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PALAEOENVIRONMENTAL INTERPRETATION OF THE LATE CRETACEOUS IDZIKÓW CONGLOMERATE MEMBER (SW POLAND, SUDETES, IDZIKÓW QUARRY) BASED ON ANALYSIS OF TRACE FOSSILS

Alina CHRZĄSTEK

Institute of Geological Sciences, Wrocław University; M. Borna 9, 50-204 Wrocław, Poland;
e-mail: alina.chrzastek@uwr.edu.pl

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Abstract: In the sandstones and conglomerates of the Idzików Conglomerate Member (Coniacian), exposed in the Idzików Quarry (SW Poland, Upper Nysa Kłodzka Graben), a moderately diverse assemblage of trace fossils has been recognized. The trace fossils include *Arenicolites* isp., *Asterosoma* isp., ?*Bergaueria* isp., *Cylindrichnus* isp., *Conichnus conicus*, *Curvolithus simplex*, *Dactyloidites ottoi*, *Diplocraterion parallelum*, ?*Diplocraterion* isp., *Gyrochorte* isp., *Gyrophyllites* aff. *kwassizensis*, *Macaronichnus segregatis*, *Ophiomorpha nodosa*, *Ophiomorpha* isp., ?*Palaeophycus* isp., ?*Rhizocorallium* isp., *Rosselia* isp., ?*Scolicia* isp., *Teichichnus* isp. and *Thalassinoides* isp. Escape traces (fugichnia) and some unidentified trace fossils also were found. The following ichnoassociations are distinguished: (IA1) *Ophiomorpha*-*Cylindrichnus*, (IA2) *Asterosoma*-*Conichnus* and (IA3) *Ophiomorpha*-*Arenicolites*. IA1 probably represents a mixture of the impoverished proximal *Cruziana* ichnofacies and the distal *Skolithos* ichnofacies, which points to the lower, weakly storm-affected shoreface. IA2 is interpreted as the archetypal *Skolithos* ichnofacies (opportunistic colonization of tempestite beds) with some elements of the *Cruziana* ichnofacies (bioturbated, fair-weather background deposits) in the middle, moderately storm-affected shoreface. IA3 is assigned to the archetypal *Skolithos* ichnofacies, which indicates the upper shoreface-foreshore settings. The trace-fossil evidence implies that the Upper Cretaceous succession was deposited in a shallow, open basin with good oxygenation of the sea floor and normal salinity, under low- to moderately high-energy hydrodynamic conditions. On the basis of ichnological and sedimentological analyses, the deposits studied originated in a system of fan-delta and shallow-shelf settings with common transitional-proximal tempestites. They were deposited in the eastern part of the Upper Nysa Kłodzka Graben during the Coniacian regression.

Key words: SW Poland, Upper Nysa Kłodzka Graben, Upper Cretaceous, ichnology, palaeoenvironment.

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INTRODUCTION

Trace fossils are a very useful tool, especially for palaeoenvironmental analysis (e.g., Seilacher, 1967, 2007; Bromley, 1996; Pemberton *et al*., 2001, 2012; Miller, 2007; Buatois and Mángano, 2011; Knaust and Bromley, 2012). The environmental sensitivity of the trace makers allows interpretation of the depositional environment (Bromley and Uchman, 2003).

This paper presents a new ichnological analysis of sandstones and conglomerates at the Idzików Quarry (Upper Nysa Kłodzka Graben, Sudetes, SW Poland; Fig. 1). The Upper Nysa Kłodzka Graben is one of the Late Cretaceous basins, situated around the Mid-European Island (after Niebuhr and Seibertz, 2018; Fig. 2). The deposits studied are called “conglomerates” by Wroński (1981), the Idzików Conglomerate Member (after Wojewoda, 1997; see also Don and Gotowała, 2008) and colloquially they are termed the Upper Idzików Beds. The studied section is exposed in the Idzików Quarry, which has been open since the 19th century. It is situated in the northern part of the village, on the right side of an unpaved road (Fig. 3). On the opposite side of the road, thin-bedded sandstones of the Lower Idzików Member are fragmentarily outcropped. The deposits studied are characterized by very well-preserved sedimentary structures and interesting assemblages of trace fossils. Sedimentological data from the site were presented by Wojewoda (1997) and Wojewoda and Raczyński (1997),

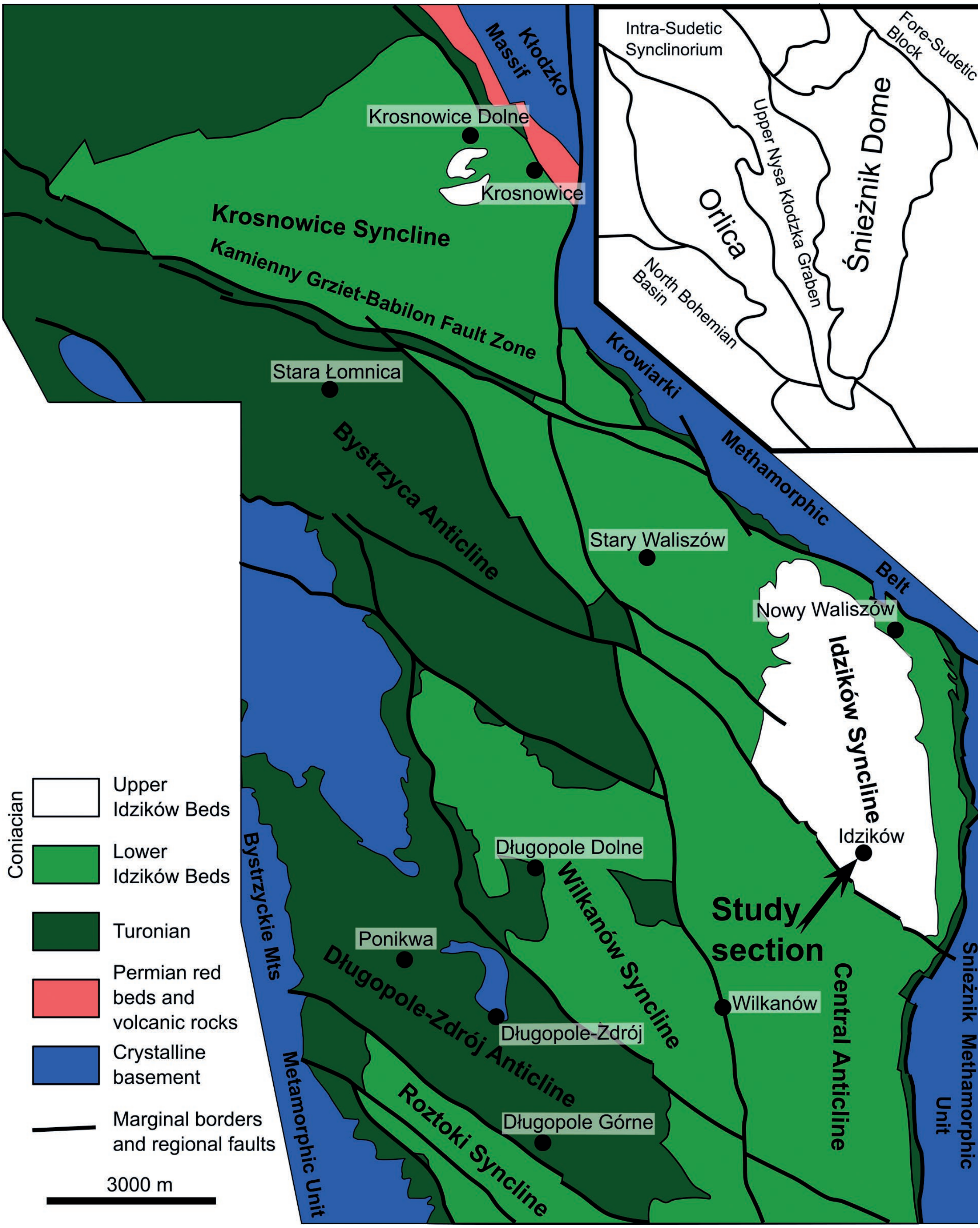
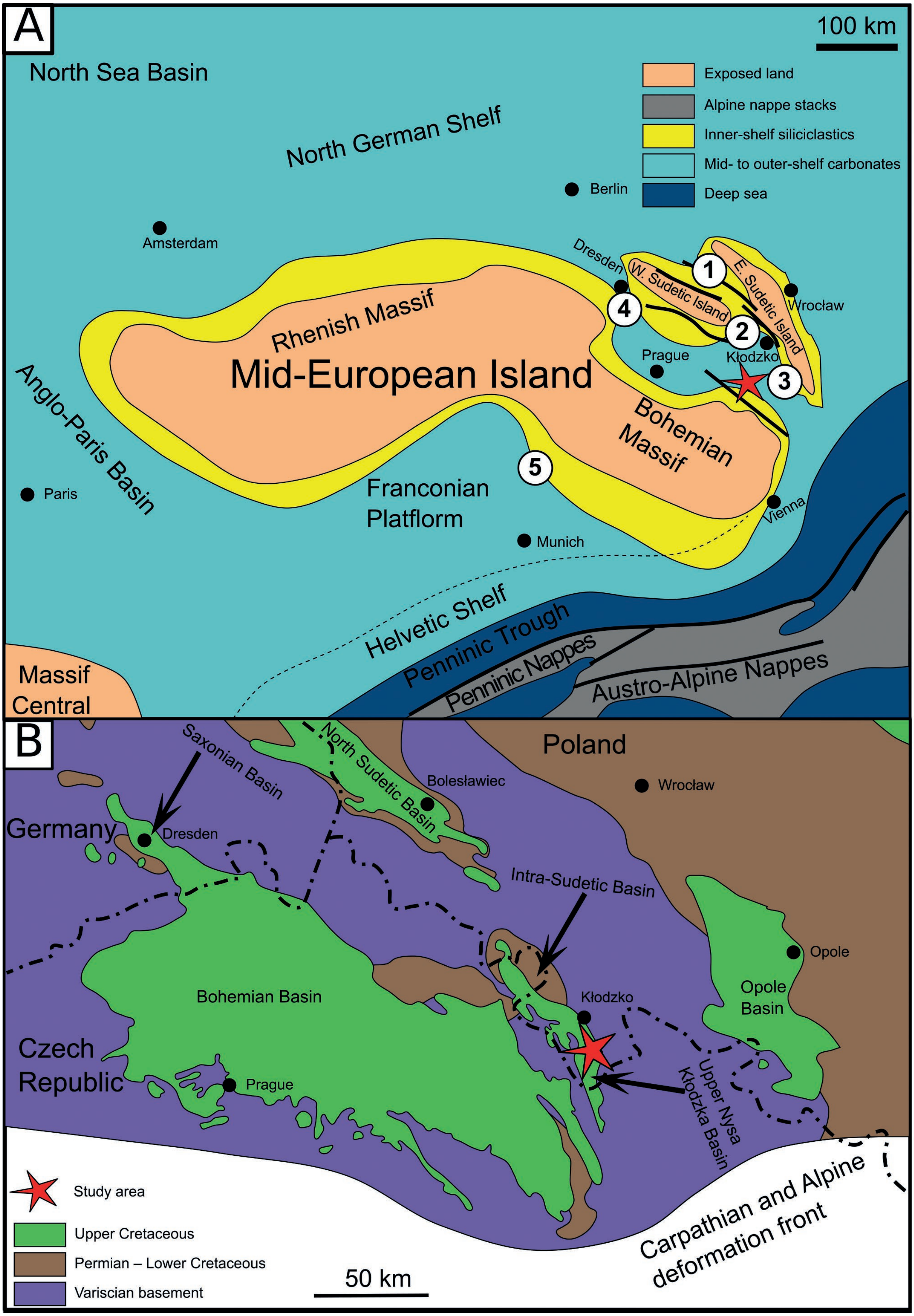


Fig. 1. A fragment of the geological map of the Upper Nysa Kłodzka Graben (after Don and Gotowała, 2008), sketch of the Upper Nysa Kłodzka Graben after Cymerman (1997).

