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TRACE FOSSILS FROM THE MISSISSIPPIAN OF THE PIASKOWA GÓRA SECTION (THE INTRA-SUDETIC BASIN, SW POLAND)

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Abstract: Eight ichnotaxa and enigmatic tubular forms were discovered and described for the first time from clastic deposits (the Culm facies) of the uppermost part of the Szczawno Formation (upper Mississippian) from in the Piaskowa Góra section in the northern part of the Intra-Sudetic Basin near Wałbrzych. The trace fossils are represented mostly by pascichnia and less numerous domichnia, fodinichnia and repichnia. *Psammichnites plummeri* and numerous *Phycosiphon* isp. are the most common ichnotaxa. They are accompanied by *Archaeonassa fossulata, Beaconites* cf. *capronus*, *Curvolithus multiplex, Dictyodora liebeana, Palaeophycus* isp., and *Planolites* isp. *D. liebeana* is described for the first time from the lower Serpukhovian. Most components of the ichnoassemblage are typical of the *Cruziana* ichnofacies, but the co-occurrence of *Dictyodora* and *Phycosiphon* could indicate a transition to deeper environmental settings (the *Zoophycos* ichnofacies). The lithological features as well as the accompanying trace fossils, wrinkle structures and floral remains of *Archaeocalamites* indicate rapid sedimentation, alternating with more tranquil periods of sedimentation, in an intermediate environment between the lower offshore (the distal *Cruziana* ichnofacies) and the fan-delta slope (below the wave base, the *Zoophycos* ichnofacies). The studied trace fossils and palynological data indicate that marine conditions in the Wałbrzych area in the Mississippian prevailed locally until the early Sepukhovian.

Key words: Trace fossils, Szczawno Formation, Intra-Sudetic Basin, lower Serpukhovian.

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INTRODUCTION

The Intra-Sudetic Basin contains Mississippian (not older than the middle Viséan) through to Permian rocks, overlain by the lower Triassic and Upper Cretaceous deposits (Bossowski *et al*., 1995; Turnau *et al*., 2002; Awdankiewicz *et al*., 2003). The total thickness of the Carboniferous–Permian molasse succession exceeds 10 km, with up to 8.5 km of Carboniferous sediments (Nemec *et al*., 1982; Dziedzic and Teisseyre, 1990).

Carboniferous trace fossils from the central part of the Polish Sudetes are still inadequately known. The best known ichnoassemblages are from the upper Viséan of the Bardo Unit (Muszer and Haydukiewicz, 2009, 2010; Muszer and Uglik, 2013). Trace fossils from the Carboniferous of the Intra-Sudetic Basin are poorly illustrated from the Viséan alluvial sediments of the Stare Bogaczowice Formation (Teisseyre, 1968, p. 267) and only noted without any descriptions from the Viséan sediments near Wałbrzych (Żakowa, 1958, 1960; Nemec *et al*., 1982; Mastalerz, 1987, 1995). Żakowa (1958, 1960) mentioned *Dictyodora liebeana* Weiss from Konradów and ?*Dictyodora* from Poniatów and Czarnota without any illustrations. Nemec *et al*. (1982) marked an occurrence of unnamed trace fossils on the lithological profile of the Lubomin Formation, while Mastalerz (1987, 1995) mentioned the presence of trace fossils in some facies of the Szczawno Formation. Recently, a preliminary reports about Mississippian trace fossils were presented by Muszer (2013, 2019) from the Intra-Sudetic Basin (the Szczawno Formation) and the Świebodzice Unit (the Pogorzała Formation).

The Mississippian fine-grained sediments are mostly locally and poorly exposed in the Sudetes. Construction of bypass roads around the city of Wałbrzych in recent years provided new outcrops and, consequently, a better understanding of the Szczawno Formation. The present study was carried out in the years 2013–2014 and completed in 2016. They provided new data on the trace fossils of this lithostratigraphic unit.

The aim of the present paper is the description of a newly discovered trace fossil assemblage from the middle part of the Piaskowa Góra section and the comparison of it to ichnoassemblages of selected Mississippian sites. On the basis of the ichnological record, the depositional environment of the upper part of the Szczawno Formation near Wałbrzych is interpreted. This paper is the first comprehensive ichnological study of the Szczawno Formation. It allows better understanding of the palaeontological record of the Szczawno Formation and its palaeoenvironment. These studies provided new data on the Mississippian regression in the Sudetes.

GEOLOGICAL SETTING

The Intra-Sudetic Basin represents a late Palaeozoic intramontane trough situated in the eastern part of the European Variscides at the northern margin of the Bohemian Massif (Awdankiewicz, 1998). It is the largest geologic unit in the central Sudetes. The Intra-Sudetic Basin (= Intra-Sudetic Synclinorium according to Żelaźniewicz *et al*., 2011) is a northwest-southeast trending elongated synclinorial structure, mostly separated from the crystalline basement by normal faults (Teisseyre, 1975). The northern part of the unit is bounded by the Izera-Karkonosze Block, the Kaczawa Metamorphic Unit, the Świebodzice Depression and the Góry Sowie Massif (Fig. 1).

The Carboniferous–Permian molasse sequence consists of mostly continental siliciclastic deposits arranged into several upward-fining megacyclothems, 200–500 m thick, and subordinate volcanics (e.g., Nemec *et al*., 1982; Mastalerz and Prouza, 1995; Awdankiewicz, 1998). The overall chronostratigraphy is based mainly on the general spatial relationships of the nonfossiliferous rocks to those, which are palaeontologically dated, as well as on some other lithological criteria commonly employed (Nemec *et al*., 1982).

The Carboniferous deposits of the Intra-Sudetic Basin are differentiated into several informal formations (Nemec *et al*., 1982; Dziedzic and Teisseyre, 1990; Bossowski *et al*., 1995; Mastalerz and Prouza, 1995), the names of which come from the 19th century local mining nomenclature (for a lithostratigraphic scheme, see Fig. 2). The formations differ in composition, colour and palaeontological content. They are mostly of continental origin, except for the Szczawno Formation, which consists of deposits laid down in fluvial-deltaic and marine environments (Mastalerz and Prouza, 1995). The Szczawno Formation was formerly named "Szczawno Culm" (Teisseyre, 1952) or "Younger Culm" (Dathe, 1892; Radwański, 1952; Żak, 1958). This unit covers the Lubomin Formation and passes upward into the Wałbrzych Formation (Fig. 2). The Szczawno Formation records a marine transgression during the late Viséan (Żakowa, 1958, 1960, 1963).

The sedimentology of the Szczawno Formation was studied by several authors (e.g., Radwański, 1952; Żak, 1958; Teisseyre, 1971, 1975; Nemec *et al*., 1982; Mastalerz, 1987, 1995; Mastalerz and Porębski, 1987; Dziedzic and Teisseyre, 1990). The upper Viséan deposits of the Intra-Sudetic Basin show facies differences as they were deposited into two distinct sub-basins (Mastalerz, 1987, 1995; Bossowski *et al*., 1995; Mastalerz and Prouza, 1995; Awdankiewicz *et al*.,

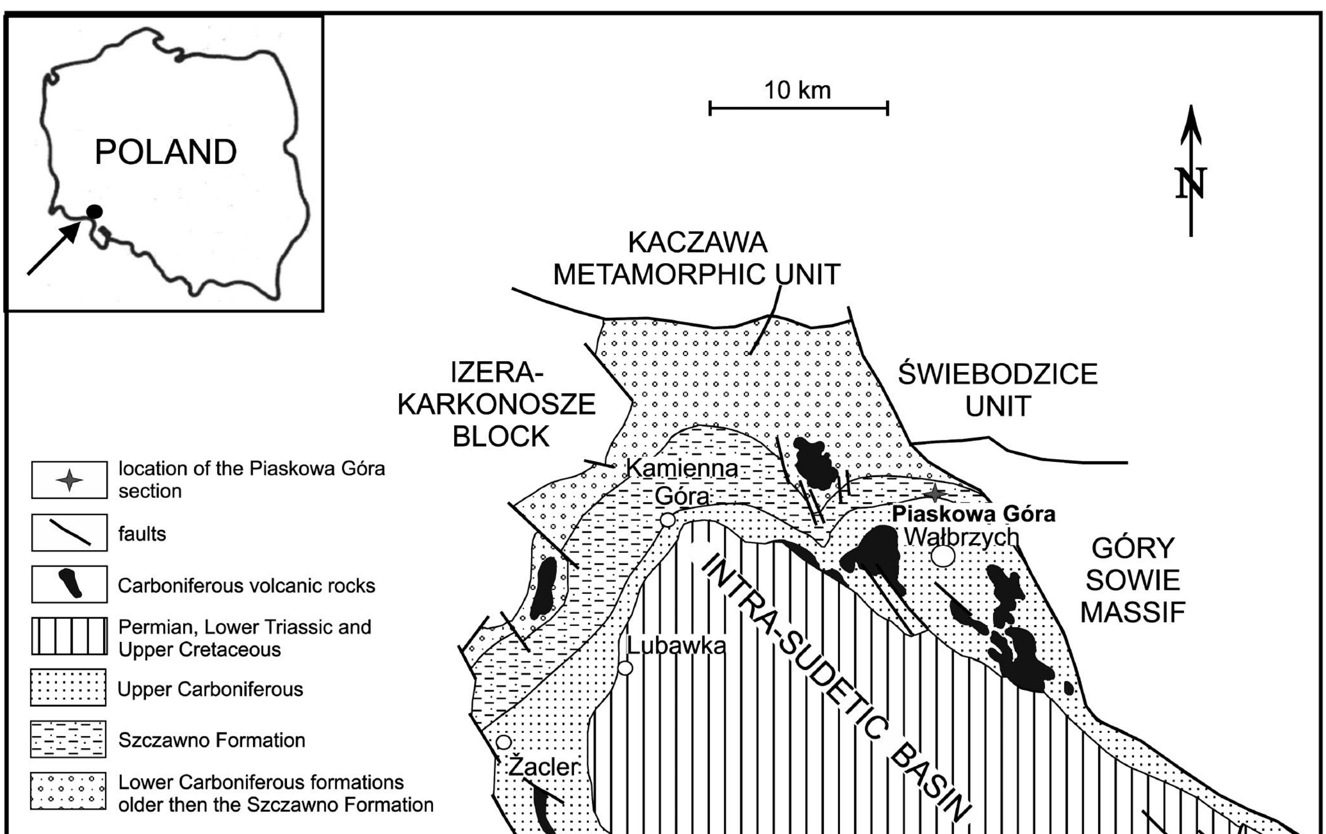

Fig. 1. Generalized geological sketch of the northern part of the Intra-Sudetic Basin (after Mastalerz 1995, modified) and location of the Piaskowa Góra section.

