuis* Fitch, 1850 – Buatois and Mángano, p. 130, fig. 2G.
2009 *Helminthoidichnites tenuis* Fitch, 1850 – Buatois *et al*., p. 294, fig. 4D.
2012 *Helminthoidichnites tenuis* Fitch, 1850 – Buatois and Mángano, p. 10, fig. 5.

Material. Nine sandstone slabs (INGUJ214P/Mr45, /Mr67–73, /St96) with numerous specimens.
Description. Hypichnial convex semirelief, curved or irregular winding, thin ridges, occasionally forming loops. The ridges are close to semicircular in cross-section. In most specimens, the surface is smooth, but in the widest specimen transverse striae occur. The ridges are 0.2–2 mm wide and up to tens of millimetres long.
Remarks. Most of the specimens included here in *H. tenuis* are almost straight or slightly winding. Only a few specimens form single loops, which are similar to those of *Gordia arcuata* Książkiewicz, 1977. However, *G. arcuata* forms symmetric meanders and is more winding than *H. tenuis* (Hofmann and Patel, 1989).

Ichnogenus *Nereites* MacLeay, 1839

Remarks. *Nereites* MacLeay, 1839 recently included *Neonereites* Seilacher, 1960 and *Helminthoida* Schafhäutl, 1851 (Uchman, 1995, 1998). More complete synonymy lists of *Nereites* were presented by Rindsberg (1994) and Uchman (1995). *Nereites* is a typical pascichnion, produced by organisms feeding within the sediment (Uchman, 1995, 1999, 2007).

Nereites isp. A
Fig. 16G

Material. One specimen (INGUJ214P/Mr79).
Description. Hypichnial, convex, biserial chain of indistinct, smooth, fusiform pads, separated by a median furrow. The pads are directed oblique to the chain axis and arranged in a chevron pattern. From one side, opposite to the "arrow" of chevrons, the chain is terminated by a distinct, oval bulge. The second termination plunges into the bed. The chain is 18 mm long and about 3 mm wide. The bulge is 5 mm wide and about 2 mm high.
Remarks. A similar specimen from the Cambrian Arumbera Sandstone, Central Australia, was illustrated by Walter *et al*. (1989).

Nereites isp. B
Fig. 16H

Material. One specimen (INGUJ214P/Ig113).
Description. Hypichnial, convex chain of six spherical or ovoid, slightly flattened pads of different size, arranged in partly overlapping series. The structure resembles chambers of biserial foraminifera or a chain of faecal pellets. The chain is 11 mm long and 5 mm wide, individual pads are 3–5 mm wide.
Remarks. *Nereites* isp. B distinctly differs from *Nereites* isp. A, mainly in having much more distinct and isolated, semicircular pads. It is similar to *Nereites biserialis* (Seilacher, 1960).

Ichnogenus *Psammichnites* Torell, 1870

Remarks. *Psammichnites* Torell, 1870 shows high variability of morphology and taphonomic variants (e.g., Kowalski, 1978; Pickerill and Peel, 1990; Gámez Vintaned *et al*., 2006; Seilacher, 2007). *Arcuatichnus* Kowalski, 1978 is one synonym of *Psammichnites* (e.g., Pacześna and Żylińska, 2008). *Psammichnites* is interpreted as a feeding structure of infauna that was connected with the sediment surface by means of a tubular organ (Seilacher, 1997, 2008; Mángano *et al*., 2002).

Psammichnites cf. *gigas* Torell, 1870
Fig. 16I, J

?1978 *Arcuatichnus wimani* nov. gen., nov. sp. – Kowalski, p. 339, pl. 1.1–1.3.
?2008 *Arcuatichnus wimani* Kowalski, 1978 – Pacześna and Żylińska, p. 6, fig. 2 [assigned there as a synonym of *Psammichnites gigas* Torell, 1870].

Material. Eleven specimens (INGUJ214P/Ig98, 99, INGUJ214P/Ja1–3, INGUJ214P/Ja8–12, INGUJ214P/St114).

Description. A hypichnial bilobate ribbon, oval or close to oval in the cross-section, preserved in full relief, with a median narrow furrow. The surface of the ribbon is more or less distinctly covered with transverse ridges. The ribbon is 10–17 mm wide, 4–6 mm high. The median furrow is 1–2.5 mm wide. The specimen with the widest median furrow displays a delicate, discontinuous, axial, corrugated crest. The corrugations may be prolonged into transverse ridges.
Remarks. The specimens described here are very similar to some specimens of *Psammichnites gigas* Torell, 1870, illustrated by Seilacher (1997, 2008), but are much smaller.

Branched structures winding and meandering

Ichnogenus *Multina* Orłowski, 1968

Remarks. *Multina* Orłowski, 1968 as well as *Pseudopaleodictyon* Pfeiffer, 1968 display overcrossings at the different levels; this feature distinguishes these ichnogenera from *Protopaleodictyon* Książkiewicz, 1958 (Uchman, 1998). According to Orłowski and Żylińska (1996), *Multina* in its type material differs from *Megagrapton* Książkiewicz, 1968 in its occurrence at the tops of beds and by less regular nets. However, other specimens ascribed to this ichnogenus can be preserved in different parts of the bed. *Multina* is interpreted as a structure, formed by feeding organisms or searching for food (e.g., Buatois and Mángano, 2004). More details on the taxonomy and ethology of *Multina* are presented by Uchman (1998, 2001) and Buatois *et al*. (2012).