Fig. 2. Palaeogeographic map of central and western Europe (**A**) and the Sudetes region (**B**). A – according to Janetschke (2014), B – after Niebuhr and Seibertz (2018); slightly changed by the author. Numbers indicate Late Cretaceous basins; 1 – North Sudetic, 2 – Intra-Sudetic, 3 – Upper Nysa Kłodzka, 4 – Saxonian, 5 – Danubian (Bavaria).


A
North Sea Basin
100 km
Exposed land
Alpine nappe stacks
Inner-shelf siliciclastics
Mid- to outer-shelf carbonates
Deep sea
North German Shelf
Berlin
Amsterdam
Dresden
W. Sudetic Island
E. Sudetic Island
Wrocław
1
2
3
4
5
Rhenish Massif
Mid-European Island
Prague
Kłodzko
Bohemian Massif
Anglo-Paris Basin
Paris
Franconian Platflorm
Munich
Vienna
Helvetic Shelf
Penninic Trough
Penninic Nappes
Austro-Alpine Nappes
Massif Central
B
Saxonian Basin
North Sudetic Basin
Poland
Bolesławiec
Wrocław
Germany
Dresden
Intra-Sudetic Basin
Opole
Opole Basin
Bohemian Basin
Kłodzko
Czech Republic
Prague
Upper Nysa Kłodzka Basin
Study area
Upper Cretaceous
Permian – Lower Cretaceous
Variscian basement
50 km
Carpathian and Alpine deformation front

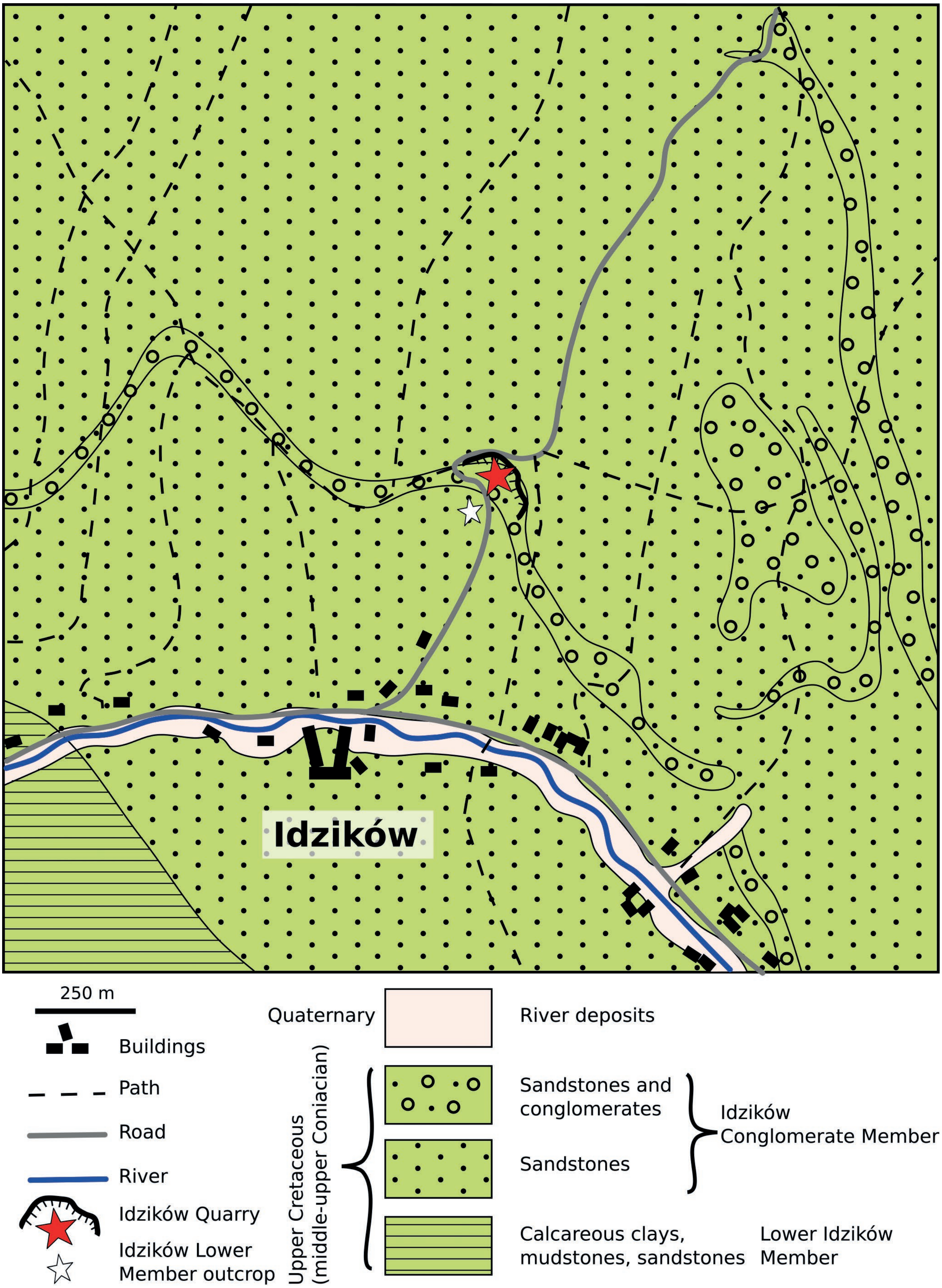


Fig. 3. Location sketch of the vicinity of Idzików Quarry (according to Wroński, 1981).

who reported fine- to medium-grained sandstones, constituting the upper part of a heterolithic succession, formed by the underlying Lower Idzików Beds (see Wojewoda, 1997, p. 87) and coarse-grained sandstones and conglomerates (the so-called Upper Idzików Beds, cf. Wojewoda, 1997; Figs 4–6). So far, more detailed ichnological studies have not been carried out in the section studied. Wojewoda and Raczyński (1997) reported sedimentary structures and *Ophiomorpha*, *Skolithos*, *Corophium* (probably *Diplocraterion,* according to the ichnotaxonomy in the present account), *Thalassinoides*, *Teichichnus* and escape traces, but without description and image documentation, except for one specimen. Earlier, Jerzykiewicz (1970, 1971) recognized the crab *Protocallianassa antiqua* (Roemer, 1841), bivalves and gastropods in the Upper Idzików Beds (Idzików village). From the Lower Idzików Beds, the author cited described the trace fossils *Halymenites* (now *Ophiomorpha*; see Uchman, 1991), *Paleodictyon*, *Gyrochorte*, *Cosmorhaphe*, *Asteriacites*, *Phycodes*, *Chondrites*, *Helminthoida* (now *Nereites*, see Uchman, 1990, 2007; Knaust, 2017), and interpreted them as a deep-sea assemblage (*Nereites* ichnofacies). More recently, these ichnotaxa, reported by Jerzykiewicz (1971), also have been reported from shallow-marine settings, e.g., *Paleodictyon* (Uchman, 1991; Fürsich *et al*., 2007; Metz, 2012; Kikuchi, 2018), *Cosmorhaphe* (Hasiotis, 2012), *Nereites* (Ekdale and Ekdale, 2018; Fernández *et al*., 2018). Moreover, *Asteriacites* is mainly an indicator of shallow-marine settings (Mángano *et al*., 2007; Knaust and Neumann, 2016; Fernández *et al*., 2019).

In the current analysis, 18 ichnogenera and 24 ichnospecies were recognized, as well as escape traces (fugichnia) and some unidentified burrows. Associated sedimentary structures also were reported. Additionally, some fossils found in the Idzików Quarry and stored in the collection of the Geological Museum of the University of Wrocław were presented, e.g., the bivalves *Vola* (*Neithea*) *quadricostata* Sowerby, 1814 (MGUWr-1382s; Fig. 8B), now *Neithea* (*Neithea*) *quadricostata*; *Cardium* (*Protocardium*) *hillanum* Sowerby, 1813 (MGUWr-1501s; Fig. 8A) and the crustacean *Callianassa elongata* (Fritsch, 1867) (MGUWr-1560s; Fig. 8D). Beside the above cited fossils, *Callianassa antiqua* von Otto, 1854 (MGUWr-3752s-1), came from the study area; it also is housed in the collection of the Geological Museum of the University of Wrocław, together with a previously unidentified bivalve (MGUWr-3752s-2; Fig. 8C) which is determined by the present author as *Pholadomya* sp.

The majority of specimens studied were not collected and are documented mainly in field photographs, owing to their occurrence on the vertical walls of the quarry or on the soles of beds (Figs 7–14). Some of the trace fossils are preserved atypically and difficult to determine in a few cases, especially because of their state of preservation. Additionally, in the small outcrop of the Lower Idzików Member (Fig. 4), situated on the left side of the field road (Fig. 3), ?*Diplocraterion* isp. and *Ophiomorpha* isp. were found (Fig. 14I, J), as well as some crinoids, described earlier by Niedźwiedzki and Salamon (2005).

The aim of the present paper is to document and to describe in detail the newly collected trace-fossil assemblages from the Idzików Quarry section, which together with sedimentary structures are used to interpret the palaeoenvironment of the deposits studied (salinity, energy of water, sedimentation rate, palaeobathymetry, oxygenation of pore and bottom waters, consistency of the substrate and availability of food). This ichnological study helps to complete and add precision to the palaeoenvironmental interpretation of the Idzików Conglomerate Member, suggested by Wojewoda (1997) and Wojewoda and Raczyński (1997).

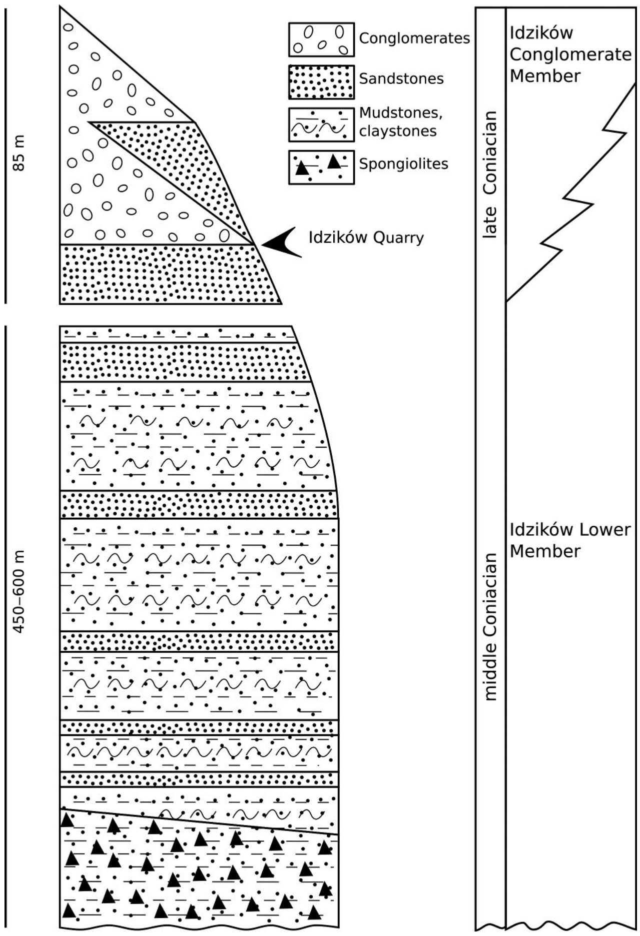


Fig. 4. Idzików Bed section in the Idzików Quarry according to Wojewoda (1997); some details after Don and Gotowała (2008), slightly changed by the author.