2003). The western part of the basin formed a shallow-marine embayment, passing southwards into an extensive, fluvial/deltaic system (Mastalerz and Prouza, 1995). In this sub-basin, the clastic material initially was deposited in a delta and associated settings that prograded into a shallow bay. The eastern part of the basin (the Wałbrzych Sub-basin) represents a relatively deeper sea. Mastalerz (1995) distinguished six facies associations within the Szczawno Formation in the Wałbrzych Sub-basin. They are interpreted as deposits of alluvial-delta plain, fan-delta front, prodelta, subaqueous fan, basin plain and slope, and shallow-marine shelf. To the east, the Szczawno Formation consists mainly of flysch-like, sandstone/mudstone beds interlayered with conglomerates, pebbly mudstones and clayey sediments, while towards the west, coarser clastics with local horizons exhibiting root structures predominate (Nemec *et al*., 1982). According to Nemec *et al*. (1982) and Bossowski *et al*. (1995), the thickness of the Szczawno Formation varies from 400–600 m in the eastern part of the basin to about 3000 m in its western part. In the Wałbrzych Sub-basin, the formation passes upwards to non-marine Namurian sediments of the Wałbrzych Formation (e.g., Grocholski, 1960, 1974; Teisseyre, 1961; Dziedzic, 1965; Nemec *et al*., 1982), which is the oldest coal-bearing lithostratigraphic unit of this region. In the western part of the Intra-Sudetic Basin, the Szczawno Formation is unconformably overlain by the Westphalian deposits (Nemec *et al*., 1982).

Several authors addressed the problem of contact between the Szczawno Formation and the Wałbrzych Formation (e.g., Teisseyre, 1961; Dziedzic, 1968; Nemec, 1984; Bossowski *et al*., 1995; Mastalerz, 1995; Mastalerz and Prouza, 1995), but it is still not fully explained. However, all the above-mentioned authors stated that the siliciclastic deposits of the Szczawno Formation are compositionally of low maturity, in contrast to the more mature clastic material of the Wałbrzych Formation. The boundary between the Szczawno Formation and the Wałbrzych Formation is marked by the disappearance of greywackes and the appearance of quartz conglomerates or a significant number of coal layers (Nemec *et al*., 1982).

The Szczawno Formation (Figs 1, 2) is palaeontologically the best documented unit of the Mississippian (formerly the Lower Carboniferous) of the Intra-Sudetic Basin (Schmidt, 1925; Żakowa, 1958 and references therein, 1960, 1963; Jerzykiewicz, 1965; Turnau *et al*., 2002). It is associated with the locally frequently occurrence of marine invertebrates (especially goniatites, brachiopods and molluscs). The Szczawno Formation contains the late Viséan goniatites, which are index taxa to the *crenistria* (Goα) Zone and the *striatus* (Goβ) Zone (Żakowa, 1958, 1963). According to Turnau *et al*. (2002), deposition of the formation was during the Asbian and continued into the Brigantian. The latest miospore studies (A. Górecka-Nowak in Muszer *et al*., 2016) allow assignation of the uppermost part of the Szczawno Formation to the *Verrucosisporites morulatus* Subzone (Vm), which corresponds to the lower Serpukhovian (= the lower part of the Namurian A; Fig. 2).

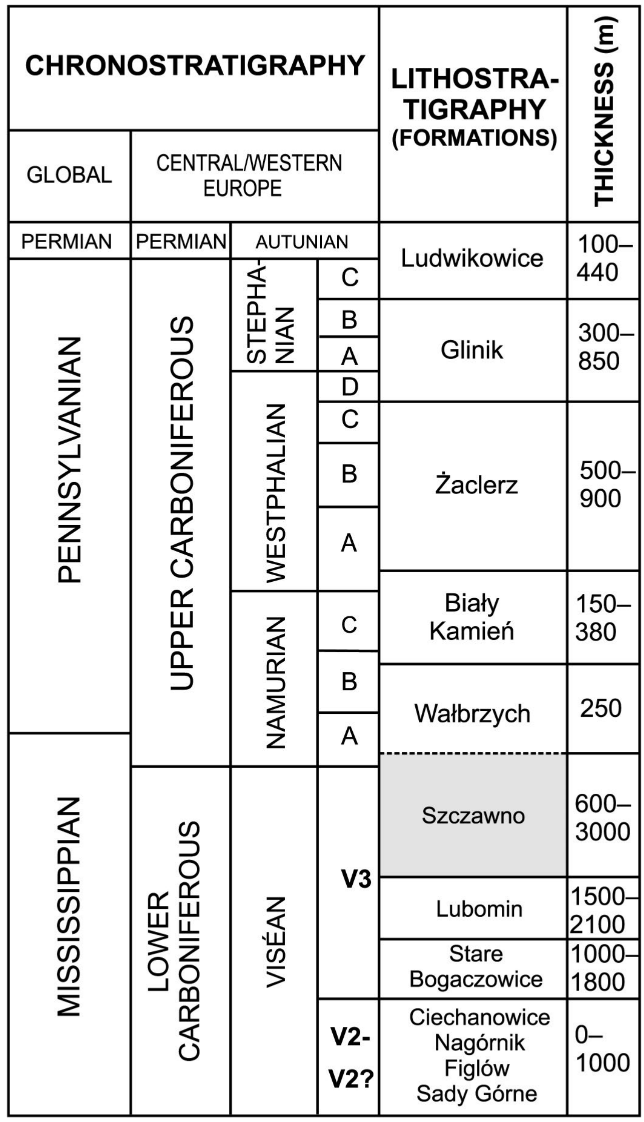

Fig. 2. Generalized lithostratigraphical scheme of the Carboniferous deposits of the Intra-Sudetic Basin based on Bossowski *et al*. (1995), Górecka-Nowak and Majewska (2002), Turnau *et al*. (2002) and Muszer *et al*. (2016), modified.

LITHOLOGY OF THE PIASKOWA GÓRA SECTION

A new outcrop of the Szczawno Formation is studied. It is situated in the northern part of the Wałbrzych Sub-basin, south of the Piaskowa Góra district, near Wyszyńskiego Street (Fig. 3A). The section is exposed in about 100 m long western escarpment by the road (GPS coordinates E 16°16′26.01″, N 50°48′05.99″). It represents the uppermost part of the Szczawno Formation (lower Serpukhovian; Muszer *et al*., 2016) and probably, the lowest part of the Wałbrzych Formation (Fig. 3B). The strata dip at 80° to the south.

The uppermost part of the Szczawno Formation (25 m thick; the lower and middle part of the succession) is composed of grey mudstones and claystones, greenish-grey and grey mudstones, rarely interbedded by thin, fine-grained sandstones and a limestone lense (Fig. 3B). The lower part of the succession studied, about 10 m thick, comprises grey mudstones and claystones. The individual strata are 1–30 mm thick, most of them are thin laminated. Unfortunately, no fossils were found in these deposits. This part of the succession is not fully exposed, owing to vegetation and rubble. The middle part of the succession, about 15 m thick, contains greenish and grey mudstones with a few thin intercalations (up to 3 cm) of grey, fine-grained sandstones with rare calamites (Figs 3B, 4G, H). Graded bedding was observed only in the sandstones. The mudstones are planar laminated. Other sedimentary structures (cross-bedding, ripple marks) and erosional surfaces were not observed in this part of the succession. In the uppermost part of these deposits, a thin 10 cm limestone lense occurs. The middle part of the succession contains numerous trace fossils and rare calamites. The trace fossils are locally abundant, especially on the bedding surfaces (Fig. 3B).

The upper part of the succession, more than 10 m thick, comprises sandstones (mainly arenites) and conglomerates probably of the Wałbrzych Formation. The individual layers of sandstones are 10–15 cm thick and locally contain abundant plant debris, while layers of conglomerates are up to 0.5–1 m thick. The contact between the Szczawno Formation and the Wałbrzych Formation is not well exposed in this profile, but probably there is a sedimentary transition.

MATERIAL AND METHODS

The trace fossils described in this paper were found in the middle and upper parts of greenish and grey mudstones of the uppermost part of the Szczawno Formation. The general morphology, dimensions and orientation of the trace fossils were recorded at the outcrop and 66 samples were collected. A part of samples was collected from debris. Several rock samples were cut and the ichnofabric was observed on polished surfaces using a Nikon SMZ-2T microscope.