Multina cf. *minima* Uchman, 2001
Fig. 16K

Material. Two specimens (INGUJ214P/Mr64, /Mr68).
Description. Hypichnial full-relief or semirelief developed as thin, irregularly curved or winding, branched, smooth strings and ridges, which are about 0.3 mm wide. Occasionally U- or Ω -shaped meanders occur. The ridges overlap each other at the different levels, forming a three-dimensional network; however, overlaps partly mask meshes of the net. The branching points are without swelling. Individual meanders are a few millimetres wide.
Remarks. Irregular, small meanders, rarely branching and overcrossing at different levels are typical of *Multina magna* Orłowski, 1968. However, the illustrated specimens differ from *M. magna* in their smaller string diameter and narrower meshes. The specimens discussed differ from *M. minima* in the absence of swellings.

U-shaped structures

Ichnogenus *Arenicolites* Salter, 1857

Remarks. *Arenicolites* Salter, 1857 differs from *Diplocraterion* Torell, 1870 by the absence of spreites (e.g., Hakes, 1977). This ichnogenus is interpreted as a dwelling structure (Bromley, 1996) and typical of shallow-marine environments (Bromley and As- gaard, 1979).

Arenicolites isp.
Fig. 17A, B

Material. Five sandstone slabs (INGUJ214P/Z1–5) with numerous specimens. Moreover, mass occurrences of specimens were observed in the field.
Description. Single, endichnial arcuate curved pipes developed mostly in the vertical plane. Their arcs are very wide, gently curved, almost horizontal over long distances, with terminations directed to the tops of beds. The pipes are circular in cross-section, with smooth surface, empty or filled by a silty deposit. Terminations of the arcs form small funnels at the top of beds. The pipes are 70–200 mm long, about 2 mm in diameter. The funnels are up to 4 mm wide. The whole structure is 10–30 mm deep.
Remarks. Rarely, more complete structures can be observed. In most cases, this trace fossil is seen as almost horizontal or indistinctly curved burrow soles, which are, however, only fragments of a more complete burrow as presented in the description. Mass occurrences of *Arenicolites* isp. are seen only in medium and thick beds of quartz arenite, where usually they are the only trace fossil.

Other structures

Ichnogenus *Curvolithus* Fritsch, 1908

Remarks. *Curvolithus* is commonly interpreted as a locomotion trace of invertebrate predators within the sediment layer (e.g., Baucon and Carvalho, 2008). Possible makers of this ichnogenus were gastropods (e.g., Häntzschel and Reineck, 1968; Heinberg, 1973; Heinberg and Birkelund, 1984), polychaetes and holothurians (Lockley *et al.*, 1987) or flatworms (Seilacher, 2007). *Curvolithus* is typical of shallow-marine environments (Chamberlain, 1977; Krobicki and Uchman, 2003).

cf. *Curvolithus* isp.
Fig. 17C

Material. Two sandstone slabs (INGUJ214P/Ig67, 68) with a few fragments of overcrossing specimens.
Description. Hypichnial, slightly convex, slightly curved ribbons, overcrossing each other, preserved in semirelief. The lower surface of the ribbons is distinctly trilobate for the entire length. The surface of the ribbons displays three indistinct ridges, separated by narrow furrows. The central ridge is flat; however, details of the surface are not preserved. Individual fragments of the ribbons are 80–100 mm long and 10 mm wide. The central ridge is 6 mm wide. The furrows between the ridges are less than 1 mm wide.
Remarks. The specimens described are only short portions of larger structures. The surface of the specimens analysed is partly abraded and determination at the ichnospecies level is impossible.

Ichnogenus *Artharia* Billings, 1872

Remarks. Fillion and Pickerill (1984) revised *Artharia* Billings, 1872 and separated it from the similar ichnogenera *Bifungites* Desio, 1940 and *Diplocraterion* Torell, 1870. These authors included in *Artharia* dumbbell-shaped trace fossils, which are parallel to bedding planes and without vertical pipes and spreites.

Artharia isp.
Fig. 17D

?1992 *Artharia* isp. A – Mikuláš, p. 20, pl. 2.6–2.8.

Material. One slab of ripple-laminated, fine-grained quartz arenite (INGUJ214P/Mr53) with three specimens.
Description. Hypichnial, symmetrical ridge with swelling at both terminations, preserved in semirelief. The structure as a whole has a typical dumbbell shape. A small, cirrous, pointed, hook-like branches occur along the structures, at both sides, between the swellings. Their pointed terminations are curved in one direction. Similar, distinctly hook-like branches also occur on one of the swellings. The structure is 20–40 mm long 1–4 mm high. The swellings are about 8 mm wide. The ridge between the swellings is about 3 mm wide. The hook-like branches are 2–3 mm long.
Remarks. The specimens discussed are similar to *Artharia* isp. A illustrated by Mikuláš (1992), but differ from this in having the hook-like branches.