METHODS

The methods used in this paper include presentation of the detailed characteristics of trace fossils and sedimentary structures in order to distinguish ichnoassociations and interpret them in relation to an ichnological-sedimentological model for shelf settings by Pemberton *et al*. (2012). This allows the interpretation of sedimentary environments for the deposits examined.

Ichnological analysis comprises the description, ethology of the studied ichnotaxa, diversity, abundance, tiering pattern, ichnodisparity and the degree of bioturbation (BI – bioturbation index) for each ichnoassociation distinguished.

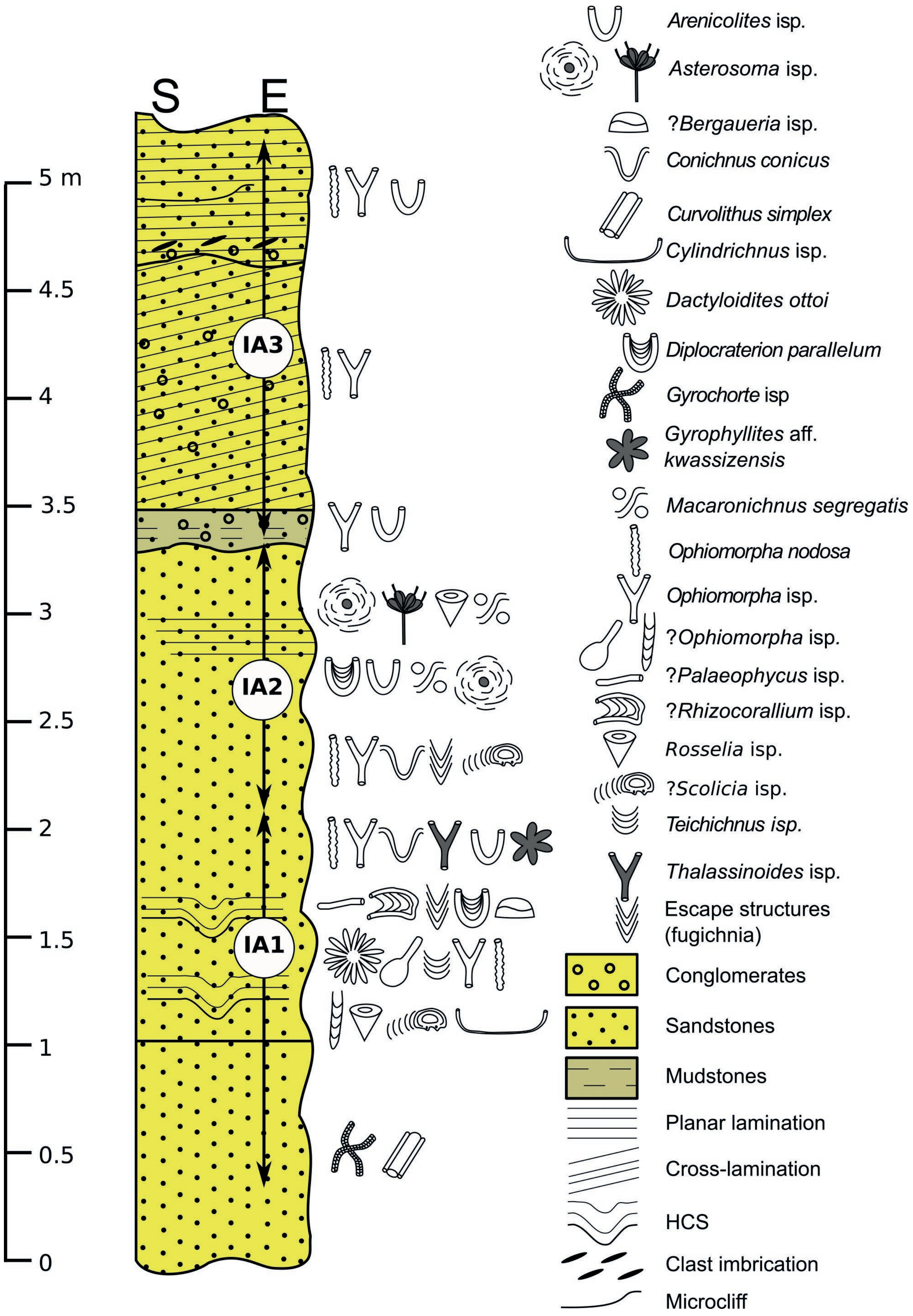


Fig. 5. Lithological section of the Idzików Conglomerate Member in the Idzików Quarry with indication of trace-fossil assemblages. IA1 – ichnoassociation *Ophiomorpha-Cylindrichnus*; IA2 – *Asterosoma-Conichnus*, IA3 – *Ophiomorpha-Arenicolites*.

Fig. 6. Photograph of the Idzików Quarry. Wall B **(A)** and walls A–C **(B)** with indication of ichnoassociations IA1–IA3 and depositional environments. Deltaic deposits in the uppermost part of the Idzików section in A according to Wojewoda (1997). Dashed lines indicate runnel erosional surface.

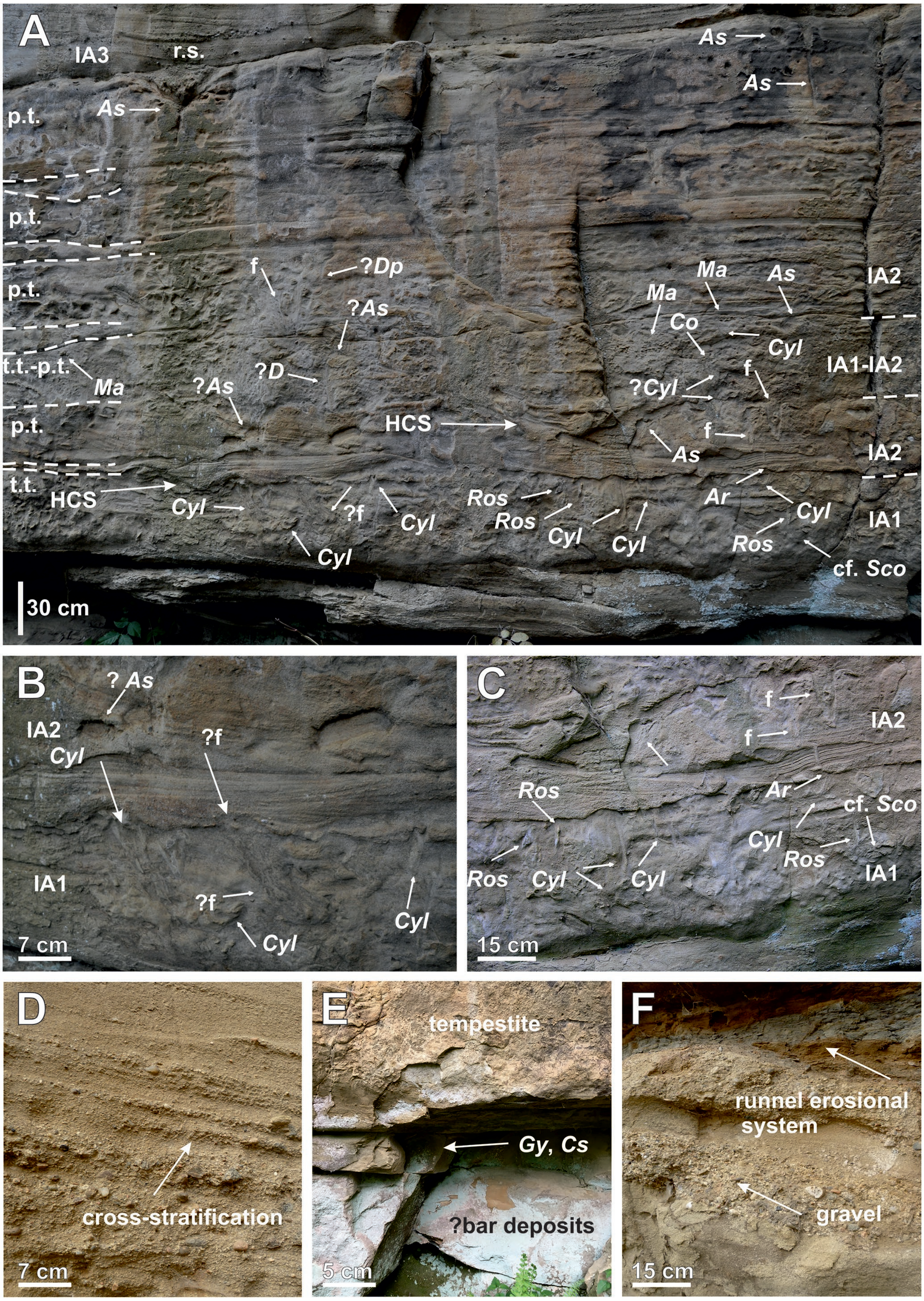


Fig. 7. Sedimentary structures and some trace fossils from the Idzików Quarry. Abbreviations: *As* – *Asterosoma* isp., ?*As* – ?*Asterosoma* isp., *Ar* – *Arenicolites* isp., *Co* – *Conichnus conicus*, *Cyl* – *Cylindrichnus* isp., ?*Dp* – ?*Diplocraterion parallelum* , ?*D* – ?*Diplocraterion* isp., *Ma* – *Macaronichnus segregatis*, *Ros* – *Rosselia* isp., cf. *Sco* – cf. *Scolicia* isp., f – fugichnia, ?f – ?fugichnia, HCS – hummocky cross-stratification, r.s. – reactivation surfaces, p.t. – proximal tempestites, t.t. – transitional tempestites. **A–C.** Succession of tempestite beds, wall B (ichnoassociations IA1–IA3); **D.** Cross-stratification and reactivation surfaces, wall C (IA3). **E.** The lowermost part of the Idzików Quarry section, arrow marks a place, where *Curvolithus simplex* (*Cs*) and *Gyrochorte* isp. (*Gy*) were found. **F.** Runnel erosional surface, wall C.