All collected specimens and fragments are housed at the collections of the Institute of Geological Sciences of

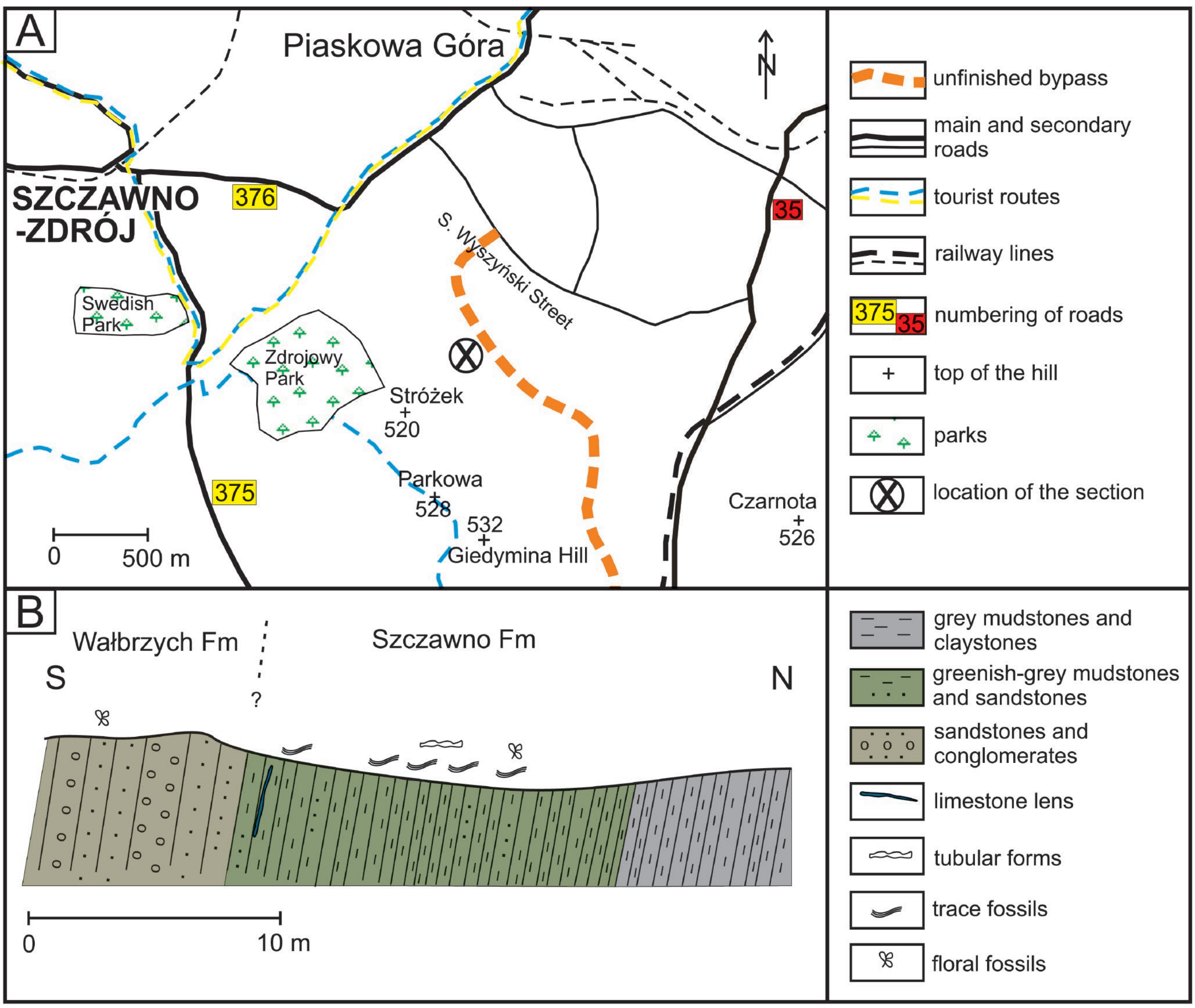

Fig. 3. Sketches of the Piaskowa Góra section. **A.** A topographical sketch and the location of the Piaskowa Góra section. **B.** Generalized lithology of the exposure of the Piaskowa Góra section.

Wrocław University (catalogue numbers Pi2/1, Pi2/2; Pi5a–Pi5d, Pi5/1–Pi5/12, Pi5-1–Pi5-5, Pi5-z1–Pi5-z20, Pi5-K/1–Pi5-K/8, Pi5/2-3/z1–Pi5/2-3/z5, Pi5/2-3sz, Pi6–Pi6a, Pi6/1–Pi6/4, Pi7–Pi7a).

SYSTEMATIC ICHNOLOGY

Deposits of the uppermost part of the Szczawno Formation near Piaskowa Góra contain a relatively moderately diverse assemblage of trace fossils, referable to eight ichnotaxa: *Archaeonassa fossulata, Beaconites* cf. *capronus, Curvolithus multiplex, Dictyodora liebeana, Palaeophycus* isp., *Phycosiphon* isp., *Planolites* isp. and *Psammichnites plummeri.* Moreover, enigmatic tubular forms and wrinkle structures are present. All of them occur in the middle part of the Piaskowa Góra succession.

Ichnogenus *Archaeonassa Fenton* and Fenton, 1937
***Archaeonassa fossulata* Fenton and Fenton, 1937**
Fig. 4A

Material: Five specimens (samples Pi5/4, Pi5-z1, Pi5-z19).
Description: Simple, unbranched, straight to meandering, narrow epichnial furrow, parallel to bedding. It is generally 2–3 mm wide and 1 mm deep, preserved on fine-grained sandstone beds. Margins of the furrow on both sides are bound by irregular and slightly raised levees. The trace is at least 75 mm long.
Remarks: The trace is very similar to *Archaeonassa fossulata*, described by Buatois and Mángano (2002: fig. 7A) from the Carboniferous of Argentina, but a V-shaped cross-section is not clear in the specimens from Piaskowa Góra and they are smaller than the Argentinian specimens. *Archaeonassa* generally is interpreted as a grazing trail or pascichnion, produced by arthropods, annelids and molluscs (Buatois and Mángano, 2002; Mángano *et al*., 2005; Carmona *et al*., 2006; Sarkar *et al*., 2009). Knaust (2007) regarded *A. fossulata* as a gastropod burrow (fodinichnion).

This ichnogenus was reviewed by Buckman (1994), who argued that these trails are typical of gastropods living in intertidal regimes. Yochelson and Fedonkin (1997) redefined the ichnogenus, designated a lectotype, and concluded that the trace fossils did not result from the activity of gastropods. It is a common element of the *Cruziana* and *Mermia* ichnofacies (Buatois and Mángano, 2002; Melchor *et al*., 2012). It is known from the Ediacaran (Häntzschel, 1975; Buckman, 1994; Buatois and Mángano, 2002) to the Recent (Netto *et al*., 2012).

Ichnogenus *Beaconites* Vialov, 1962
***Beaconites cf. capronus* (Howard and Frey, 1984)**
Fig. 5H

Material: Three specimens (sample Pi5c).
Description: Horizontal, straight and cylindrical burrow with meniscate backfill and thin, up to 1 mm distinct lining. It is 13–15 mm wide and 50–93 mm long. Branching has not been observed. There is no contrast between burrow fill and host sediment. Meniscate backfill is homogeneous and merges laterally with the burrow lining, which is slightly darker than the host rocks. The menisci are thin and strongly curved.
Remarks: The specimens from Piaskowa Góra are very similar to *Beaconites capronus* (Howard and Frey, 1984), described from the Carboniferous of Northeast England by Boyd and McIlroy (2017: figs 2–8), but they are wider and they have not the distinctive chevron-shaped meniscate backfill. They differ from other ichnospecies of *Beaconites* by lack of heterogeneous backfill. However, the small number of specimens and their state of preservation do not permit the determination of ichnospecies in greater detail. The ichnospecies *B. capronus* was originally described as *Ancorichnus capronus* by Howard and Frey (1984).

Meniscate burrows (ichnogenera *Ancorichnus* Heinberg, 1974; *Beaconites* Vialov, 1962; *Taenidium* Heer, 1877) were classified on the basis of the presence and type of a wall, and differences in the type of meniscate backfilling (see Keighley and Pickerill, 1994; Boyd and McIlroy, 2017). There is still no consensus regarding the distinction between *Ancorichnus* and *Beaconites* for a long time (see Draganits *et al*., 2001). The ichnogeneric diagnosis of meniscate burrows was emended by Keighley and Pickerill (1994). According to these authors, *Beaconites* has "distinct, smooth and unornamented burrow linings", while meniscate traces with an outer mantle belong to *Ancorichnus*, and *Taenidium* is an unwalled ichnotaxon. Unwalled *Beaconites barretti* was included by these authors in *Taenidium* Heer, 1877 as *T. barretti.* Ichnotaxonomic problems concerning meniscate filled burrows were also presented by e.g. Bradshaw (1981), Frey *et al*. (1984), D'Alessandro and Bromley (1987) and Bromley *et al*. (1999).

Beaconites is reported from the Cambrian to Recent (Knaust, 2004). *Beaconites capronus* often occurs in the Carboniferous of USA and England in intertidal to outer-shelf settings (Keighley and Pickerill, 1994; Boyd and McIlroy, 2017). It has also been described from the Tithonian-Miocene flysch deposits of the Polish Carpathians (Uchman, 1998).

According to Knaust (2004), this ichnospecies represents a fodinichnion of a worm-like deposit feeder. However, *Beaconites* is a combination of locomotion and feeding trace and could be regarded as a pascichnion. It is a common element of the *Cruziana* and *Skolithos* ichnofacies (Knaust, 2004), but also occurs as a typical component of the *Scoyenia* ichnofacies in non-marine settings (Buatois and Mángano, 2011a; Melchor *et al*., 2012).

Ichnogenus *Curvolithus* Fritsch, 1908
***Curvolithus multiplex* Fritsch, 1908**
Fig. 4B

Material: Four specimens (samples Pi5c, Pi6a).
Description: Straight to curved, horizontal, flattened and unbranched endostratal structure with three rounded lobes on upper surface and four lobes on the convex lower surface. The central lobe on the upper surface is smooth and wider than the outer lobes, which are separated by shallow furrows. The described specimens are 4–6 mm wide and visible at the distance of 24–43 mm.