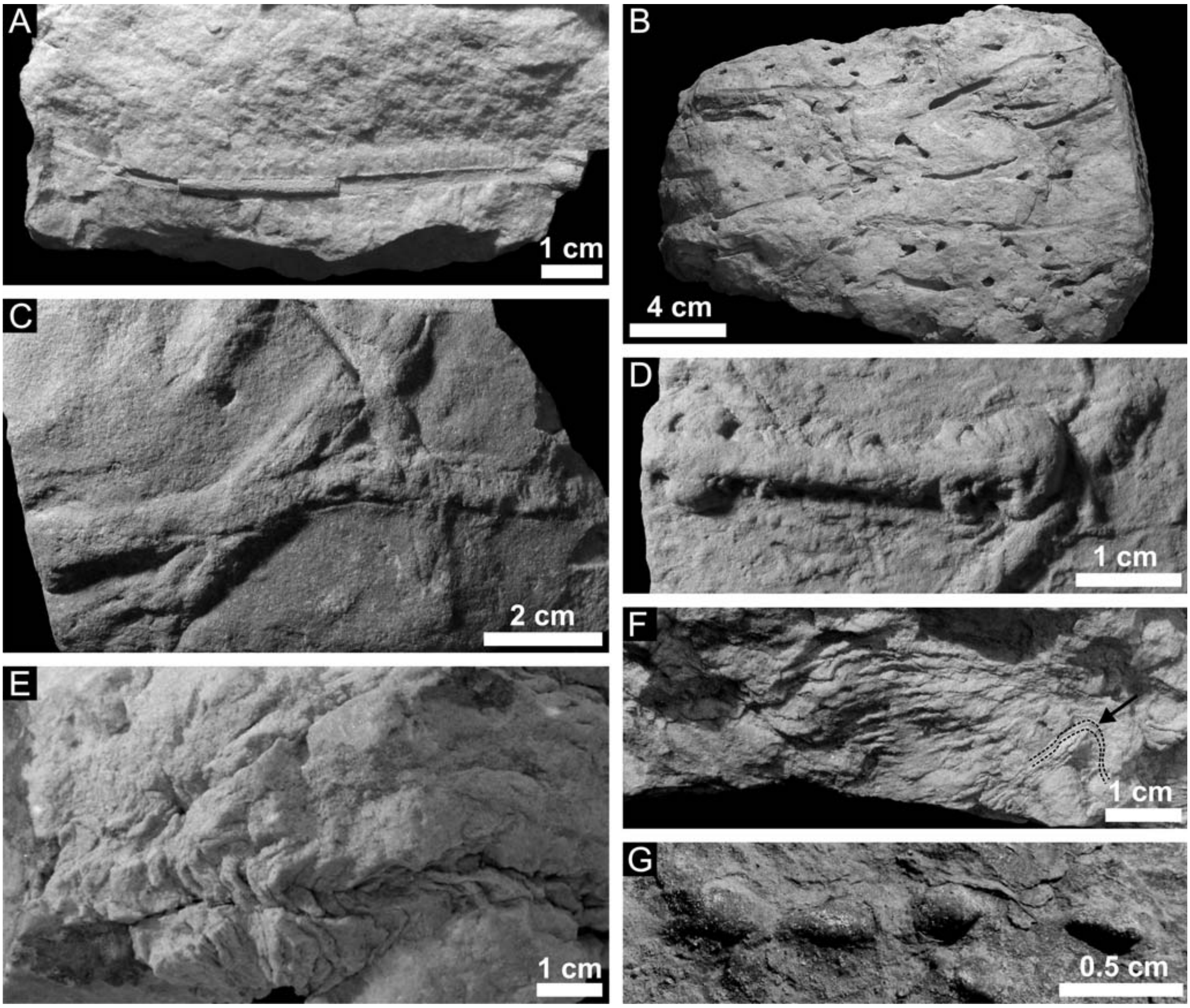

Fig. 17. Trace fossils from the Ociesęki Formation, U-shaped and other structures. **A, B.** Arenicolites isp., endichnia in thin or medium quartz arenite beds, fractured bed, side views; *Protolenus-Issafeniella* Zone, Łapigrosz; A – INGUJ214P/Z3, B – INGUJ214P/Z1. **C.** cf. *Curvolithus* isp., hypichnial convex semirelief in medium quartz arenite bed, INGUJ214P/Ig67; *Schmidtiellus- Holmia* Superzone, Igrzyczna Hill. **D.** *Artharia* isp., hypichnial convex semirelief in thin quartz arenite bed, INGUJ214P/Mr53; *Schmidtiellus-Holmia* Superzone, Sterczyna Hill. **E, F.** *Multilamella spatiosa* Orłowski, 1989, endichnia in thin quartz arenite bed, E – INGUJ214P/Ja13, contortion forming trilobate pattern arrowed, F - INGUJ214P/Ja15; *Schmidtiellus-Holmia* Superzone, Jaźwina Hill. **G.** *Ptychoplasma* cf. *vagans* Książkiewicz, 1977, hypichnial convex semirelief in thin quartz arenite bed, INGUJ214P/Mr50; *Schmidtiellus- Holmia* Superzone, Sterczyna East.

Ichnogenus *Multilamella* Orłowski, 1989

Emended diagnosis. Sets of thin, straight or undulating shingled lamellae, parallel to one another, but bent in one direction on the sole of bed or within the bed. The sets of the lamellae are inclined at diverse angles to the bedding.

Remarks. The original diagnosis of the ichnogenus *Multilamella* (Orłowski, 1989, p. 223) reads: "Groups of thin laminae parallel to each other, straight to undulating, covering the surface on the sole of sandstone beds or situated inside the beds near the sole. As a rule, the groups are parallel to the bedding plane, rarely slightly oblique. Single laminae are convex in the same direction. Laminae situated perpendicularly to bedding plane. Groups of laminae are sometimes associated with single, meandering track, oval in cross section, with concave laminae inside, retrusive. Longitudinal tracks often perpendicular to bedding plane and to groups of laminae." This is confusing, because of the arrangement of laminae with respect to the bedding plane. For this reason, an emended diagnosis is proposed.