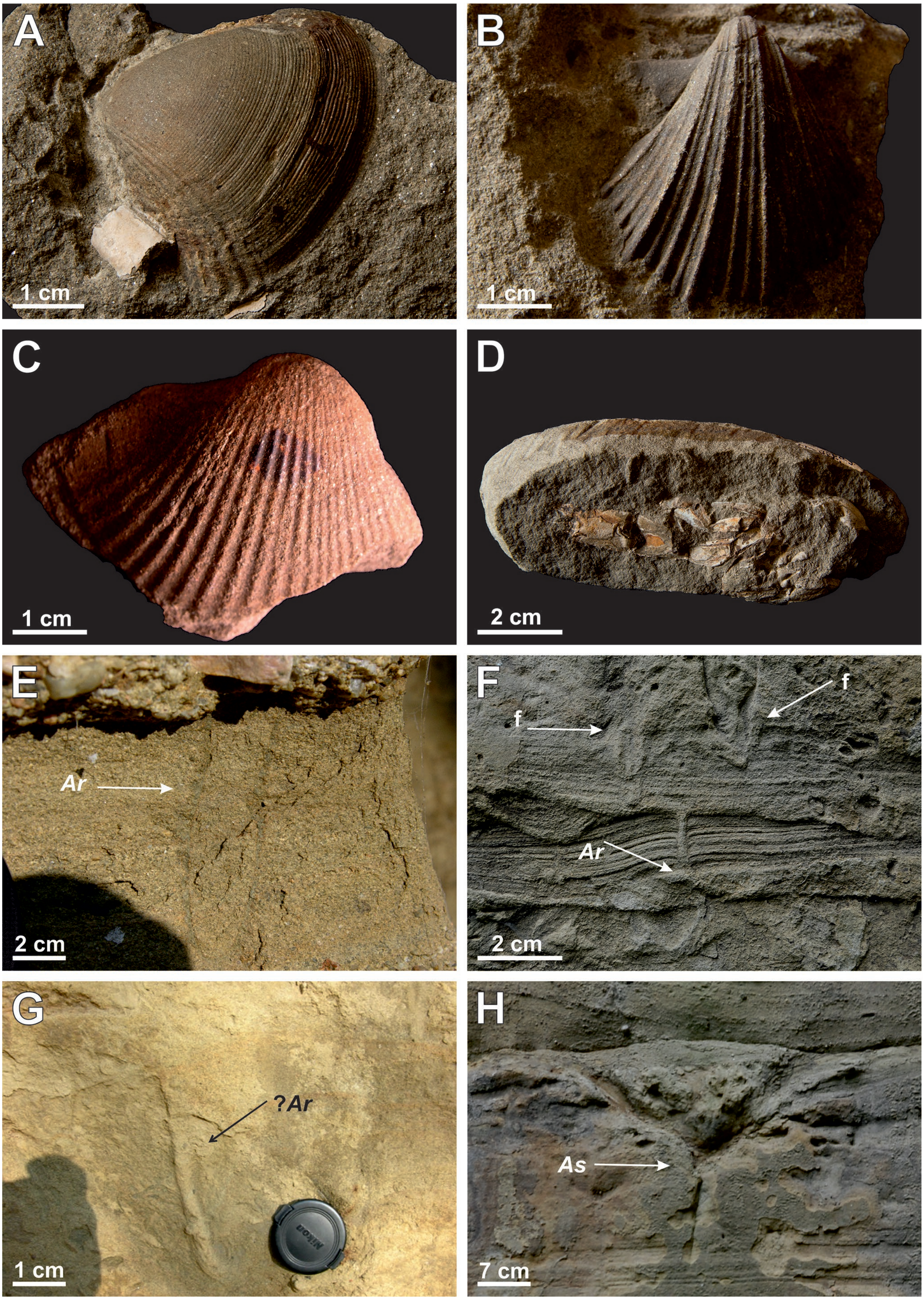


Fig. 8. Body fossils and some trace fossils. Abbrevations explained in Figure 7; moreover, ?*Ar* – *Arenicolites* isp. **A.** *Cardium* (*Protocardium*) *hillanum* Sowerby, 1813 (formerly *Protocardia hillana*; MGUWr-1501s). **B.** *Neithea* (*Neithea*) *quadricostata* Sowerby, 1814 (formerly *Vola quadricostata* or *Pecten quadricostatus*; MGUWr-1382s). **C.** *Pholadomya* sp. (MGUWr-3752s-2). **D.** *Callianassa elongata* (Fritsch, 1867) (MGUWr-1560s). **E.** *Arenicolites* isp., wall C. **F.** *Arenicolites* isp., fugichnia, wall B. **G.** ?*Arenicolites* isp., wall C. **H.** *Asterosoma* isp., whole specimen, wall B.

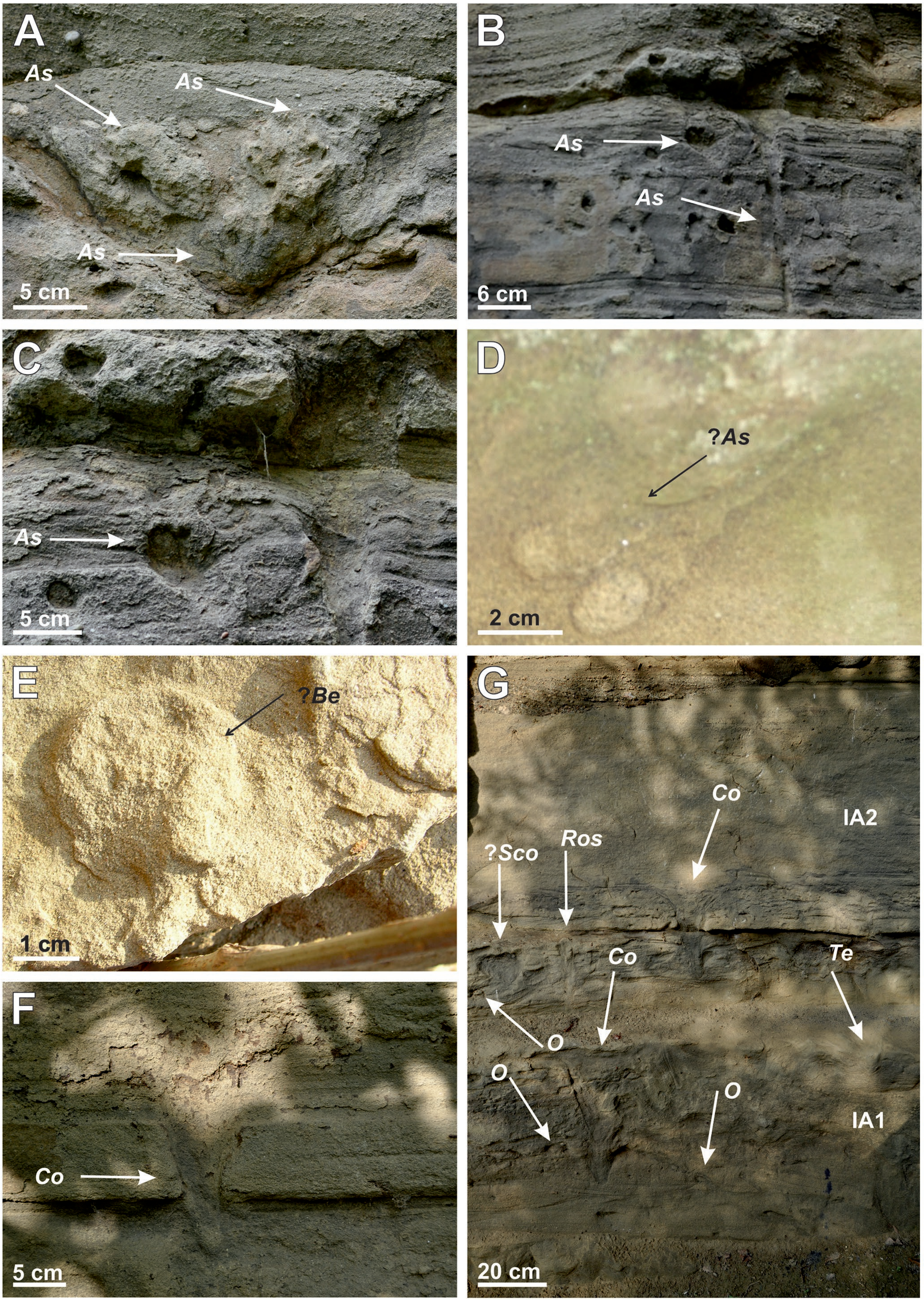


Fig. 9. Trace fossils from the Idzików Quarry. Abbrevations explained in Figure 7; moreover, ?*Be* – ?*Bergaueria* isp., *O* – *Ophiomorpha* isp., ?*Sco* –?*Scolicia* isp., *Te* –*Teichichnus* isp. **A–C.** *Asterosoma* isp., wall B. **D.** ?*Asterosoma* isp., wall A. **E.** ?*Bergaueria* isp., wall C. **F.** *Conichnus conicus*, wall C. **G.** Distribution of trace fossils of ichnoassociations IA1–IA2 in wall C.

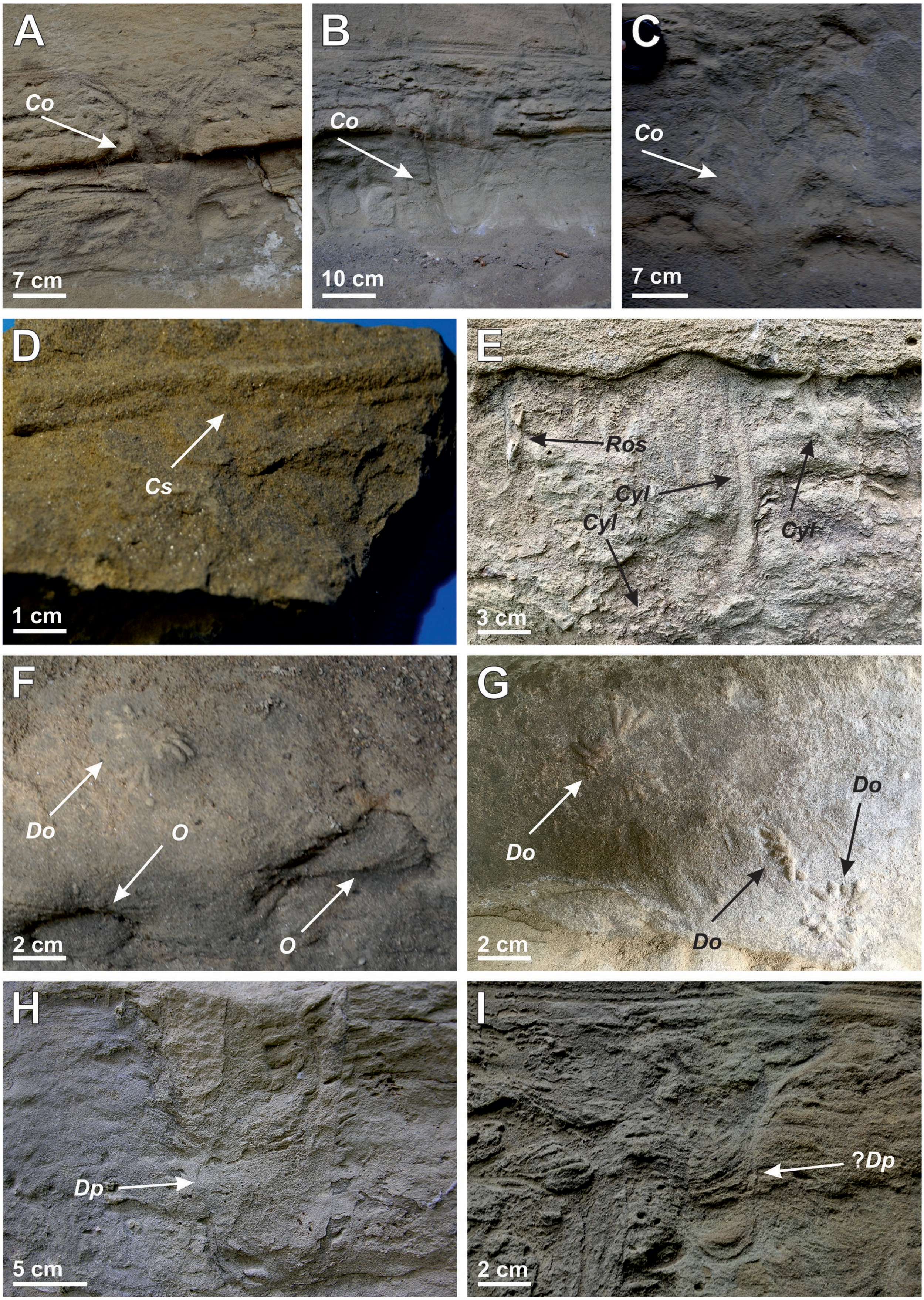


Fig. 10. Trace fossils in sandstones with the ichnoassociations IA1 and IA2. Abbrevations as in Figures 7, 9; moreover, *Do* – *Dactyloidites ottoi*, *Dp* – *Diplocraterion parallelum*. **A–C.** *Conichnus conicus*, wall C. **D.** *Curvolithus simplex*, wall B. **E.** *Cylindrichnus* isp., *Rosselia* isp., wall B. **F–G.** *Dactyloidites ottoi*, *Ophiomorpha* isp., wall C. **H.** *Diplocraterion parallelum*, wall C. **I.** ?*Diplocraterion parallelum*, wall B.