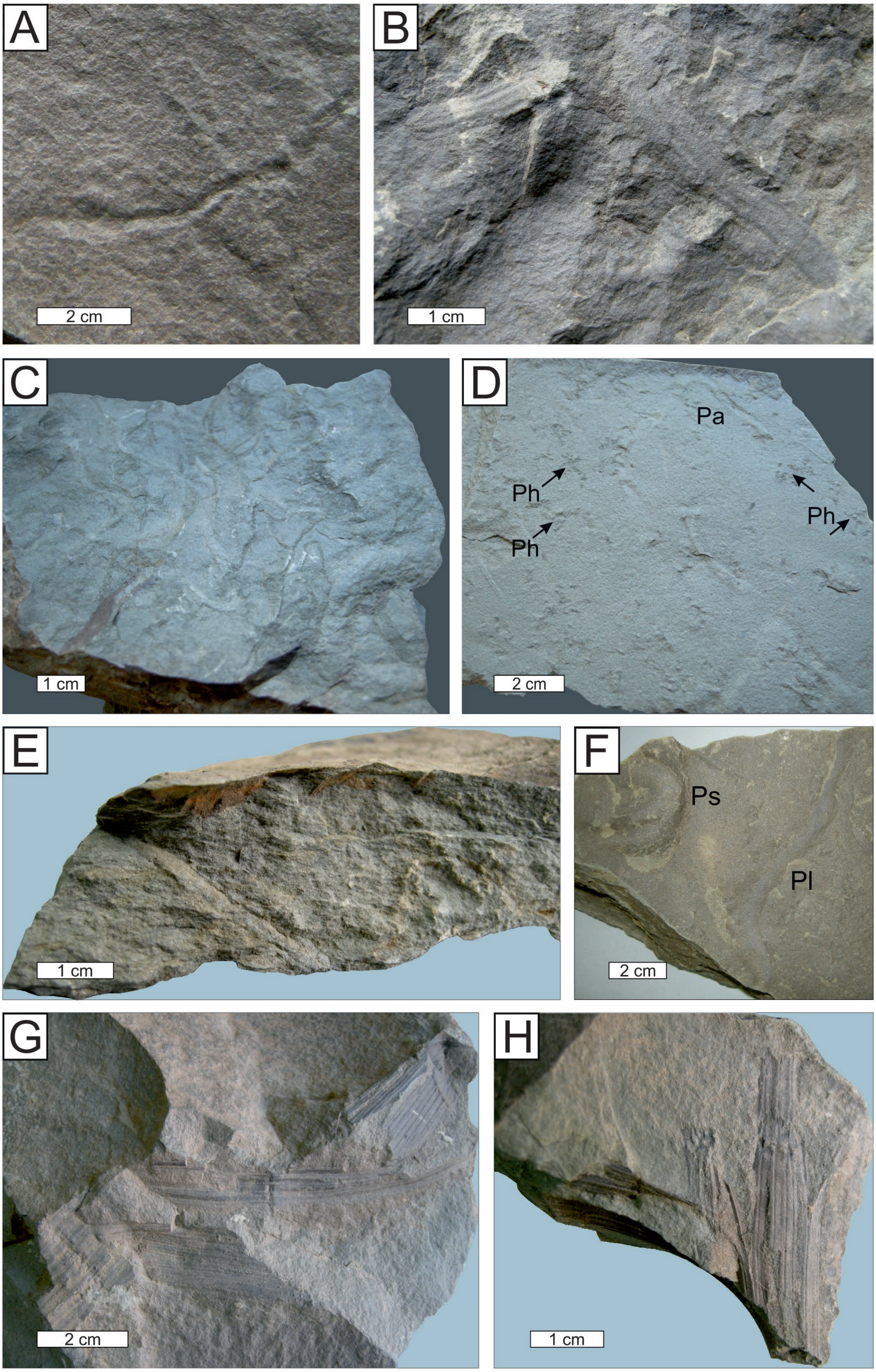

Fig. 4. Trace fossils and floral fossils from the Piaskowa Góra section. **A.** *Archaeonassa fossulata* Fenton and Fenton, 1937; Cat. No. Pi5/4. **B.** *Curvolithus multiplex* Fritsch, 1908; Cat. No. Pi5c. **C.** *Dictyodora liebeana* (Geinitz, 1867); Cat. No. Pi5-z8. **D.** *Phycosiphon* isp. (Ph, black arrows) and *Palaeophycus* isp. (Pa); Cat. No. Pi5-z12. **E.** *Palaeophycus* isp.; Cat. No. Pi5c. **F.** *Planolites* isp. (Pl) and *Psammichnites plummeri* (Fenton and Fenton, 1937) (Ps); Cat. No. Pi5-z6. **G–H.** *Archaeocalamites* sp.; Cat. No. Pi5a.

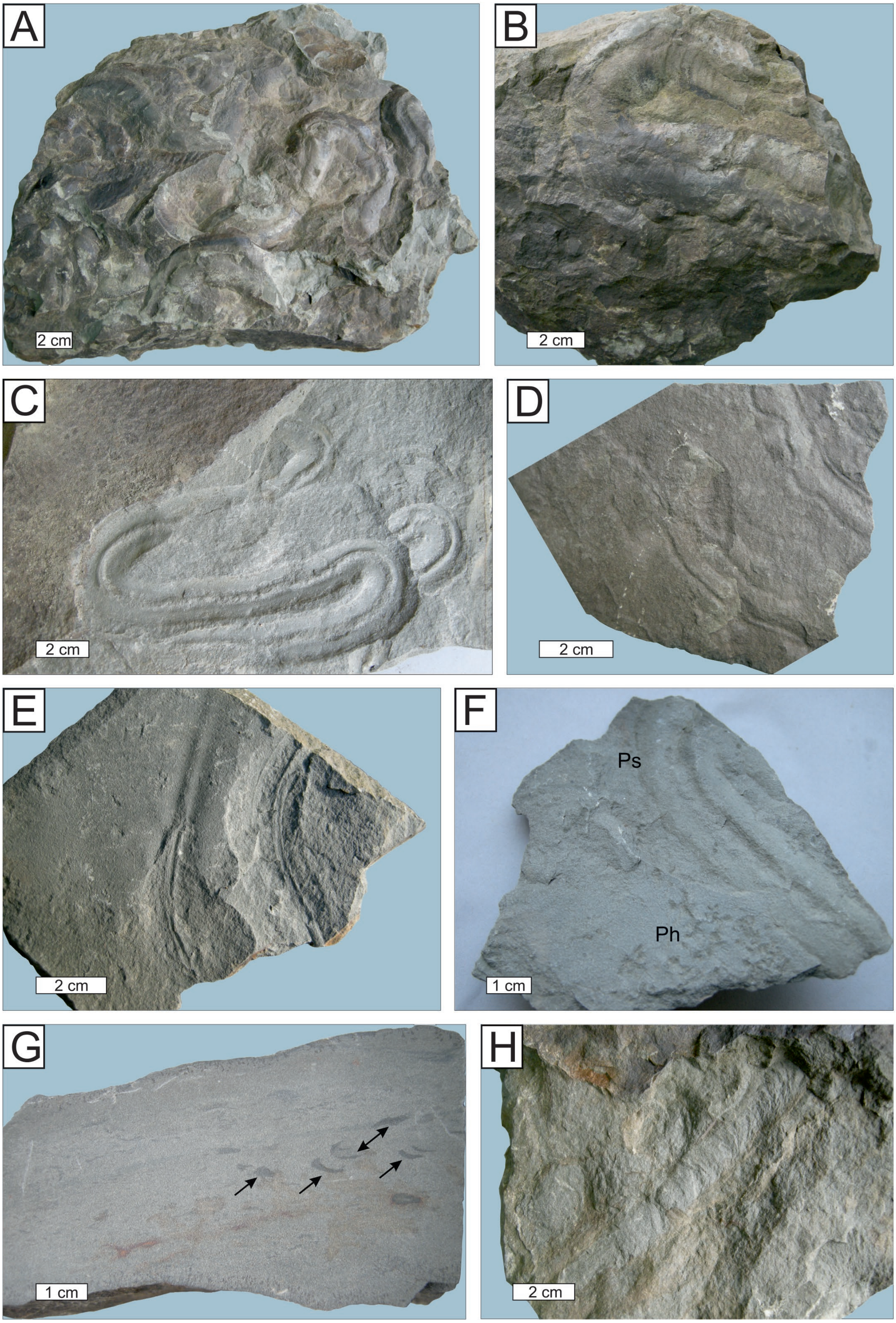

Fig. 5. Trace fossils from the Piaskowa Gora section. **A–D.** *Psammichnites plummeri* (Fenton and Fenton, 1937), positive hyporelief. A. Cat. No. Pi6/4; B. Cat. No. Pi6/3; C. Cat. No. Pi5-K/1; D. Cat. No. Pi5-3. **E.** *Psammichnites plummeri* (Fenton and Fenton, 1937), negative epirelief with axial tube; Cat. No. Pi5-5. **F.** *Psammichnites plummeri* (Fenton and Fenton, 1937) (Ps) and *Phycosiphon* isp. (Ph); Cat. No. Pi5-z4. **G.** *Phycosiphon* isp. on polished surface of vertical cross-section (black arrows); Cat. No. Pi5c. **H.** *Beaconites* cf. *capronus* (Howard and Frey, 1984); Cat. No. Pi5c.

Remarks: *Curvolithus* was revised by Buatois *et al*. (1998). It is commonly interpreted as a locomotion trace (repichnion) of endostratal invertebrate carnivores (Buatois *et al*., 1998 and references therein). The potential tracemakers are gastropods, wormlike polychaetes, oligochaetes, nemerteans or holothurians. Lockey *et al*. (1987) suggested that the animal has a flattened cross-section.

Curvolithus is a common element of the *Cruziana* ichnofacies *sensu* Seilacher (1967). Lockey *et al*. (1987) defined the *Curvolithus* ichnofacies, which is actually considered as a subset of the *Cruziana* ichnofacies (Bromley, 1996; McIlroy, 2008). This ichnogenus is commonly associated with shallow-marine deposits, either of normal or slightly brackish salinity (Buatois *et al*., 1998). It also occurs in fully marine, fan-deltaic to offshore settings (Webby, 1970; Fürsich and Heinberg, 1983; Heinberg and Birkelund, 1984; Maples and Suttner, 1990).

The stratigraphical range of *Curvolithus* is from Precambrian to Miocene (Buatois *et al*., 1998; Krobicki and Uchman, 2003; Hofmann *et al*., 2011), and this ichnogenus commonly occurs in the Carboniferous and Jurassic deposits (Eagar *et al*., 1985).