Multilamella spatiosa Orłowski, 1989
Fig. 17E, F

*1989 *Multilamella spatiosa*, gen. nov., sp. nov. – Orłowski, p. 224, pls 19.1–19.4, 20.2, 20.3.

2008 *Multilamella spatiosa* Orłowski, 1989 – Pacześna and Żylińska, p. 12, fig. 14A, B.

Material. Four specimens (INGUJ214P/pZg/1, INGUJ214P/Ja13, 15, INGUJ214P/W14).

Emended diagnosis. As for the ichnogenus *Multilamella*.

Description. Set of a thin, parallel, arcuate lamellae visible on the sole of the bed or on the fractured bed surface. The set is more or less elongated, bent in diverse directions. Some sets are strongly curved and form a trilobate shape in cross- section. The whole structure is 5–40 mm wide and up to 40 mm long, individual lamellae are about 1.5 mm thick.

Remarks. The systematic position of *M. spatiosa* is unclear. According to Orłowski (1989), this ichnospecies is a deposit-feeding structure of organisms with elongated, narrow, worm-like bodies. However, the trilobate shape of some lamellae visible inside the bed (Fig. 17E, F) indicates burrowing trilobites as possible trace-makers. In contrary to *Curvolithus, Multilamella* does not form ribbon-like traces on a bed surface, but only endichnial, irregular structures.

Ichnogenus *Ptychoplasma* Fenton and Fenton, 1937

Remarks. According to Uchman *et al*. (2011), *Ptychoplasma* Fenton and Fenton, 1937 includes hypichnial, continuous or discontinuous, amygdaloid, carinate or blocky in cross-section, subhorizontal ridges. *Ptychoplasma* differs from *Protovirgularia* McCoy, 1850 in the absence of chevron-like ribs (Pieńkowski and Uchman, 2009; Uchman *et al.*, 2011). *Ptychoplasma* was produced by single-footed organisms, mostly bivalves (Uchman *et al.*, 2011).

Ptychoplasma cf. *vagans* Książkiewicz, 1977
Fig. 17G

Material. One sandstone slab with one specimen (INGUJ214P/Mr50).

Description. Hypichnial, short, almost straight, slightly sigmoid, discontinuous ridges, composed of four small amygdaloid segments. The segments are semicircular or carinate in cross-section. Their surface is smooth. The individual segments are 3 mm long and 2 mm wide, about 1 mm high. The distances between neighbouring segments are 2–3 mm.

Remarks. The described specimen differs from *P. vagans* by more discontinuous ridges composed of distinctly separated segments. *Ptychoplasma conica* Pieńkowski and Uchman, 2009 differs by less elongated, conical segments that are not carinate in cross-section.

DISCUSSION

Environment of deposition

The interpretation of environments of the deposits studied is based on sedimentological features, ichnofabric index and trace fossil assemblages, which were compared with the standard models in textbooks (e.g., Pemberton *et al.,* 2001; Buatois and Mángano, 2011; MacEachern *et al*., 2012; Pemberton *et al*., 2012). However, such models are based mainly on the Cretaceous clastic deposits of the North America. Some amendments to the interpretations are necessary because of the specific Cambrian infaunal assemblages. The most important difference is the lower degree of bioturbation of the Cambrian sediments, which were deposited at locations deeper than offshore (e.g., Droser and Bottjer, 1988, 1989). As a result, Cambrian deposits can contain distal tempestites preserved in the deeper-water settings, while such tempestites are totally erased by bioturbation in younger sediments (cf. Pemberton *et al*., 2001, 2012).

The Ociesęki Formation, along with the Cambrian formations of the Kielce Block (Northern Małopolska Massif), was deposited in a basin close to the Baltica palaeocontinent (e.g., Cocks, 2002; Cocks and Torsvik, 2005). According to the commonly accepted view, sands were deposited on the elevated areas, while silts dominated in the deeper part of the siliciclastic shelf bordered by shallower elevations (e.g., Łydka and Orłowski, 1978; Pożaryski *et al*., 1981; Lendzion *et al*., 1982; Kowalski, 1983; Kowalczewski *et al*., 1987, 2006; Studencki, 1989). The material was deposited relatively far from the source area and fluctuations of the storm wave base occurred episodically (Kowalczewski *et al*., 1987). Details about the bathymetry and oxygenation of these sediments are so far unknown. According to Studencki (1989), the material of the Ociesęki Formation was deposited in the littoral sandy area far from the coast of a shallow sea during a time of diminished clastic supply. Generally, an increase in coarser material toward the top of the lower Cambrian in the western and the central part of the Kielce Block (Kowalczewski *et al*., 2006) indicates a shallowing of the basin (Mizerski *et al*., 1986; Studencki, 1989). This shallowing was accompanied by deepening in the eastern Holy Cross Mountains (Kowalczewski *et al.,* 2006), expressed as a change from sandy deposition (Ociesęki Formation) to silty deposition (Kamieniec Formation). Probably, such differentiation was an effect of tectonic movements even during the early Cambrian (Cambrian Epoch 2 according to Peng *et al.*, 2012; cf. Mizerski, 1994; Mizerski *et al*., 1999; Gągała, 2005).