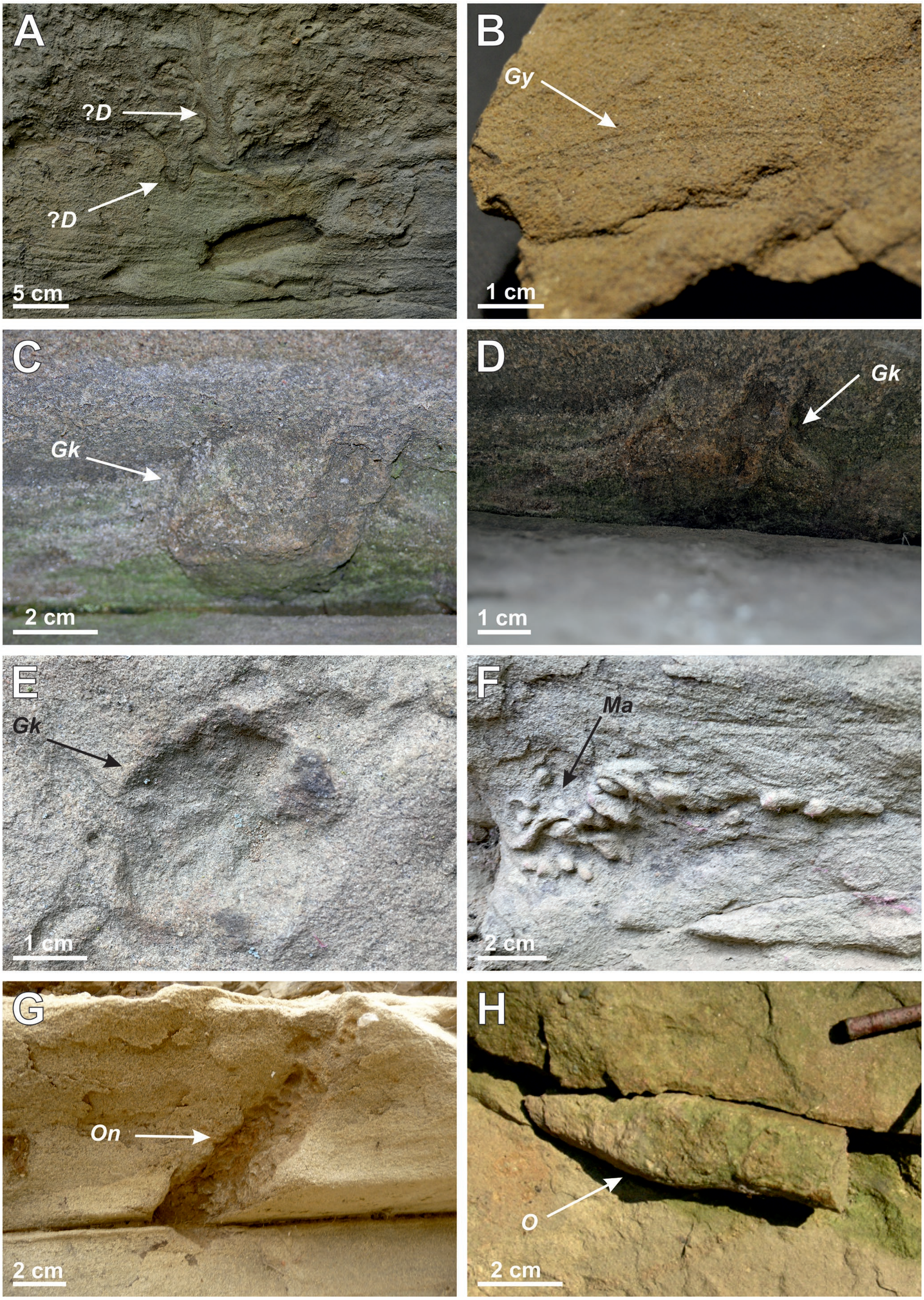


Fig. 11. Trace fossils in sandstones with ichnoassociations IA1–IA3. Abbreviations explained in Figure 7; moreover, *Gk* – *Gyrophyllites* aff. *kwassizensis*, *On* – *Ophiomorpha nodosa*. **A.** ?*Diplocraterion* isp., wall B. **B.** *Gyrochorte* isp., wall B. **C–D.** *Gyrophyllites* aff. *kwassizensis*, wall A. **E.** *G.* aff. *kwassizensis*, wall C. **F.** *Macaronichnus segregatis*, wall C. **G.** *Ophiomorpha nodosa*, wall C, specimen previously presented by Wojewoda and Raczyński (1997, fig. 38). **H.** *Ophiomorpha* isp., wall B.

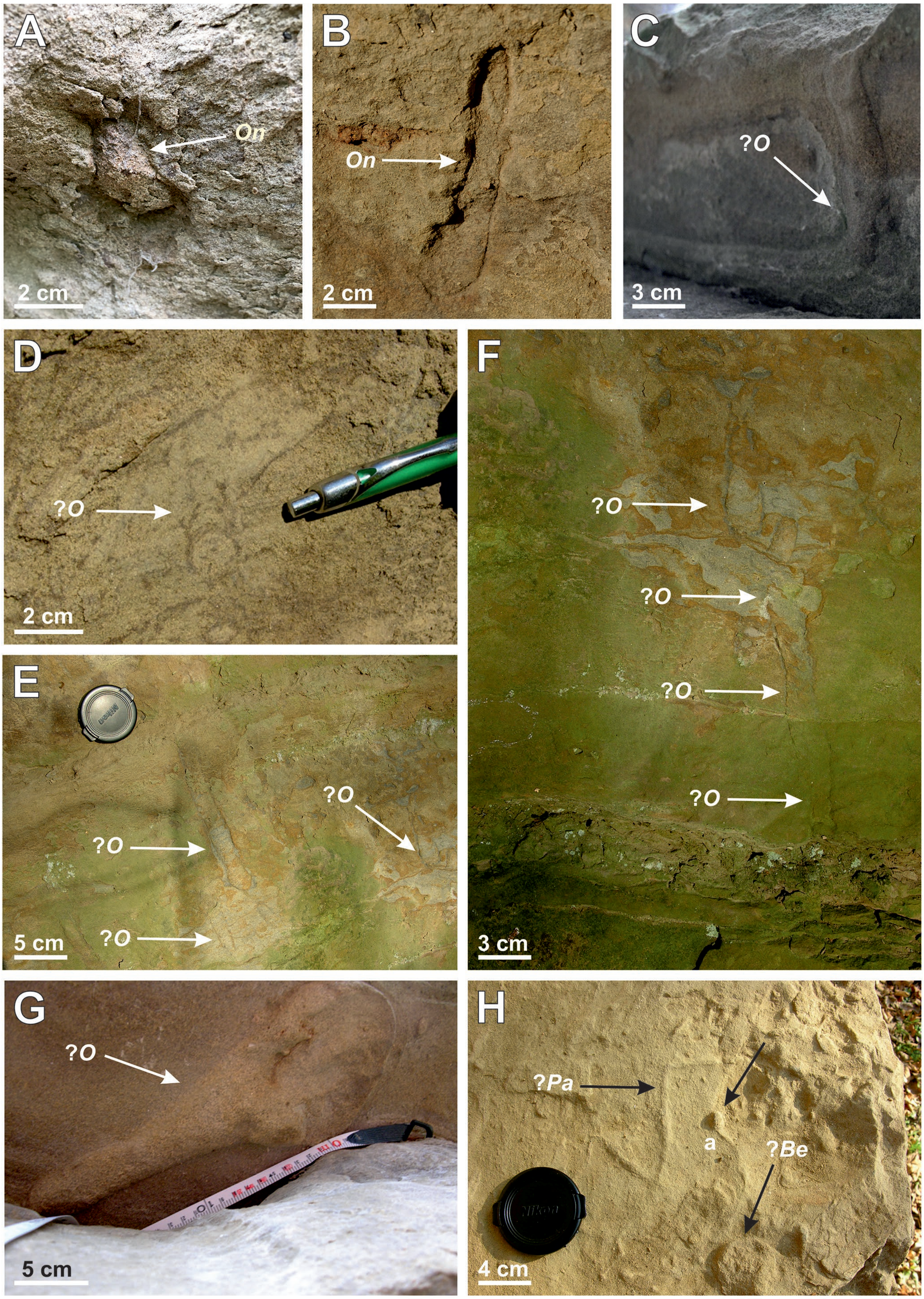


Fig. 12. Trace fossils in sandstones of ichnoassociations IA1–IA2. Abbrevations explained in Figures 9, 11; moreover, ?*O* – ?*Ophiomorpha* isp., ?*Pa* – ?*Palaeophycus* isp. **A–B.** *Ophiomorpha nodosa*, wall C. **C.** ?*Ophiomorpha* isp., wall A. **D–F.** A few specimens of ?*Ophiomorpha* isp. with meniscate structure, wall C. **G.** ?*Ophiomorpha* isp. with swollen chamber, wall A. **H.** ?*Palaeophycus* isp., ?*Bergaueria* isp., a – ?bivalve burrow resembling *Lockeia* isp., wall C.