Ichnogenus *Dictyodora* Weiss, 1884
***Dictyodora liebeana* (Geinitz, 1867)**
Fig. 4C

- * 1867 *Dictyophyton? Liebeanum* – Geinitz, pp. 286–288, Taf. 3, fig. 3
- 1870 *Nemertites sudeticus* – Roemer, p. 33, pl. 6 (7).
- 1967 *Dictyodora liebeana* (Weiss) – Ruchholtz, pp. 514–516, figs 13–15, pl. 4.
- 1982 *Dictyodora liebeana* – Benton, pp. 123–126, figs 7, 8.
- 1996 *Dictyodora liebeana* – Orr *et al*., pp. 246–248, fig 7A–F.
- 2004 *Dictyodora liebeana* – Mikuláš *et al*., p. 84, pl. 2, fig. 4; pl. 3, figs 1, 2, 4; pl. 4, figs 1–4; pl. 6, fig. 2
- 2006 *Dictyodora liebeana* – Baucon and Neto de Carvalho, p. 98–100, fig. 10.

Material: Several fragments of specimens (samples Pi5c, Pi5d, Pi7a, Pi5-z8, Pi5-z20).
Description: Meandering, three-dimensional spreite burrow, which is steeply inclined to vertical with respect to the bedding. The described specimens are visible in horizontal cross-sections on bedding surfaces as irregular meandering and undulated spreite “bands”, which are up to 1 mm wide. The meanders are mainly asymmetrical and often intersect. Complex meanders (third-order at the most) also occur. The meanders are 0.2–10 mm apart.
Remarks: The specimens described are preserved only as fragments of much larger structures, but they display features characteristic of *Dictyodora liebeana*. This ichnospecies represents a complex feeding-trace of worm-like endobionta (Benton, 1982). According to Uchman and Wetzel (2012), *Dictyodora* is a deep-tier pascichnion reported only from the Palaeozoic deep-sea sediments, while Buatois and Mángano (2011) regarded this ichnogenus as fodinichnion. The producer of this trace fossil is still unknown, although a worm or a mollusc without a shell has been suggested (Benton and Trewin, 1980). According to Seilacher (2007), the tracemaker explored deep tiers while being connected to the surface by a long snorkel-like tube.

According to Uchman (2004), the ichnogenus *Dictyodora* ranges from the Ordovician to the Carboniferous, although its ichnospecies display narrower ranges. *D. liebeana* has the chronostratigraphic value and is considered as good trace fossil indicator of the Lower Carboniferous (Uchman, 2004, 2007; Buatois and Mángano, 2011a). *D. liebeana* occurs mostly in deep-sea deposits of Europe, rich in clay, especially in the Culm facies (e.g., Benton, 1982; Stepanek and Geyer, 1989; Pek and Zapletal, 1990; Orr *et al*., 1996; Uchman, 2004: table 1; Mikuláš *et al*., 2004; Baucon and Neto de Carvalho, 2008). However, this ichnogenus has been described also from Silurian prodeltaic deposits in Argentina (see Pazos *et al*., 2015a). This ichnogenus is regarded as typical of the deep-sea *Nereites* ichnofacies (Seilacher, 1967, 1974; Buatois and Mángano, 2011).

Ichnogenus *Palaeophycus* Hall, 1847
***Palaeophycus* isp.**
Fig. 4D, E

Material: A dozen specimens (samples Pi5c, Pi5-z16, Pi6a).
Description: Simple or branched, cylindrical, straight to curved or undulating, predominantly horizontal to inclined endichnial burrows. They are 2–3 mm wide and up to 28 mm long. Wall is smooth, non-ornamented. Filling is similar to the host rock.
Remarks: *Palaeophycus* is interpreted as a dwelling burrow (domichnion) produced by deposit-feeders or predators, mostly by polychaetes, usually moving parallel to the sediment surface (e.g., Pemberton and Frey, 1982; Uchman, 1995). This ichnogenus is considered as either a freshwater or marine eurybathic trace fossil, described from the Precambrian to Recent (Pemberton and Frey, 1982).

Ichnogenus *Phycosiphon* Fischer-Ooster, 1858
***Phycosiphon* isp.**
Figs 4D, 5F–G

Material: Several dozen fragments of specimens on the bedding plane and polished sections (samples Pi5c, Pi5-z1, Pi5-z4, Pi5-z12, Pi5-z16).
Description: Mainly horizontal or oblique, small U-shaped or hook-like structures forming lobes, which are conjoined and irregularly meandering. Individual lobes are 1–2 mm in diameter and up to 1 cm long. In polished sections, *Phycosiphon* resembles clusters of closely spaced elliptical spots, comma-shaped dots or hooks (0.5 mm thick) filled with darker sediments. For the studied specimens a narrow pale mantle was not observed.
Remarks: In the specimens studied, spreite structures were not observed, but it is not considered as essential characteristic of this ichnogenus (Ineson, 1987). The specimens are very similar to specimens of *Phycosiphon* from the Jurassic of the United Kingdom (Bednarz and McIlroy, 2012: fig. 2D),

specimens of *Phycosiphon incertum* from the Palaeocene of Japan (Naruse and Nifuku, 2008: fig. 1) and large specimens of *P. incertum* from the Eocene of Spitsbergen (Rodríguez-Tovar et al., 2014: fig. 3A). They have similar dimensions and oval to comma-shaped or U-shaped vertical cross-sections. They differ in shape, dimensions and character of the halo in the *Nereites* ichnofabric (see Bednarz and McIlroy, 2012: fig. 2G).

Phycosiphon has been previously differently described (for lists of synonyms see Fu, 1991; Goldring *et al*., 1991; Wetzel and Bromley, 1994). The *Phycosiphon*-producer generally colonized sediments enriched in organic matter (Wetzel, 2010). The tracemaker was an opportunistic highly selective deposit feeder (fodinichnion), but it remains unrecognized (Wetzel and Bromley, 1994; Wetzel and Uchman, 2001; Wetzel, 2008, 2010). According to Bednarz and McIlroy (2009), producers of phycosiphoniform burrows were small, probably vermiform organisms. This ichnogenus was reported from the Palaeozoic to Holocene strata deposited in various marine environments from continental shelves to submarine fans (Seilacher, 1978; Fu, 1991; Goldring *et al*., 1991; Savrda *et al*., 2001; Naruse and Nifuku, 2008), but it is the most typical of the deep-sea *Nereites* ichnofacies (Ineson, 1987) and of the *Zoophycos* ichnofacies (Frey and Pemberton, 1984; Buatois and Mángano, 2011a).

Ichnogenus *Planolites* Nicholson, 1873
***Planolites* isp.**
Fig. 4F

Material: Four specimens (samples Pi5-z6, Pi5c).
Description: Horizontal or irregularly sinuous, unlined, smooth cylindrical burrow, which is unbranched and filled with material different than the host rock. It is elliptical in cross-section and 6–11 mm in diameter. The length of the preserved trace reaches 10 cm. The filling is structureless, finer grained and darker than the host rocks.
Remarks: *Planolites* is usually interpreted as a pascichnion structure of deposit feeders, which actively backfilled the burrows (Pemberton and Frey, 1982; Keighley and Pickerill, 1995; Bromley, 1996; Rodríguez-Tovar and Uchman, 2004; Pervesler *et al*., 2011). It may be produced by "worms", arthropods, molluscs, insects (Gradziński and Uchman, 1994; Keighley and Pickerill, 1995; Bromley, 1996; Uchman, 1998; Buatois and Mángano, 2002) or infaunal holothuroids (Chen *et al*., 2011). *Planolites* is an eurybathic trace found in various marine and continental environments (Rodríguez-Tovar and Uchman, 2004; Sarkar *et al*., 2009; Leszczyński, 2010; Hofmann *et al*., 2011; Phillips *et al*., 2011; Buatois and Mángano, 2011a). It has been reported from the latest Neoproterozoic to Recent (e.g., Pemberton and Frey, 1982; Rodríguez-Tovar and Uchman, 2004).

Ichnogenus *Psammichnites* Torell, 1870
***Psammichnites plummeri* (Fenton and Fenton, 1937b)**
Figs 4F, 5A–F, 6, 7G–H

Material: Several dozen of specimens and fragments (samples Pi5-1–Pi5-5; Pi5-K/1–Pi5-K/8; Pi5-z1–Pi5-z18; Pi5b, Pi5c; Pi6a; Pi6/1–Pi6/4; Pi7a), several specimens observed in the field, three polished cross-sections. Additionally, several samples were collected from debris.

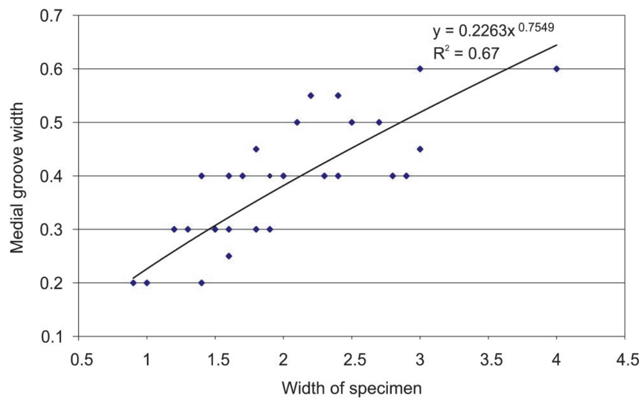

Fig. 6. Graph of the medial groove width to the width of the specimens of *Psammichnites plummeri*, dimensions (in cm) and the trend curve.

Description: Predominantly horizontal, strongly sinuous to meandering ribbon-shaped trace fossil preserved as positive hyporelief, characterized by a narrow median groove, and two convex lobes with fine crenulated transverse ridges. A negative epirelief is represented by a narrow medial ridge and two wide grooves. This trace fossil is unbranched, but crossovers or interpenetrations are found. It is 9–40 mm, mostly 13–27 mm wide (Fig. 6). The transverse ridges are 4–17 mm wide. The median groove or ridge is 2–6 mm wide, commonly straight and occasionally sinuous (Fig. 5C, D). The trace fossil shows a significant correlation between the width of specimen and the medial groove width and the coefficient of determination is equal to $R^2 = 0.67$ (Fig. 6). Maximum observed length of the ichnospecies is approximately 26 cm, but the specimens studied are often incomplete because of the fragile host rock.

The trace fill is similar to the host rock and meniscate internal structures are preserved only in some specimens (Figs 5A, B, 7G–H). Locally, a well-developed marginal levee is present (Fig. 5C, D). Some specimens are partially preserved (ridges locally broken) and traces exhibit a clear axial tube, 2 mm in diameter (Fig. 5E).
Remarks: The described trace fossil is locally abundant. According to Gaillard and Racheboeuf (2006), the axial tube could be a fecal string.