According to Orłowski (1989), the lower part of the Ociesęki Formation was deposited close to the fair-weather wave base, while the upper part of this formation was laid down above the fair-weather wave base. Studencki (1989) suggested that the sandstones of the Ociesęki Formation were deposited in the transition zone between the littoral sands and the shelf muds, while sandstones with silty and clayey intercalations were deposited at a great distance from the coast, but still in the shallow part of the basin. A high degree of bioturbation points to physico-chemical conditions favourable for macroinfauna. Closer determination of the depositional environment of the entire Ociesęki Formation is not possible, because of the small sizes of exposures of the formation (mostly 1–2 m high) and its great thickness (at least 1,200 m, according to Mizerski *et al*., 1986). However, almosty twenty small outcrops studied, representing different parts of the formation, permit some interpretations. Numerous discontinuous deformations also cause problems for correlation of individual exposures. In such situations, only a general palaeoenvironmental interpretation of the entire formation can be accomplished. More precise conclusions can be made only with regard to the individual sections studied.

Two facies can be distinguished in the Ociesęki Formation on the basis of lithology and the trace fossil assemblages (Fig. 18). They correspond to the informal lithostratigra-phical members A and B, described by Orłowski and Mizerski (1996). Member A is composed mostly of isolated, amalgamated beds of wackes and quartz arenites with silty material and ripple cross-lamination and with combined wave-current ripples on bedding surfaces. This member (e.g., at Igrzyczna North and South, Jaźwina, Sterczyna Quarry, Sterczyna East, Zbelutka Quarry) contains the ethologically diverse trace fossils (mostly *Rusophycus*, *Teichichnus*, *Helminthoidichnites*, *Phycodes, Trichophycus, Pla-*