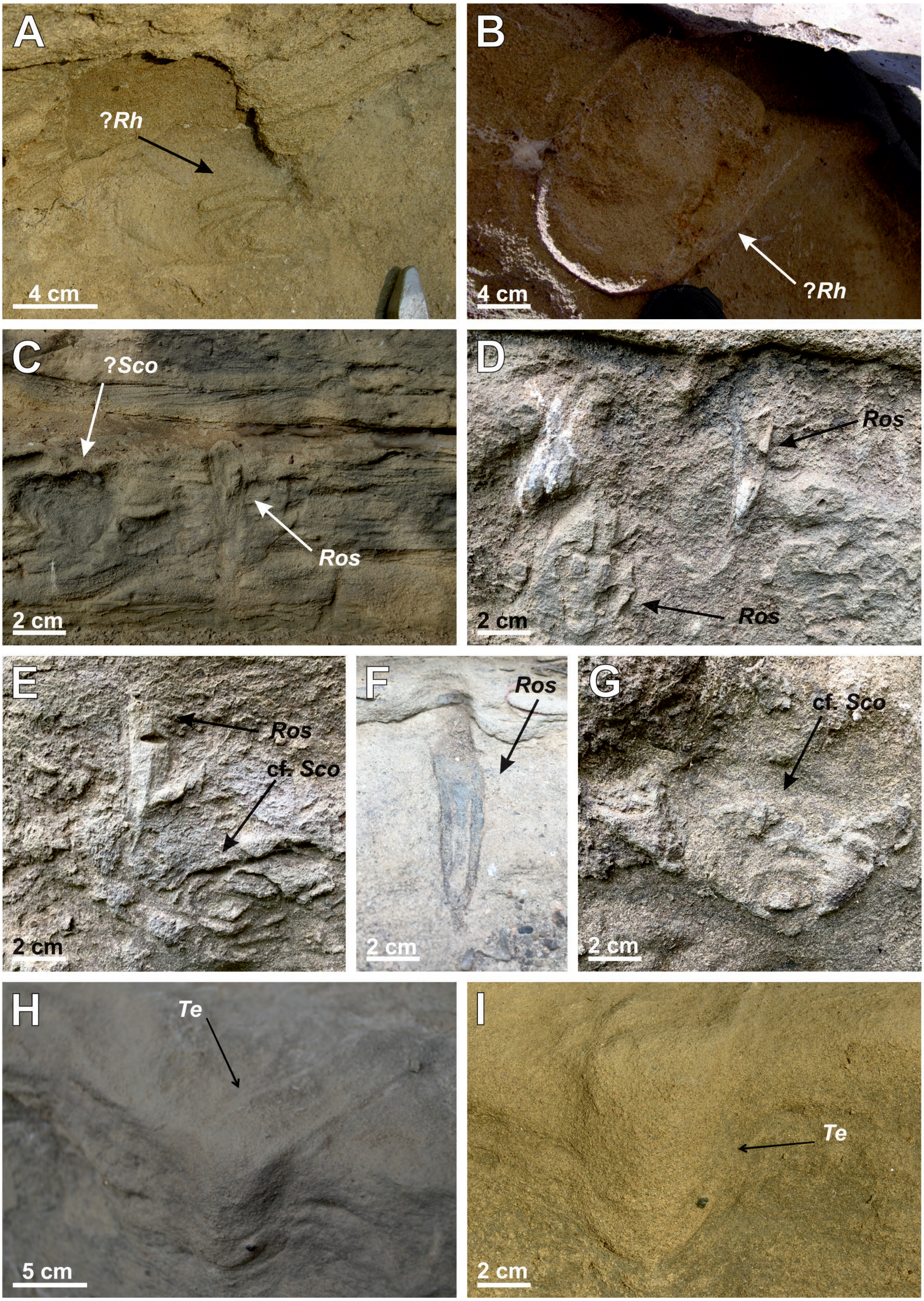


Fig. 13. Trace fossils in sandstones with ichnoassociations IA1–IA2. Abbreviations explained in Figures 7, 9; moreover, ?*Rh* – ?*Rhizocorallium* isp. **A.** ?*Rhizocoralium* isp., wall C. **B.** ?*Rhizocorallium* isp., wall A. **C.** *Rosselia* isp. and ?*Scolicia* isp., wall C. **D.** *Rosselia* isp., wall B. **E.** *Rosselia* isp. and cf. *Scolicia* isp., wall B. **F.** *Rosselia* isp., wall C. **G.** cf. *Scolicia* isp., wall B. **H–I.** *Teichichnus* isp., the same specimen in different views, wall C.

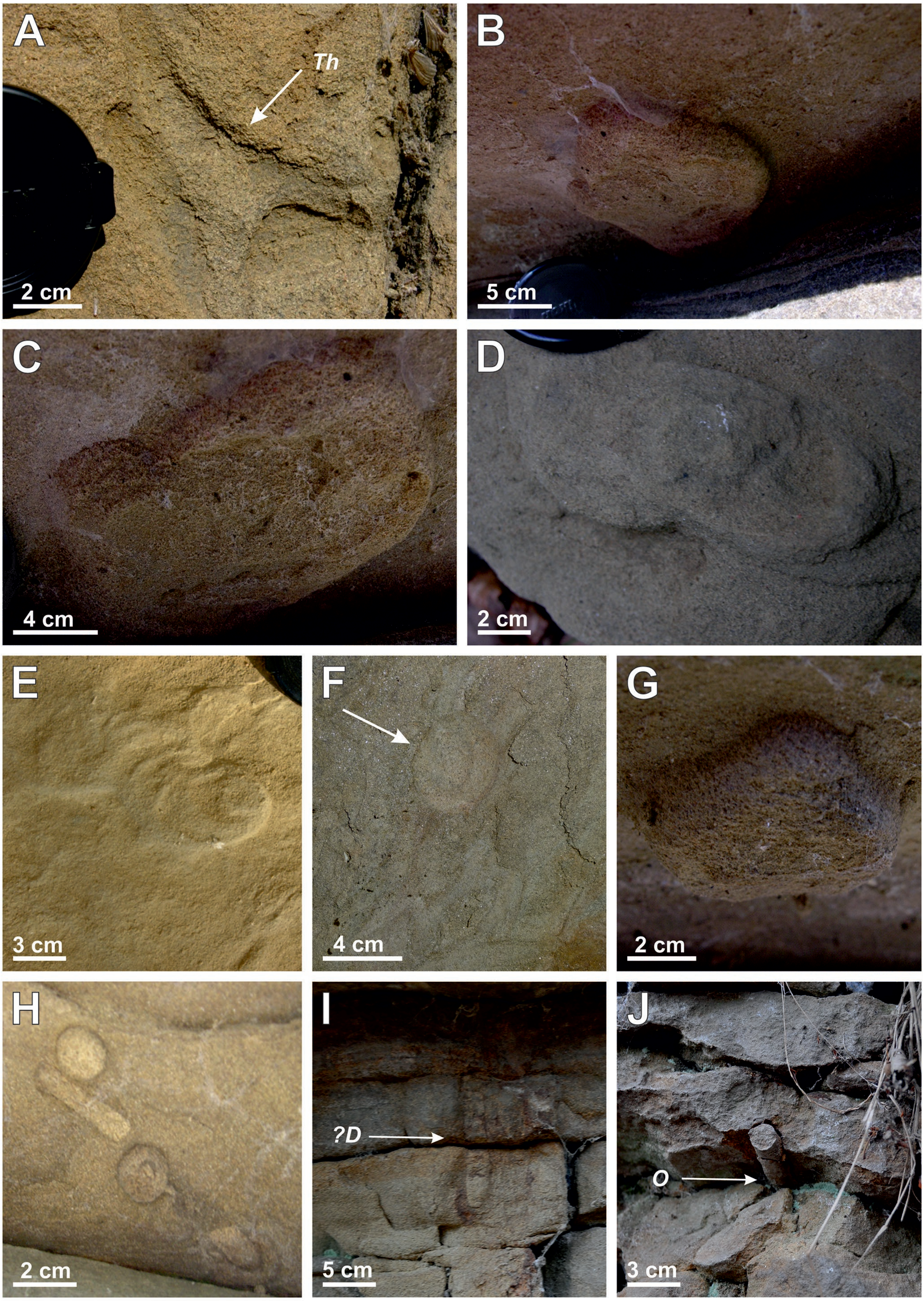


Fig. 14. Remaining trace fossils and other structures from the Lower Idzików Member. Abbrevations explained in Figures 7, 9, 13, moreover, *Th* – *Thalassinoides* isp. **A.** *Thalassinoides* isp., wall C. **B–C.** Trace fossil (?) resembling ?*Rhizocorallium* wall A. **D–E.** Unrecognizable trace fossils, wall C. **F.** Jellyfish trace (?), wall B. **G–H.** Crustacean burrows (?), wall A. **I–J.** ?*Diplocraterion* isp. and *Ophiomorpha* isp., outcrop of the Lower Idzików Member near the Idzików Quarry (localization in Fig. 3).

The bioturbation index (BI), after Taylor and Goldring (1993) and Taylor *et al*. (2003), modified by Baniak *et al*. (2014), was applied, where BI = 0 (unbioturbated); BI = 1 (sparse bioturbation; 1–4%); BI = 2 (low; 5–30%); BI = 3 (moderate; 31–60%); BI = 4 (common; 61–90%); BI = 5 (abundant; 91–99 %); and BI = 6 (complete or homogenization; 100%).

Ichnodisparity, adopted in ichnology by Buatois and Mángano (2013) and redefined by Buatois *et al*. (2017), was defined as the number of architectural categories in individual ichnoassociations, while ichnodiversity as the number of ichnotaxa present, usually at the ichnogeneric level (see Luo *et al*., 2020). Abundance, understood as a frequency of individual ichnotaxa in the presented ichnoassociations, was followed after Knaust (2017), where very rare means 1 ichnotaxon, rare – 2–6 ichnotaxa, common – 7–9, very common – 10–22, abundant – 23–41, very abundant – >42 (see Tab. 1).

The palaeoenvironmental interpretation is focused mainly on the common ichnotaxa. The other ichnospecies, questionable or very rare (represented by one specimen; Tab. 1), are of secondary importance. However, their appearance in the Idzików section is not insignificant. Additionally, the schematic tiering pattern for the ichnoassociation IA1 (*Ophiomorpha*-*Cylindrichnus*) also was presented (e.g., Fig. 17).

Ichnological analysis is based on the integrated ichnological-sedimentological model for shoreface settings by Pemberton *et al*. (2012) and redefined from MacEachern *et al*. (1999) and MacEachern and Bann (2008). In this model, the offshore transition is not further subdivided and the fair-weather wave base occurs between the proximal and distal parts of the lower shoreface. The results of the ichnological analysis are presented in Figure 15 and Table 1. Additionally, the distribution of trace fossils in the ichnoassociations IA1 (*Ophiomorpha*-*Cylindrichnus*), IA2 (*Asterosoma*-*Conichnus*) and IA3 (*Ophiomorpha*–*Arenicolites*) is shown in Figure 16 (block diagram).

Table 1

Ichnoabundance of individual ichnospecies
in the Idzików section (Idzików Conglomerate Member,
Idzików Quarry).
Abundance: + – very rare, ++ – rare,
+++ – common, ++++ – abundant.

	Ichnospecies	Abundance
1	*Arenicolites* isp.	++
2	?*Arenicolites* isp.	+
3	*Asterosoma* isp.	+++
4	*?Asterosoma* isp.	++
5	?*Bergaueria* isp.	+
6	*Conichnus conicus* Mänill, 1966	+++
7	*Curvolithus simplex* Buatois, Mángano, Mikuláš, Maples, 1998	+
8	*Cylindrichnus* isp.	+++
9	*Dactyloidites ottoi* Geinitz, 1849	++
10	*Diplocraterion parallelum* Torell, 1870	+
11	?*Diplocraterion parallelum* Torell, 1870	++
12	?*Diplocraterion* isp.	++
13	*Gyrochorte* isp.	+
14	*Gyrophyllites* aff. *kwassizensis*	++
15	*Macaronichnus segregatis* Clifton and Thompson, 1978	+++
16	*Ophiomorpha nodosa* Lundgren, 1891	++++
17	*Ophiomorpha* isp.	++++
18	?*Ophiomorpha* isp.	++
19	?*Palaeophycus* isp.	+
20	?*Rhizocorallium* isp.	++
21	*Rosselia* isp.	++
22	?*Scolicia* isp.	++
23	*Teichichnus* isp.	+
24	*Thalassinoides* isp.	++

GEOLOGICAL SETTING

Upper Nysa Kłodzka Graben

The outcrops of the Idzików Conglomerate Member are situated in the eastern part of the Upper Nysa Kłodzka Graben, along its marginal faults (Fig. 1). The Idzików Quarry is placed in the Idzików Upland, developed on the Idzików Syncline (Don and Gotowała, 2008). The Upper Nysa Kłodzka Graben, which is regarded as one of the youngest tectonic units in the Sudetes (Żelaźniewicz *et al*., 2011), started to develop during the Coniacian, when synsedimentary activity on the eastern fault margin caused asymmetric subsidence in a basin, accompanied by the elevation of the Śnieżnik Massif (after Don and Don, 1960; Wojewoda, 1997; Don and Gotowała, 2008). It is filled with the detrital sediments, deposited from the late Cenomanian to probably the late Coniacian (see Kędzierski, 2002; Niedźwiedzki and Salamon, 2005; Trzęsiok *et al*., 2014; Halamski and Kvaček, 2015). During the pre-tectonic stage, Cenomanian and Turonian sandstones and marls were deposited on a strongly peneplained pre-Upper Cretaceous surface (Don and Don, 1960; Don, 1996; Sobczyk, 2019). Later, during the tectonic stage (late Turonian–Coniacian), these deposits were deformed into a monocline, which is very steep along the graben's margins (after Don and Gotowała, 2008 and references therein). The Upper Cretaceous succession in the Nysa Kłodzka Graben ranges in thickness to over 1200 m and consists of calcareous or siliceous mudstones and sandy limestones, spongiolites, sandstones and conglomerates (Wojewoda, 1997; Don and Wojewoda, 2005). It is developed on the metamorphic rocks of the Orlica-Śnieżnik Dome (Jerzykiewicz, 1971; Żelaźniewicz and Aleksandrowski, 2008). The sandstones (the so-called Quadersandstein megafacies; see Chrząstek, 2013a) appear in the upper Cenomanian and middle and upper Turonian of the Upper Nysa Kłodzka Graben.