Following a recent systematic reevaluation, *Olivellites* Fenton and Fenton, 1937b and *Aulichnites* Fenton and Fenton, 1937c may be considered as the synonyms of the ichnogenus *Psammichnites* (Mángano *et al*., 2002; see also D'Alessandro and Bromley, 1987). *Psammichnites* is commonly referred to the feeding activity of a large soft-bodied marine animal, probably a mollusc, moving through the sediment and being connected to the sediment surface by a snorkel device (Seilacher, 1997; Seilacher-Drexler and Seilacher, 1999; Aceñolaza and Aceñolaza, 2006; Gámez Vintaned *et al*., 2006; Baucon and Neto de Carvalho, 2008). *Psammichnites plummeri* is regarded as a grazing trace

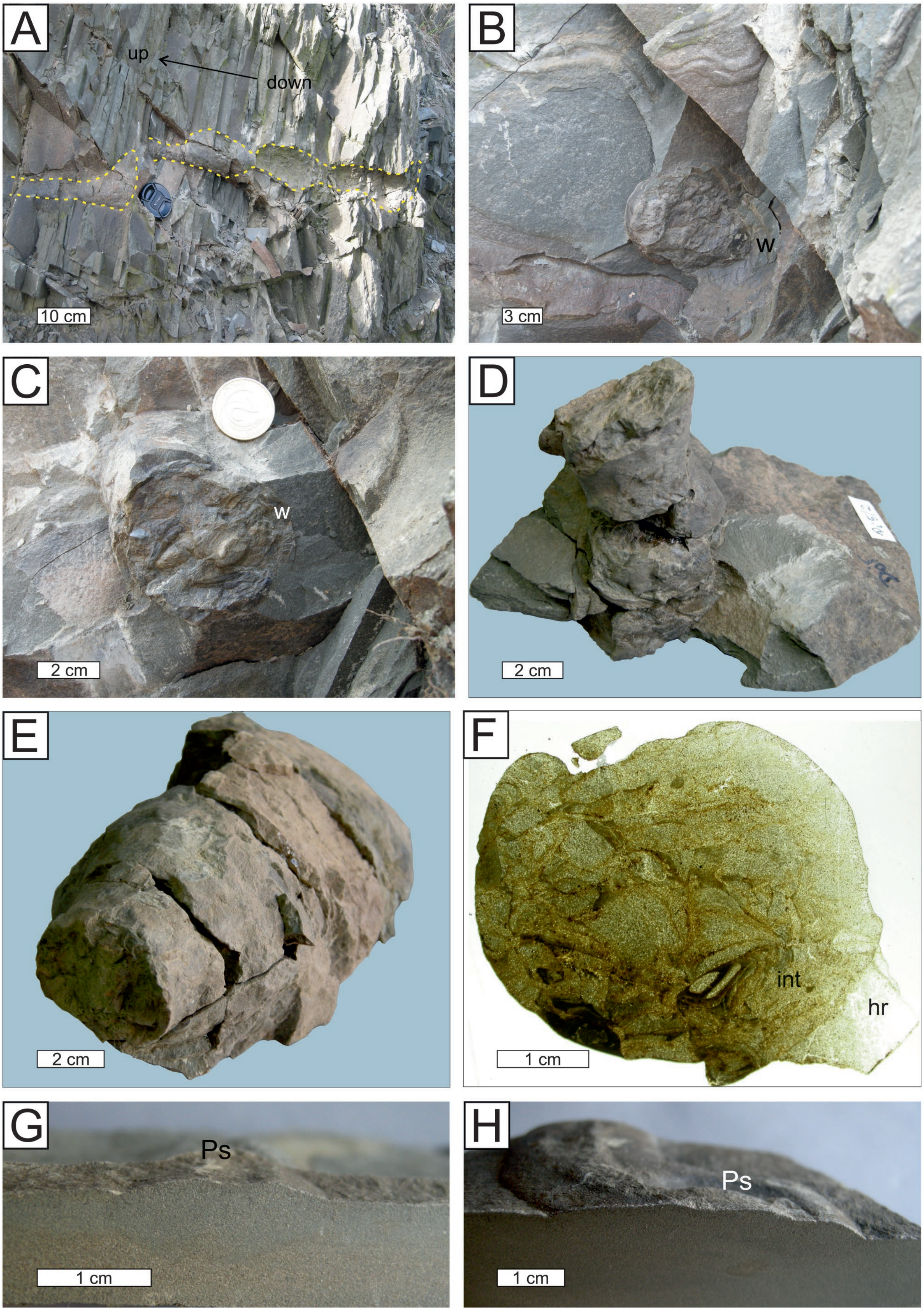

Fig. 7. Tubular forms from the Piaskowa Góra section. **A.** Photograph in the field before extraction of moulds. Yellow lines show a contour of tubular forms (right – specimen 1; left – specimen 2). **B.** Tubular form observed in the field and associated trace fossils *Psammichnites* isp.; w – wall. **C.** Cross-sections of the tubular form observed in the field with characteristic bioturbated structure of the fill and double layered wall (w) in the enlargement. **D.** Fragment of mould – constriction; Cat. No. Pi5/2-3. **E.** Fragment of mould – enlargement; Cat. No. Pi5/1a-b. **F.** A thin section of contraction; Cat. No. Pi/2-3/sz1; hr – hosted rock, int – internal part of the tubular form. **G–H.** Polished cross-sections of *Psammichnites plummeri*. G. Cat. No. Pi5-z5. H. Cat. No. Pi5-z3.

(pascichnion) of an arthropod deposit feeders (Mángano *et al*., 2002; Buatois and Mángano, 2011).

The stratigraphic range of the ichnogenus is from the lower Cambrian to probably Permian (see Mángano *et al*., 2002). *Psammichnites* is often reported from marginal-marine environments (Mángano *et al*., 2002), while Carboniferous *Psammichnites* is listed as a common element of lower estuarine settings (Mángano *et al*., 2005; Buatois and Mángano, 2007). This ichnotaxon is present in siliciclastic shallow-marine deposits, typically in intertidal and shallow subtidal settings (e.g., Mángano *et al*., 2002; Buatois and Mángano, 2011a, Desjardins *et al*., 2012). It also occurs in muddy substrates in offshore settings and thick turbidite series (see Álvaro and Vizcaïno, 1999). Seilacher-Drexler and Seilacher (1999) considered that both kinds of medial grooves (straight or sinuous) seem to represent an ethological response due to a change in the grazing strategy.

Psammichnites plummeri is described from the Carboniferous (Mississippian–Pennsylvanian) of the United States, Europe and Australia (Maples and Suttner, 1990; Mángano *et al*., 2002) and from the Pennsylvanian of Argentina (Alonso-Muruaga *et al*., 2013).

OTHER STRUCTURES

Tubular forms

Fig. 7 A–E

Material: Two specimens (17 fragments of external moulds; samples Pi5/1–Pi5/12), negative impression of a tunnel studied in the field, fifteen polished cross-sections and three thin sections (samples Pi5/2-3/z1–Pi5/2-3/z5; Pi5/2-3sz1; Pi5/2-3/z4; Pi5/2-3/z5).

Description: Large, unbranched and nearly vertical to slightly oblique tube-like forms resembling burrows. They consist of alternating and irregular constrictions and enlargements (Fig. 7A), which are sharply demarcated from the host rocks (Fig. 7A–D). The enlargements (swollen chambers) are elongated and asymmetric, 13.5–15 cm long (Fig. 7C). The constrictions are up to 13 cm long (Fig. 7D). It was very difficult to estimate the total length of the trace fossil, because of its incompleteness. The wall (or double wall) is present only in enlargements and is composed of the same material as the host rock (Fig. 7B). Macroscopic observations, polished sections and a thin section (Fig. 7E) of the tubular forms have shown fill of a characteristic bioturbated structure.

Remarks: The mudstones surrounding this form, except for planar bedding and lamination, show no other sedimentary and deformation structures. Inside of these tubular forms there is no conduits, central hole or cementation zones or any traces of cementation supporting cold seep origin or root origin. Because of the complicated nature of the enigmatic tubular forms, the detailed description and the ichnological and petrological study of these forms will be presented in a separated paper.

Wrinkle structures

Fig. 8A–B

Material: Three examples (samples Pi2/1, Pi2?2, Pi5/z9).

Description: These are wrinkled or pitted impressions preserved on bedding planes. They form thin surfaces, which consist of slightly bent ridges and troughs up to 50 mm long and up to 2 mm wide. They cover several tens of square centimetres of a bedding surface.

Remarks: These structures (MISS – microbially induced sedimentary structures) are interpreted as matgrounds, which involved substrate modification by microbial activity (Marriott *et al*., 2013; Pazos *et al*., 2015b; Vodrážková *et al*., 2019). According to Noffke *et al*. (2001) microbial mats dominated by cyanobacteria depend on photosynthesis and are bathymetrically controlled. The MISS occur at the turning points of regression-transgression (Noffke *et al*., 2006). Wrinkle structures are known from the Archean onwards and they are very common in shallow-marine to marginal-marine environments (Noffke *et al*., 2001, 2006; Porada *et al*., 2008; Buatois *et al*., 2014).