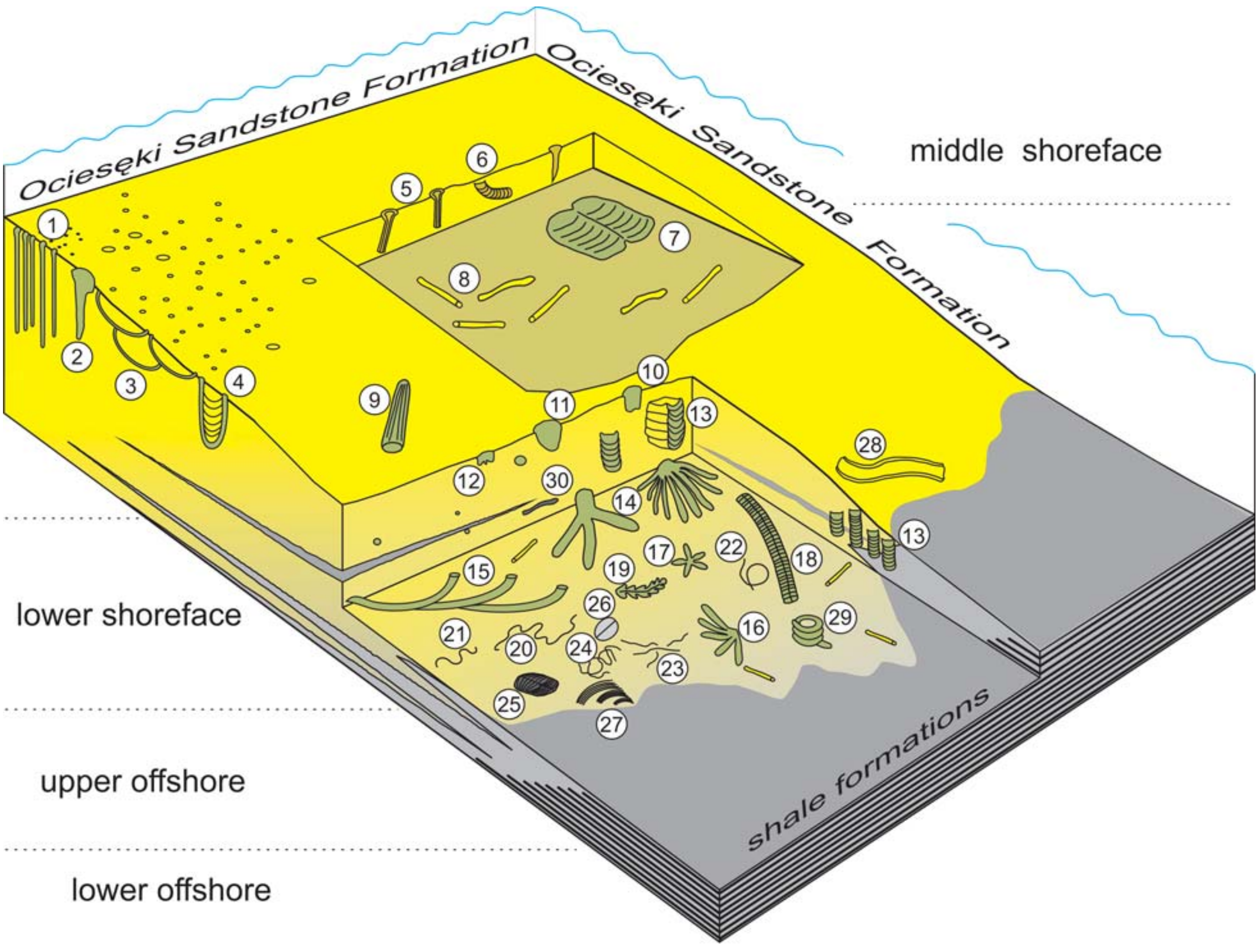

Fig. 18. Model of depositional environments of the Ocieskęki Formation and distribution of selected, important trace fossils. Trace fossils: 1 – *Skolithos* isp., 2 – *Monocraterion* isp., 3 – *Arenicolites* isp., 4 – *Diplocraterion parallelum*, 5 – *Cylindrichnus operosus*, 6 – *Multilamella spatiosa*, 7 – *Rusophycus magnus*, 8 – *Planolites* ispp., 9 – *Halopoa* isp., 10 – *Bergaueria perata,* 11 – *Conostichus* isp., 12 – *Mammillichnis aggeris*, 13 – *Teichichnus* ispp., 14 – *Phycodes* ispp., 15 – *Trichophycus* ispp., 16 – *Treptichnus pedum*, 17 – *Dactyloidites asterioides*, 18 – *Psammichnites* cf. *gigas*, 19 – *Nereites* ispp., 20 – ?*Cosmorhaphe* isp., 21 – *Cochlichnus anguineus*, 22 – *Gordia* isp., 23– *Helminthoidichnites tenuis*, 24 – *Multina* cf. *minima*, 25 – *Rusophycus dispar*, 26 – *Rusophycus carbonarius*, 27 – cf. *Dimorphichnus* ispp., 28 – cf. *Curvolithus* isp., 29 – *Gyrolithes* isp., 30 – ?*Palaeophycus tubularis.*

nolites and cf. *Dimorphichnus*), typical of the *Cruziana* ichnofacies (*sensu* Seilacher, 1967). Member B is represented by amalgamated beds of quartz arenite, which contain thin silty intercalations only in a few horizons, e.g., at Zamczysko Hill, Zamczysko Reserve, Łapigrosz, Wysokówka, Koziel, and the Zgórskie Range. This lithofacies contains mostly vertical domichnia (especially *Monocraterion*, *Skolithos* and *Arenicolites*), which are typical of the *Skolithos* ichnofacies (*sensu* Seilacher, 1967). The facies is characteristic of the lower part of the Ociesęki Formation, included in the *Schmidtiellus-Holmia* Superzone, whilst the second facies occurs in the upper part of the formation, which is included in the *Protolenus-Issafeniella* Zone.

The lower part of the Ociesęki Formation (*Schmidtiellus-Holmia* Superzone) is composed mostly of wackes with thin to medium beds (1–20 cm) of quartz arenites and rare, isolated layers of siltstone, which show diverse degrees of bioturbation. Unbioturbated, mostly amalgamated beds show primary sedimentary structures, including ripple cross-lamination and combined wave-current ripples at the tops of beds and horizontal or oblique, low-angle lamination (?quasi-planar lamination, cf. Arnott, 1993). In the medium and thick, amalgamated beds, lens-like relicts of unbioturbated arenite layers, 3–20 mm thick, are visible within the bioturbated background deposits. They are interpreted here as distal tempestites. The thickness of tempestites is underestimated, because their upper part is totally bioturbated and looks identical to totally bioturbated sandy background sediments. Probably the most distal tempestites less than a centimetre in thickness were totally destroyed by bioturbation. The thicker tempestites preserve unbioturbated beds of quartz arenites with sharp bases and often with ripple cross-lamination or combined wave-current ripples at the top. The absence of bioturbation structures and the occurrence of primary sedimentary structures in such beds indicate the burial of macrobenthos by storm deposits with only very rare and questionable escape traces. Some of these beds include buried trilobites (Stachacz, 2013). The dominance of the bioturbated, sandy-silty material (wackes) intercalated with the tempestites indicates deposition around the fair-weather and between the fair-weather and storm wave bases (e.g., Reinson, 1984; Pemberton *et al*., 2001, 2012; MacEachern *et al.*, 2012).

The trace fossil assemblages dominating this part of the Ociesęki Formation are represented mostly by the structures formed by deposit-feeders (especially *Planolites*, *Teichichnus*, *Phycodes*, and *Cruziana*), typical of the *Cruziana* ichnofacies (Fig. 18). However, vertical domichnia of suspension-feeders (mostly *Monocraterion*), more typical of the *Skolithos* ichnofacies (*sensu* Seilacher, 1967) also occur (Fig. 18). Such trace fossils are typical of the proximal *Cruziana* ichnofacies, which indicates an environment with permanent wave influence (e.g., Pemberton *et al*., 2001, 2012 and references).

The sedimentological and ichnological features of the lower part of the Ociesęki Formation imply that this part of the formation was deposited on the upper offshore to lower shoreface at depths between the fair-weather and storm wave bases and above the fair-weather base. Storms evidently controlled the accumulation rate. Erosional channels filled with cross-bedded sandstones are known in the lower part of the Ociesęki Formation at Gieraszowice (eastern part of the Holy Cross Mountains) and interpreted as the result of rip currents during intense storms. Such conditions were interpreted as an effect of possible tectonic earthquakes on the shelf (Mizerski *et al*., 1999).

Among the outcrops analysed, the Zbelutka Quarry shows different features than other outcrops. Here, mostly unbioturbated, horizontally or low-angle (?quasiplanar) laminated quartz arenites and wackes rich in mud dominate. Such material was deposited in the transition zone from the sandy to the silty facies. Some horizons contain abundant *Teichichnus* that forms a monoichnospecific assemblage, which indicates hostile ecological conditions, probably caused by reduced salinity, and favouring opportunistic organisms, such as deposit-feeders.

The upper part of the Ociesęki Formation (*Protolenus-Issafeniella* Zone) is dominated by medium and thick, usually amalgamated beds of quartz arenites, diversified in the degree of bioturbation. The arenites are composed mostly of well sorted, fine-grained quartz and contain rare siltstone clasts. Less common are very thin intercalations of silt. This part of the formation mostly contains numerous vertical domichnia, i.e., *Arenicolites*, *Monocraterion* and *Skolithos* (Fig. 18), usually without horizontal trace fossils. Rarely, beds contain both vertical and horizontal trace fossils. These beds are totally bioturbated, without primary sedimentary structures (e.g., the Koziel pit). Some arenite beds show wave ripples at the top (usually within the amalgamated beds) and unbioturbated beds are often ripple cross-laminated or hummocky cross-stratified. These beds are interpreted as proximal tempestites.