The youngest, middle Coniacian deposits (Lower Idzików Member, 450–600 m thick) consist of calcareous claystones and mudstones, containing sandstone layers, which are up to 0.5 m thick. The quantity and thickness of sandstone intercalations increase upward in the section (Fig. 4). The overlying sandstones and conglomerates of the late Coniacian age (Idzików Conglomerate Member) are 85 m

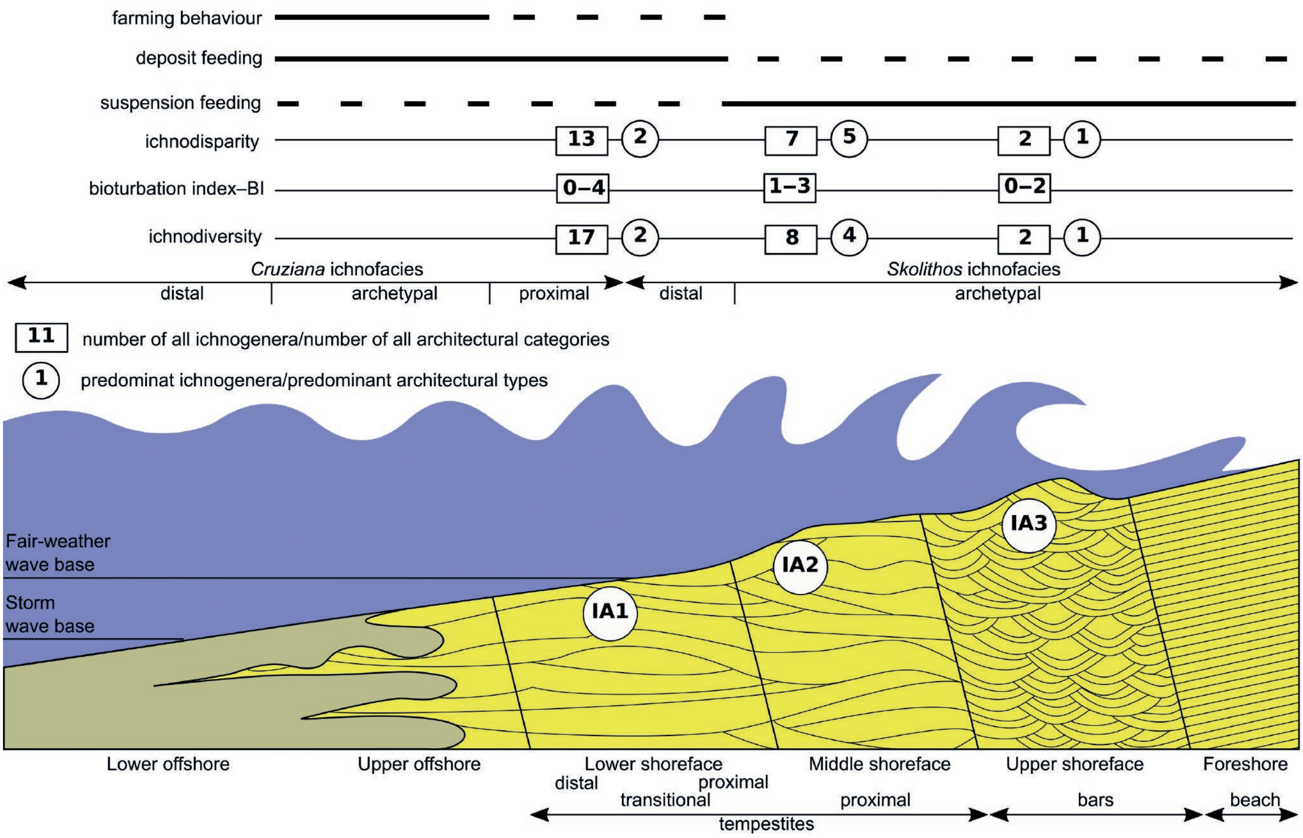


Fig. 15. Sketch showing ichnodiversity, ichnodisparity, and bioturbation index for the ichnoassociations IA1–IA3. Drawing after Buatois and Mángano (2011), Wojewoda *et al*. (2011) and Baniak *et al*. (2014).

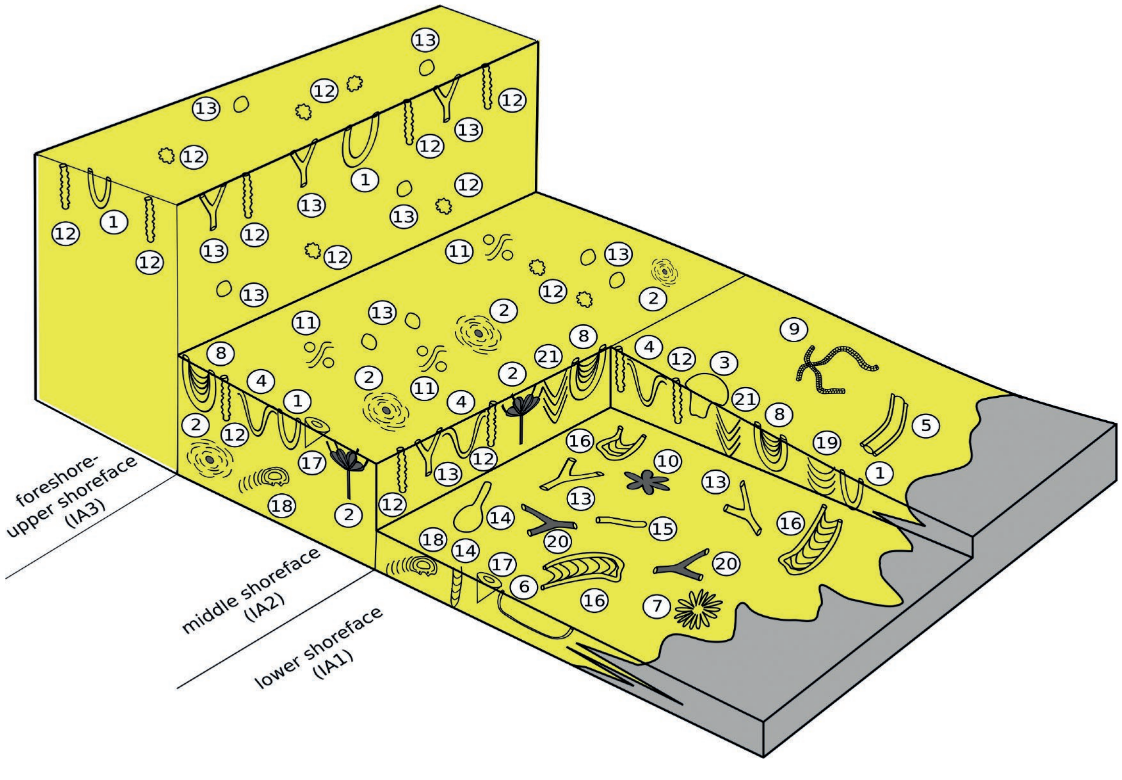


Fig. 16. Block diagram showing distribution of trace fossils in ichnoassociations IA1–IA3 (some details after Pemberton *et al*., 2001 and Stachacz, 2016); walls A–C. 1 – *Arenicolites* isp., 2 – *Asterosoma* isp., 3 – ?*Bergaueria* isp., 4 – *Conichnus conicus*, 5 – *Curvolithus simplex*, 6 – *Cylindrichnus* isp., 7 – *Dactyloidites ottoi*, 8 – *Diplocraterion parallelum*, 9 – *Gyrochorte* isp., 10 – *Gyrophyllites* aff. *kwassizensis*, 11 – *Macaronichnus segregatis*, 12 – *Ophiomorpha nodosa*, 13 – *Ophiomorpha* isp., 14 – ?*Ophiomorpha* isp., 15 – ?*Palaeophycus* isp., 16 – ?*Rhizocorallium* isp., 17 – *Rosselia* isp., 18 – ?*Scolicia* isp., 19 – *Teichichnus* isp., 20 – *Thalassinoides* isp., 21 – fugichnia.