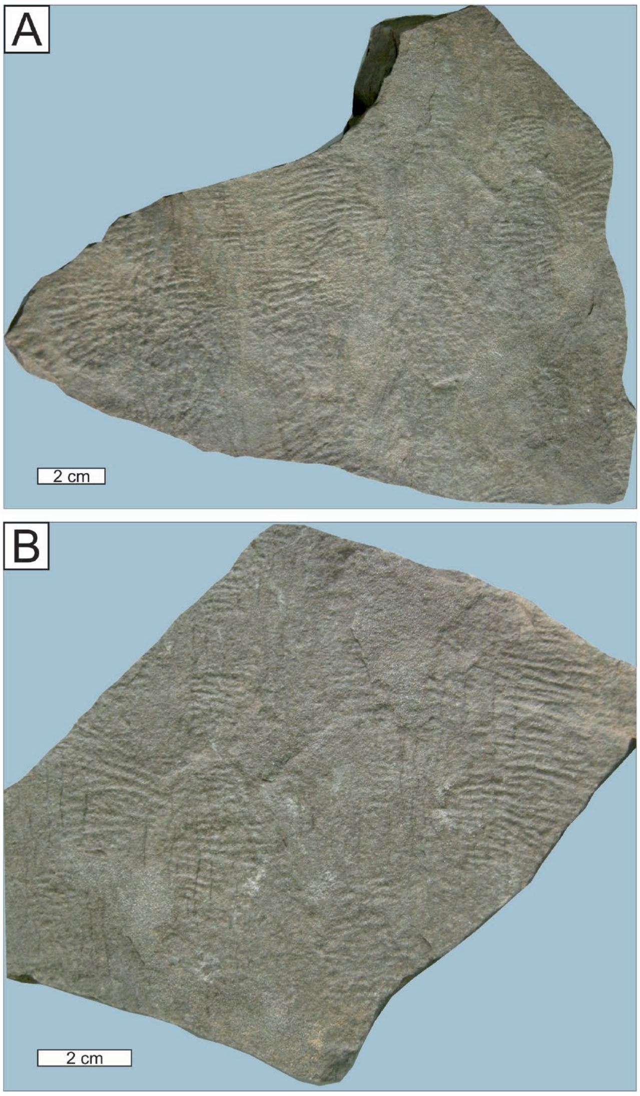

Fig. 8. Wrinkle structures from the Piaskowa Góra section. **A.** Cat. No. Pi2/1. **B.** Cat. No. Pi2/2.

TRACE FOSSIL ASSEMBLAGE AND ENVIRONMENTAL INTERPRETATION

The ichnoassemblage described occurs only in the greenish-grey mudstones with rare beds of thin, fine-grained sandstones (Figs 3B, 9), which form the Culm facies. It is moderately diverse (eight ichnotaxa) and ranges from eight or seven ichnotaxa in the middle part of the mudstones to two ichnotaxa in the upper part of the mudstones. The greatest diversity of ichnotaxa coincides with the occurrence of "tubular forms", which are rare. The abundance of individual ichnotaxa varies. *Psammichnites plummeri* is the most common and it has the longest, local, vertical range. It appears with calamite debris in the middle part of the greenish-grey mudstones and sandstones and vanishes just below a limestone lense (Figs 3B, 9). *Psammichnites plummeri* is accompanied by abundant *Phycosiphon* isp., less numerous *Dictyodora liebeana* and *Palaeophycus* isp. and rare *Archaeonassa fossulata* (Fig. 9). The vertical range of *Dictyodora liebeana* is similar to that of *Psammichnites* range. Other ichnotaxa, such as *Beaconites* cf. *capronus*, *Curvolithus multiplex,* and *Planolites* isp*.,* are rare and they occur locally (Fig. 9).

Ethologically, the ichnoassemblage is diversified and represented by most common pascichnia (*Archaeonassa*, *Dictyodora*, *Planolites*, *Psammichnites, Beaconites*), and less numerous fodinichnia (*Phycosiphon*), domichnia (*Palaeophycus*, tubular forms?) and repichnia (*Curvolithus*). According to Rindsberg (2012), "preservation potential [of pascichnia] is low and depends on rapid burial without

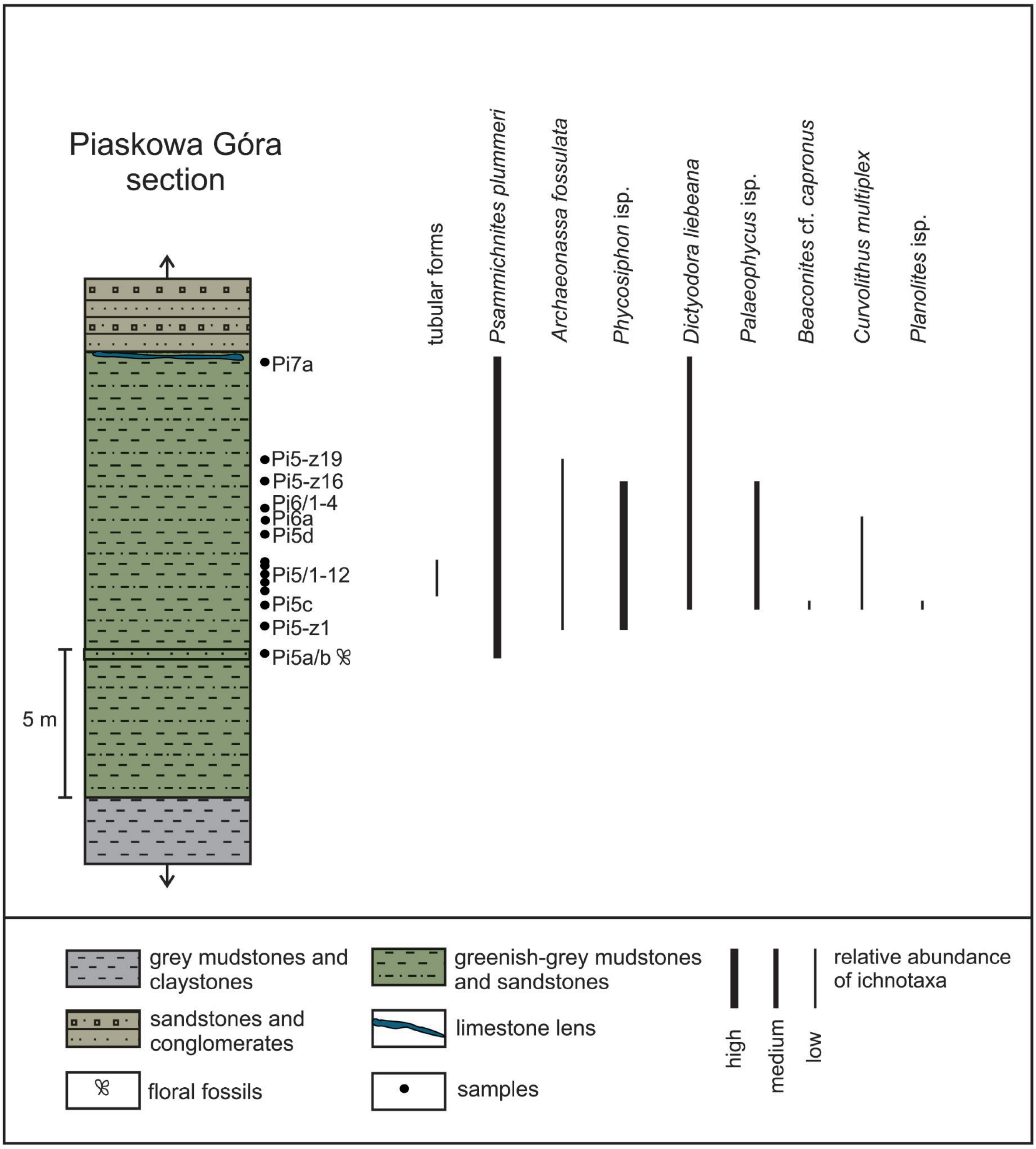

Fig. 9. Schematic lithology and distribution of ichnotaxa in the middle part of the Piaskowa Góra section.

much erosion". In marine settings, pascichnia are a dominant element of the *Nereites* ichnofacies; they are common in the *Cruziana* ichnofacies, but also subordinate in the *Zoophycos* ichnofacies (e.g., Buatois and Mángano, 2011). Among the post depositional trace fossils, *Dictyodora*, *Phycosiphon, Palaeophycus, Planolites*, and *Beaconites* are present (see Uchman and Wetzel, 2012).

The ichnoassemblage described has a mixed character, which could indicate a transition from the *Cruziana* to the deeper ichnofacies (*Zoophycos* or *Nereites*). The typical representatives of the *Cruziana* ichnofacies include *Archaeonassa fossulata*, *Curvolithus multiplex, Psammichnites plummeri* and *Beaconites* cf. *capronus* (e.g., Bromley, 1996; Buatois and Mángano, 2002, 2011a; McIlroy, 2008; Melchor *et al*., 2012), though the last three are also found in the offshore conditions (Webby, 1970; Heinberg and Birkelund, 1984; Maples and Suttner, 1990; Álvaro and Vizcaïno, 1999). *Phycosiphon* isp. and *Dictyodora liebeana* are the most characteristic of the deeper *Zoophycos* or the *Nereites* ichnofacies (e.g., Seilacher, 1974; Benton, 1982; Frey and Pemberton, 1984; Pek and Zapletal, 1990; Uchman, 2004; Buatois and Mángano, 2011), but are also known from the shallower settings (Savrda *et al*., 2001; Naruse and Nifuku, 2008; Pazos *et al*., 2015a). It is worth noting, that *Dictyodora* occurs without any graphoglyptids and *Nereites* in the section studied. Some ichnotaxa of the assemblage (*Palaeophycus* isp., *Planolites* isp.) are eurybathic (e.g., Pemberton and Frey, 1982; Hofmann *et al*., 2011).

An important component of the findings from the Piaskowa Góra section are also wrinkle structures, which are rare in the middle part of the section. The presence of these structures on the surfaces of layers is an evidence of microbial mats and might indicate shallower settings within the photic zone. According to Buatois and Mángano (2011b), microbial mats persisted into the late Palaeozoic in the innermost, freshwater region of estuarine systems, fluvio-lacustrine deposits, glacial lakes and fjords, while Buatois *et al*. (2013) presented matgrounds from the Carboniferous–Permian open-marine deposits of the western Argentina. The trace fossil association with *Dictyodora*, *Nereites*, *Zoophycos* and microbial mat structures and without graphoglyptids also was described by Pazos *et al.* (2015a, b) from the Silurian–Devonian prodelta deposits of Argentina.

The quantitative predominance of horizontal traces, which are elements of the *Cruziana* ichnofacies compared to less numerous components typical of the *Zoophycos* or the *Nereites* ichnofacies (containing 3D-spreite structures) and dominant behaviour (pascichnia), indicate an intermediate environment between the lower offshore (the distal *Cruziana* ichnofacies) and the fan-delta slope (below wave base, the *Zoophycos* ichnofacies; see Pemberton *et al*., 2012). Additionally, the presence of floral remains implies a not too distant continental area.