Both sedimentological and ichnological features indicate that the upper part of the Ociesęki Formation was deposited on the lower to middle shoreface (cf. Pemberton *et al*., 2001, 2012 and references) in high-energy conditions (Reinson, 1984; Pemberton *et al*., 2001, 2012; MacEachern *et al*., 2012). Storms were the main factor controlling the accumulation rate, erosion and the intensity of bioturbation. During fair weather, the sea floor was intensively reworked by benthic organisms. Between the frequent storms the colonization window was too short for the reworking of newly deposited sediment, and the partial cannibalism of former storm beds resulted in amalgamated, unbioturbated arenite beds (Pemberton *et al*., 2001, 2012).

During the early Palaeozoic, cross-bedded sand bars, controlled by tides and deposited at some distance from coast, generally display ichnoassemblages typical of the *Skolithos* ichnofacies (Mángano and Buatois, 1999). The trace fossil assemblage of the upper part of the Ociesęki Formation represents partly the archetypal *Skolithos* ichno- facies (*sensu* Seilacher, 1967) and partly the *Cruziana* ichnofacies.

Ichnocoenosis of Cambrian Series 2 of the Holy Cross Mountains and other areas – a comparison

The Cambrian Series 2 Ociesęki Formation shows much more frequent and diversified trace fossils than Cambrian Series 3 and the Furongian deposits of the Holy Cross Mountains (Orłowski *et al.*, 1970; Orłowski and Żylińska, 2002; Sadlok, 2010, 2013, 2014a, b; Sadlok and Machalski, 2010). The Czarna Formation (Cambrian Series 2 and probably older) and the Kamieniec Formation (Cambrian Series 2), dominated by silty shales, show only sparse trace fossils and low degrees of bioturbation (Stachacz, 2012b).

In contrast, the Ociesęki Formation contains about 74 ichnospecies referable to 43 ichnogenera (Kowalski, 1978, 1987; Pacześna, 1985; Orłowski, 1989, 1992b; Orłowski and Żylińska, 2002; Stachacz, 2012a, this study), of which 53 ichnospecies in 33 ichnogenera are described here (Appendix 1). The underlying and in part laterally interfingering Czarna Formation contains 12 ichnospecies in 10 ichnogenera (Stachacz, 2012b), and the Kamieniec Formation only 11 ichnospecies in 9 ichnogenera (Orłowski, 1989; M. Stachacz, unpubl. data, 2011). Among the recognized ichnotaxa in the Ociesęki Formation, 36 ichnospecies included in 16 ichnogenera are described for the first time in this paper. The trace fossils of the Cambrian Series 2 described here are very diverse; however, only a small part of ichnotaxa is common, while the others occur only in a few outcrops or even as single specimens.

Worldwide trace fossil assemblages differ geographically because of zoogeographical provincialism during the Cambrian (e.g., Orłowski, 1985; Żylińska and Masiak, 2007). However, comparisons are hampered by the uneven state of ichnotaxonomic research, with possible misidentifications and diverse application of open nomenclature. The Cambrian zoogeographical differentiation is confirmed by trilobite trace fossils. In the Ociesęki Formation, *Rusophycus dispar* is typical of Scandinavia (Baltica palaeocontinent; e.g., Jensen, 1997). The ichnospecies typical of the Avalon province of North America (e.g., Fillion and Pickerill, 1990) and Western Europe (e.g., Gámez Vintaned *et al*., 2006) are almost totally absent. Nevertheless, *Astropolichnus hispanicus*, which is typical of Gondwana and Avalonia palaeocontinents and corresponds to trilobite Redlichiid realm (Pillola *et al.*, 1994), is present. It is noteworthy that also the trilobite assemblage from the Ociesęki Formation displays similarities to those of the western Gondwana and Avalonia palaeocontinents (e.g., Żylińska, 2013).

However, the trace fossils of some soft-bodied organisms have worldwide distribution, e.g., *Treptichnus pedum* (Seilacher, 1955), which is common around the world (e.g., Seilacher, 1955; Crimes and Anderson, 1985; Fillion and Pickerill, 1990; Geyer and Uchman, 1995; Pacześna, 1996; Jensen, 1997), albeit with great morphological variation (Geyer and Uchman, 1995). Some ichnotaxa are age- and facies-crossing, e.g., *Planolites montanus, P. beverleyensis, Palaeophycus tubularis,* and *Teichichnus rectus*.

The trace fossils from siliciclastic formations of Cambrian Series 2 are known mostly from Canada (Crimes and Anderson, 1985; Hofmann and Patel, 1989; MacNaughton and Narbonne, 1999), China (e.g., Young, 1972; Weber *et al*., 2007), Australia (e.g., Webby, 1970; Walter *et al*., 1989), Sweden (e.g., Jensen, 1997; Jensen and Grant, 1998), Norway (e.g., Knaust, 2004), India (e.g., Ahmad and Kumar, 2014; Pandey *et al*., 2014), Jordan (e.g., Mángano *et al*., 2013) and Africa (e.g., Geyer and Uchman, 1995). In addition to the Holy Cross Mountains, Cambrian ichnoassemblages have been described from the Polish part of the East European Craton (Pacześna, 1996).