The interesting fan-delta deposits also are reported by Hovikoski *et al.* (2018) from the Lower Cretaceous in Greenland. The ichnological record in these strata is strongly mixed, containing elements of the impoverished *Skolithos*, *Cruziana*, *Zoophycos* and *Nereites* ichnofacies. Trace fossils are dominated by infaunal locomotion, feeding trails and crustacean burrows. This fan-delta system differs from traditional deep sea fans in many aspects (organization, architectural elements and ichnological properties; Hovikoski *et al*., 2018, tab. 4). One of the important ichnological differences is the absence of graphoglyptids in overbank, depositional lobe, and fan-fringe facies, but the presence of the proximal to distal *Cruziana* ichnofacies. As noted by the authors cited above, the occurrence of graphoglyptids usually is referred to stable uniform conditions, while unstable physico-chemical conditions on the sea floor were the limiting factors responsible for the absence of this group of trace fossils. Additionally, the other factor, which protected the area from colonization by some, typically deep-sea trace makers, is the isolation of the basin from the open ocean.

The nearest site with numerous *Dictyodora liebeana* and without graphoglyptids occurs in the Pogorzała Formation (Witoszów region) in the Świebodzice Unit, which was deposited in prodelta settings (Muszer, 2019). This ichnoassemblage contains also numerous *Palaeophycus* and rare *Archaeonassa, Chondrites, Curvolithus, Diplopodichnus, Lockeia, Lophoctenium,* and ?*Psammichnites*. Recent palynological investigations allow dating of these deposits to give a late Visean–Serpukhovian age (Pluta and Górecka-Nowak, 2018).

Singh *et al*. (2017) presented a different Visean-Serpukhovian trace fossil assemblage, but without *Dictyodora*, from the Po Formation (Himalayas), which indicates the upper shoreface to lower shoreface *Cruziana* ichnofacies of an open shelf. These storm beds are highly bioturbated, with numerous sedimentary structures and wrinkle structures. These deposits comprise *Asteriacites*, *Biformites*, *Helminthoidichnites*?, *Lingulichnus*, *Lockeia*, *Palaeophycus*, *Planolites*, *Protovirgularia*, *Psammichnites*, *Rusophycus,* and *Treptichnus*.

The other Mississippian ichnoassemblages with *Dictyodora liebeana* occur in Europe in the Culm facies (mainly in sandstones, siltstones, mudstones), which occharacterize sedimentary basins, bordering active margins of the Variscan orogeny (see Mikuláš *et al*., 2004 and references therein). A diverse ichnofauna from Menorca contains *D. liebeana, Chondrites, Lophoctenium*, *Nereites, Neonereites, Arthrophycus, Phycosiphon, Syncoprulus* and graphoglyptids are also absent (Orr *et al*., 1996). These sediments are interpreted mostly as deposits of an inner- to mid-fan palaeoenvironment. Similar ichnoassemblages were described from Thuringia by Benton (1982) and from Frankenwaldes (Stepanek and Geyer, 1989). They represent the *Nereites* ichnofacies, which contains, among others, *Dictyodora*, *Chondrites*, *Lophoctenium*, *Protovirgularia* and *Nereites*, but also *Phycosiphon* and the graphoglyptids, such as *Paleodictyon* or *Megagrapton*. Another similar *Dictyodora-Nereites* ichnoassemblage occurs in the Pramollo area in Carnic Alps (Baucon and Neto de Carvalho, 2008) and it is referred to deep marine settings associated to delta-front, organic rich-muds. It includes *Dictyodora, Nereites* and *Protopalaeodictyon* as an accessory component. Additionally, these fine sediments also are characterized by the presence of floral remains. In the Pramollo area, nine recurrent ichnoassemblages also occur and *Psammichnites*-*Skolithos*-*Cylindrichnus* (lower estuarine deposits) among them. Two ichnoassemblages with *Dictyodora liebeana* are also known from Moravia and Silesia (Zapletal and Pek, 1987; Mikuláš *et al*., 2002, 2004). In the first one, this ichnospecies is accompanied by *Chondrites*, *Phycosiphon*, *Planolites*, *Spirodesmos*, *Falcichnites*, *Pilichnus*, *Protopaleodictyon* and *Zoophycos*. The second ichnoassemblage besides *Dictyodora* contains *Diplocraterion*, *Rhizocorallium*, *Cosmorhaphe* and *Paleodictyon*.

The Carboniferous storm deposits from the Upper Silesia (Poland) described by Głuszek (1998) are stratigraphically equal (Pendleian = Namurian A), but represent the different paralic facies. In this region, 17 ichnogenera were found, e.g. *Phycosiphon*, *Chondrites*, *Zoophycos*, *Nereites*, but *Dictyodora* was absent. These deposits represent zone between upper offshore to lower shoreface.

Other examples of the Carboniferous deltaic deposits of the paralic facies from the Central Pennine Basin in England were presented by Eagar *et al*. (1985), who distinguished three types of sequences (turbidite deltas, shallow-water sheet deltas, swamp deltas). Among the Pendleian (lowest Namurian) deposits, they described three types of depth-related sedimentary associations corresponding with trace-fossil assemblages: the turbidite, the delta slope, and the delta top association. The slope association (laminated sandstones and siltstones) is dominated by *Lophoctenium*, *Curvolithus*, and *Cochlichnus* (Eagar *et al*., 1985, p. 105, fig. 4). These authors interpreted the assemblage as occurring on a prograding delta slope with reduced salinity and belonging to the *Zoophycos* ichnofacies. In the upper Namurian (upper Kinderscoutian and Marsdenian) deposits, they described (Eagar *et al*., 1985, fig. 5) among others the "*Scolicia*"-*Olivellites* (= *Psammichnites*) assemblages of the *Cruziana* ichnofacies, which represents a delta-top environment.

The ichnoassemblage from the Piaskowa Góra section shows some similarities and differences to the others Mississippian ichnoassemblages from the European Culm facies. *Dictyodora liebeana* is present in all these sections and *Phycosiphon* occurs in almost all sites. In most of them graphoglyptids are present or occur as an accessory component. The exception is the ichnoassemblage from Menorca (Orr *et al*., 1996), in which graphoglyptids are absent. It represents an inner to mid-fan environment, and is the most similar to the ichnoassemblage described, because of the presence of *D. liebeana*, *Phycosiphon* and the absence of graphoglyptids. However, that ichnoassemblage contains *Nereites* and others ichnogenera (*Chondrites*, *Lophoctenium*, *Arthrophycus, Syncoprulus*). The differences in the composition of the Piaskowa Góra ichnoassemblage compared to others from the Culm facies could be the result of relatively fast shallowing the environment in the final, early Serpukhovian stage of the Mississippian sea regression in the Intra-Sudetic Basin.

The lithological features of the Piaskowa Góra section (dominated by greenish-grey mudstones, rarely interbedded with by thin, fine-grained sandstones) and well-developed parallel lamination are characteristic of the low-energy lower-offshore settings (see Pemberton *et al*., 2012) and deeper settings (slopes and deep-sea fans; see Hubbard *et al*., 2012; Uchman and Wetzel, 2012). According to Mastalerz (1995), turbidity currents played an important role in sedimentation on the delta front of sediments of the Szczawno Formation.

In summary, the middle part of the Piaskowa Góra succession is characterized by a high rate of sedimentation of fine-grained deposits, which did not allow the settlement of a typical sessile benthos. The fauna has left only trace fossils. The delivery of sediments was periodically interrupted, and then mobile benthos and infauna could develop. Most of the fauna was probably an opportunistic. The environment was oxygenated, photic and of low hydrodynamic energy. Sediments were locally rich in organic matter, and that allowed to the appearance of deposit feeders and their development.

CONCLUSIONS

Eight, ethologically diverse ichnotaxa, dominated by pascichnia, and including also fodinichnia, domichnia and repichnia, have been documented for the first time in the Mississippian (the lower Serpukhovian) succession from the Piaskowa Góra section. They were discovered in the middle part of the studied succession, in greenish-grey mudstones with thin fine-grained sandstones of marine origin, which represent the uppermost part of the Szczawno Formation. Enigmatic tubular forms and rare wrinkle structures also were discovered.

The ichnoassemblage is dominated by *Psammichnites plummeri*, accompanied by *Archaeonassa fossulata, Beaconites* cf. *capronus*, *Curvolithus multiplex, Dictyodora liebeana, Palaeophycus* isp*., Phycosiphon* isp. and *Planolites* isp. The ichnoassemblage described contains either typical representatives of the *Cruziana* ichnofacies or less numerous elements of the *Zoophycos* or the *Nereites* ichnofacies. The mixed character of the components, the quantitative predominance of elements of the *Cruziana* ichnofacies, and the absence of graphoglyptids and others representatives of the *Nereites* ichnofacies indicate an intermediate environment between lower offshore (the distal *Cruziana* ichnofacies) and fan-delta slope (the *Zoophycos* ichnofacies). The palaeoenvironment was relatively oxygenated, but of low-energy and quiet waters within the photic zone. Frequent and periodically occurring delivery of fine-grained sediments, did not allow colonization by a typical sessile benthos, but only by infauna and mobile benthos.

The ichnoassemblage described shows some similarities (the presence of *Dictyodora liebeana* and *Phycosiphon*) and differences (the lack of *Nereites* and graphoglyptids), when compared to the others Mississippian ichnoassemblages from the European Culm facies. This could be the result of relatively fast shallowing of the environment in the final, early Serpukhovian stage of marine regression in the Mississippian of the Intra-Sudetic Basin.

Dictyodora liebeana has a chronostratigraphic value and its stratigraphic range is regarded as restricted to the Lower Carboniferous (Uchman, 2004, 2007). *D. liebeana* was observed previously in the upper Visean Szczawno Formation (Żakowa, 1958; Muszer, 2013), but now is described for the first time from the upper Mississippian (lower Serpukhovian).

Acknowledgements

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