The trace fossil assemblages described here show the greatest similarity to the ichnoassemblages from the Polish part of the East European Craton (Pacześna, 1996) and Sweden (Jensen, 1997), which belong to the Cambrian Baltica palaeocontinent. The early Cambrian formations of the Polish part of the East European Craton contain slightly less diverse trace fossils, including 30 ichnogenera and about 47 ichnospecies (Pacześna, 1996), while the Swedish Mickwitzia Sandstone contains 25 ichnogenera and about 36 ichnospecies (Jensen, 1997). Among the trace fossils of the Ociesęki Formation, 18 ichnogenera and 12 ichnospecies occur also in the Mickwitzia Sandstone (Jensen, 1997), and 21 ichnogenera and 11 ichnospecies occur in the Cambrian strata of the Polish part of the East European Craton (Pacześna, 1996). It is hard to conclude that the similarity between these ichnoassemblages is very strong, merely because the ichnodiversity of the Ociesęki Formation is higher than in the Cambrian of Baltica (Sweden and Polish part of East European Craton). However, it is noteworthy that trace fossils from the Polish part of the East European Craton have been analysed only in cores (Pacześna, 1996) and those from the Sweden come from the Mickwitzia Sandstone, the thickness of which does not exceed 10 m (Jensen, 1997), while the thickness of the Ociesęki Formation is greater than 1,200 m (Mizerski *et al*., 1986).

CONCLUSIONS

The Ociesęki Formation (Cambrian Series 2) for the most part comprises totally to strongly bioturbated deposits, only in a few places are primary sedimentary structures visible.

– Trace fossils are very common and taxonomically diverse (about 74 ichnospecies in 43 ichnogenera, of which 53 ichnospecies in 33 ichnogenera are described here; the others are known from the literature). Thirty-six ichnospecies in 16 ichnogenera are noted for the first time in the Ociesęki Formation. This formation shows a higher ichnodiversity than any other Cambrian formation in the Holy Cross Mountains.

– The lower part of the formation contains the trace fossil assemblages, typical of the *Cruziana* ichnofacies, while the upper part is typical of the *Skolithos* ichnofacies.

– The lower part of the formation was deposited on the lower shoreface at depths close to the fair-weather wave base. The upper part was deposited on the middle shoreface above the fair-weather wave base.

– Storms were the most important factor controlling the benthic communities. They were responsible for the burial of benthic populations on the shallow, sandy seafloor.

– The trace fossil assemblage of the Ociesęki Formation shows greatest similarity to other Cambrian assemblages from the Polish and Swedish parts of the East European Platform.

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Appendix 1. List of ichnotaxa from the outcrops studied

Ichnotaxa	Sterczyna East	Sterczyna Quarry	Jaźwina Hill	Igrzyczna North	Igrzyczna South	Leśniakowa Dębina	Zamczysko	Łapigrosz	Wysokówka Hill	Zamczysko Reserve	Koziel pit	Zbelutka Quarry	Chojnów Dół ravine	Łagowica Road	Zagrody	Zgórskie Range	Plebańska Góra
Mammillichnis aggeris	X			X							X						
Bergaueria perata		X		X										X			
Conostichus isp.				X													
Astropolichnus hispanicus				X													
Rusophycus dispar	X																
Rusophycus cf. *avalonensis*	X				X												
Rusophycus crebrus	X	X															
Rusophycus magnus									X		X						
Rusophycus carbonarius	X	X		X													
Rusophycus versans	X																
Rusophycus exsilius	X																
Rusophycus isp. A		X															
Rusophycus isp. B				X													
Rusophycus isp. C	X	X			X												
cf. *Dimorphichnus* isp. A					X												
cf. *Dimorphichnus* isp. B	X																
Planolites beverleyensis		X		X										X			
Planolites montanus		X		X		X	X	X	X	X	X						
Planolites annularis	X	X															
?*Palaeophycus tubularis*		X															
Halopoa isp.	X	X															
Cylindrichnus operosus	X								X								
Monocraterion isp.		X		X			X	X		X							
Skolithos isp.										X							
Phycodes circinatus	X			X		X											
Phycodes palmatus				X													
Phycodes cf. *flabellum*	X																
Treptichnus pedum		X	X	X													
Trichophycus cf. *tripleurum*		X															
Trichophycus isp. A		X															
Trichophycus isp. B		X															
Polykladichnus cf. *aragonensis*									X								
Dactyloidites asterioides				X													
Gyrolithes isp.				X													
Teichichnus rectus	X	X		X	X							X				X	X
Teichichnus duplex	X	X		X													
Diplocraterion parallelum					X										X		
Cochlichnus anguineus	X																
?*Cosmorhaphe* isp.	X																
Gordia isp.				X													
Helminthoidichnites tenuis	X																
Nereites isp. A	X																
Nereites isp. B				X													
Psammichnites cf. *gigas*		X	X	X													
Multina cf. *minima*	X																

Ichnotaxa	Sterczyna East	Sterczyna Quarry	Jaźwina Hill	Igrzyczna North	Igrzyczna South	Leśniakowa Dębina	Zamczysko	Łapigrosz	Wysokówka Hill	Zamczysko Reserve	Koziel pit	Zbelutka Quarry	Chojnów Dół ravine	Łagowica Road	Zagrody	Zgórskie Range	Plebańska Góra
Arenicolites isp.							X	X	X								
Artharia isp.		X															
cf. *Curvolithus* isp.				X													
Multilamella spatiosa									X							X	
Ptychoplasma cf. *vagans*	X																