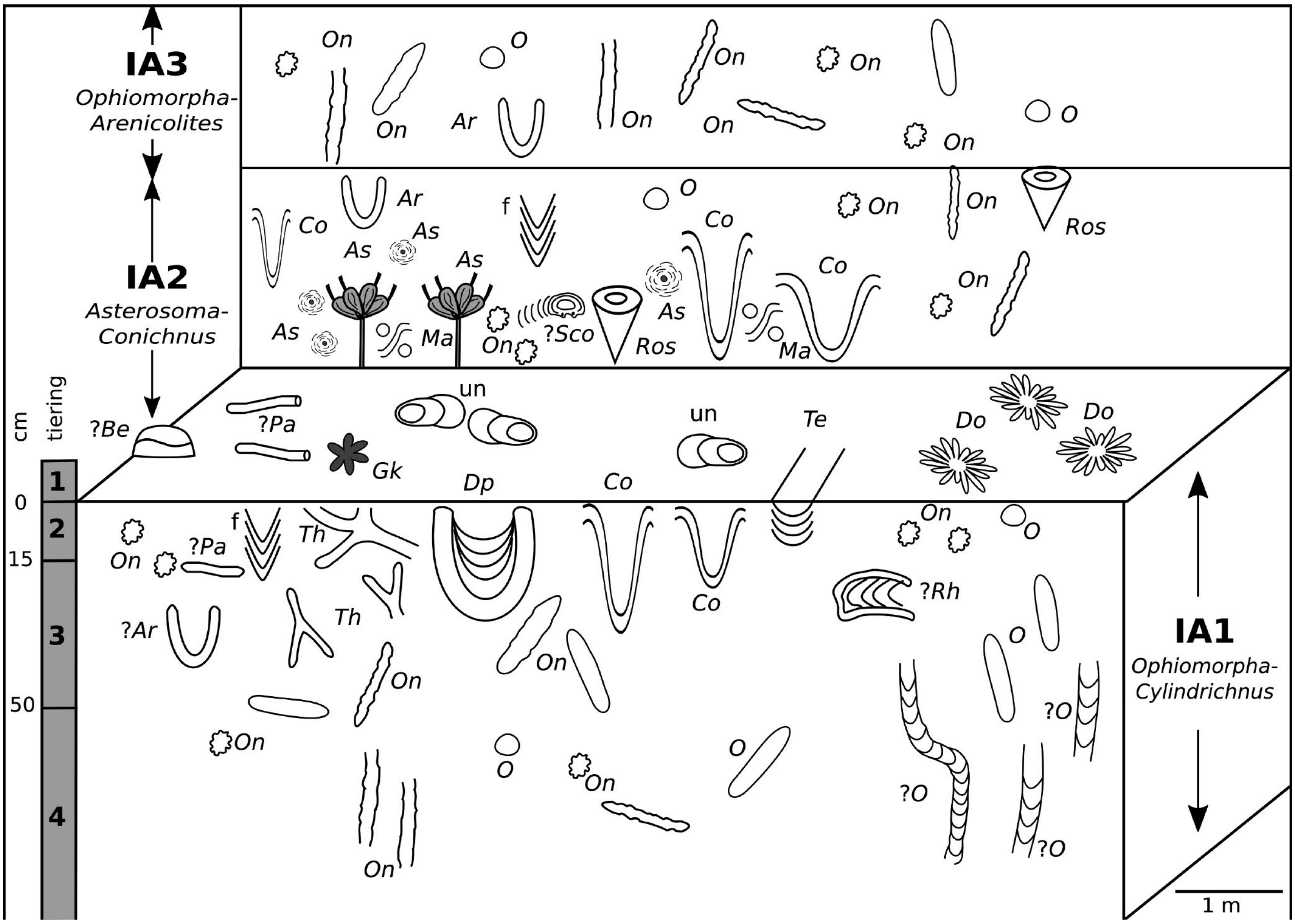


Fig. 17. Tiering pattern of trace fossils in IA1 after Rodríguez-Tovar *et al.* (2017); wall B. IA1 – IA3 (ichnoassociations IA1 – IA3), *Ar* – *Arenicolites* isp., ?*Ar* – ?*Arenicolites* isp., *As* – *Asterosoma* isp., ?*Be* – ?*Bergaueria* isp., *Co* – *Conichnus conicus*, *Do* – *Dactyloidites ottoi*, *Dp* – *Diplocraterion parallelum*, *Gk* – *Gyrophyllites* aff. *kwassizensis*, *Ma* – *Macaronichnus segregatis*, *On* – *Ophiomorpha nodosa*, *O* – *Ophiomorpha* isp., ?*O* – ?*Ophiomorpha* isp., ?*Pa* – ?*Palaeophycus* isp., ?*Rh* – ?*Rhizocorallium* isp., *Ros* – *Rosselia* isp., ?*Sco* – ?*Scolicia* isp., *Te* – *Teichichnus* isp., *Th* – *Thalassinoides* isp., f – fugichnia, un – unrecognizable burrows.

thick (Don and Gotowała, 2008). According to Don and Don (1960), the conglomerates rest on sandstones. In the lower part of Idzików Conglomerate Member, conglomerates form intercalations, whereas in the middle and upper part of this unit, they form some levels. In summary, transgressive deposits in the Upper Nysa Kłodzka Graben originated in the Cenomanian–early Turonian and late Turonian–middle Coniacian, while regressive deposits accumulated in the middle Turonian and late Coniacian (see Don and Don, 1960; Wojewoda, 1997).

In palaeogeographic interpretations, the Idzików Conglomerate Member is recognized as littoral-beach and fan-delta deposits (coarse-grained sandstones and conglomerates – Upper Idzików Beds) and a succession of transitional-proximal tempestites (fine- and medium-grained sandstones; see Wojewoda, 1997; Wojewoda and Raczyński, 1997; Chrząstek and Wojewoda, 2011), which were deposited during the regression that affected the eastern part of the Upper Nysa Kłodzka Graben (see Wojewoda, 1997). The thick deposits of the Lower Idzików Member, regarded as distal and transitional tempestites, are related to strong subsidence of the basin. On the basis of new, palaeogeographic and sedimentological studies, these deposits were interpreted as having been laid down in a shallow basin, which was 60–100 m deep (Valečka, 1984; Wojewoda, 1997). Trzęsiok *et al.* (2014) proposed an even shallower setting for them, i.e. the upper sublittoral zone. In the past, these deposits were regarded as deep-marine turbidites (Jerzykiewicz, 1970, 1971; Jerzykiewicz and Teisseyre, 1974).

Idzików Conglomerate Member

The deposits studied in the Idzików Quarry are fine- to medium-grained and less frequently coarse-grained sandstones and conglomerates. Their beds are 1–2 m thick and lie almost horizontally. The entire thickness of the section is about 8–12 m. The lower part of the quarry, composed of fine- to medium-grained sandstones, is very rich in trace fossils. The upper part of the quarry, which consists of pebbly sandstones and conglomerates, is rather poor in them. In sandstones, following trace fossils have been found: ?*Arenicolites*, ?*Asterosoma* isp., ?*Bergaueria* isp., *Conichnus conicus*, *Curvolithus simplex*, *Cylindrichnus* isp., *Dactyloidites ottoi*, *Diplocraterion parallelum*, *Gyrochorte* isp., *Gyrophyllites* aff. *kwassizensis*, *Ophiomorpha nodosa*, *Ophiomorpha* isp., ?*Palaeophycus* isp., ?*Rhizocorallium* isp., *Rosselia* isp., cf. *Scolicia* isp., *Teichichnus* isp., *Thalassinoides* isp., fugichnia and a few unidentified burrows (in the lower part of the sandstones); whereas *Arenicolites* isp., *Asterosoma* isp., *Conichnus conicus*, ?*Diplocraterion parallelum*, ?*Diplocraterion* isp., *Macaronichnus segregatis*, *Ophiomorpha nodosa*, *Ophiomorpha* isp., *Rosselia* isp., ?*Scolicia* isp. and escape traces occur in the upper part of the sandstones (Fig. 5). The associated sedimentary structures, such as hummocky cross-stratification (HCS) and planar lamination (reported earlier by Wojewoda, 1997 and Wojewoda and Raczyński, 1997) are also recognized in this part of the section (in the fine- to medium-grained sandstones). In the pebbly sandstones and conglomerates, lying above in the section, a low-diversity trace-fossil assemblage was found, comprising mainly *Arenicolites* isp. and *Ophiomorpha nodosa* (more abundant). Additionally, in these deposits, cross-stratification and ripple-marks occur, as well as reactivation surfaces, clast imbrication and microcliffs (see also Wojewoda, 1997; Wojewoda and Raczyński, 1997).

Analysis of thin sections under the microscope confirmed the earlier descriptions made by Pachucki (1959). The sandstones studied contain feldspars and biotite (less muscovite) and fragments of rocks from the adjacent East Sudetic Island (the eastern limb of the Orlica-Śnieżnik Dome), which was the main source area at that time (see Jerzykiewicz, 1971; Wojewoda, 1997; Don and Gotowała, 2008; Biernacka and Józefiak, 2009).

The Idzików Conglomerate Member previously was considered as being not only Coniacian (Pachucki, 1959; Radwańska, 1960; Radwański, 1966) but also partially Santonian in age (Don and Don, 1960; Jerzykiewicz, 1971; Wojewoda, 1997, 2004; Don and Wojewoda, 2005; see also discussion in Kvaček *et al*., 2015). On the basis of the nannoplankton zones, Kędzierski (2002) proposed a middle Coniacian age for the Lower Idzików Beds but late Coniacian for the Upper Idzików Beds. According to recent studies of crinoids (*Styracocrinus* cf. *peractus* Peck, 1943), Niedźwiedzki and Salamon (2005) suggested that the Upper Idzików Beds are middle Coniacian –?late Coniacian in age (see also Trzęsiok *et al*., 2014). Halamski and Kvaček (2015, pp. 100, 140), on the basis of the ammonite *Placenticeras semiornatum* (d'Orbigny, 1850), also reported a late Coniacian age for the Upper Idzików Beds outcropping in the neighbourhood of Nowy Waliszów. Additionally, the Upper Cretaceous flora from Idzików that was studied by Kvaček *et al*. (2015) also points to a Coniacian age for the Idzików Beds.

DESCRIPTION OF TRACE FOSSILS

Twenty-four ichnospecies belonging to the following 18 ichnogenera were identified in the Idzików section. The ichnogenera include *Arenicolites*, *Asterosoma*, ?*Bergaueria*, *Conichnus*, *Curvolithus*, *Cylindrichnus*, *Dactyloidites*, *Diplocraterion*, *Gyrochorte*, *Gyrophyllites*, *Macaronichnus*, *Ophiomorpha*, ?*Palaeophycus*, ?*Rhizocorallium*, *Rosselia*, ?*Scolicia*, *Teichichnus* and *Thalassinoides*. Moreover, escape structures (fugichnia) and some unrecognizable burrows occur. The distribution of individual trace fossils on the walls A–C of the Idzików Quarry is shown in Figures 7A, 9G, 16, 17. The ichnodiversity, ichnodisparity and the bioturbation index of the trace-fossil assemblages are presented in Figure 15, while ichnoabundance in Table 1.

Arenicolites Salter, 1857

Arenicolites isp.

Figs 7A, C, 8E–G

Material: Three specimens collected (walls B, C).

Description: U-shaped, simple, unornamented burrow, which consists of vertical limbs perpendicular to the bedding planes, without spreiten, and the basal part, which is broadly curved. It is filled with the same structureless sediment as in the host rock. The whole structure is 3.5 cm wide (between limbs) and 6–9 cm high. The limbs are circular or elliptical in cross-sections and 0.5 cm wide. In some specimens (Fig. 8F), only a part of the burrow (a half) is observed. Individual laminae adjacent to the limbs are bent slightly downwards (Fig. 8F). One specimen observed on the sandstone wall B (Fig. 8G) is incomplete, but a subvertical limb and the U-shaped basal part are partly visible. The diameter of the tube is 0.5 cm, the length of the whole structure is 12 cm. This specimen is determined as ?*Arenicolites* isp.

Remarks: *Arenicolites* is considered as a domichnion of suspension- and filter-feeders or probably partially surface deposit-feeders (Gradziński and Uchman, 1994; Pemberton *et al*., 2001; Rindsberg, 2012). The trace makers are worm-like organisms, probably polychaetes or annelids, amphipod crustaceans and insects (Bromley, 1996; Chen *et al*., 2011). Modern analogues of possible producers are the polychaetes *Arenicola* (Pemberton *et al*., 2001; Carvalho *et al*., 2005) or *Nereis* (Hauck *et al*., 2009), the amphipod *Corophium* (Pemberton *et al*., 2001; Dashtgard *et al*., 2008) and the crab *Ocypode* (De, 2005). *Arenicolites* belongs to the *Skolithos*, *Cruziana* and the *Glossifungites* ichnofacies (MacEachern *et al*., 2007, 2012) in shallow-marine and marginal-marine settings (Zonneveld *et al*., 2001; Šimo and Olšavský, 2007). It ranges from the Cambrian (Häntzschel, 1962; Carbone and Narbonne, 2014), specifically from the lower Cambrian (Mángano and Buatois, 2016) to the Holocene (Baucon and Felletti, 2013; Knaust, 2017).

Asterosoma von Otto, 1854

Asterosoma isp.

Figs 7A, B, 8H, 9A–D

Material: Five specimens collected from walls B and C, including two very well preserved, more complete structures with several bulbs (Figs 8H, 9B) and three poorly preserved structures. Moreover, six cross-sections on the sandstone walls B and C were noticed. Some questionable specimens, described as ?*Asterosoma* isp., which appear on the sole of the bed (wall A, Fig. 9D) and on the sandstone surface (wall B, Fig. 7A, B) also were observed.

Description: A vertical, complex trace fossil, composed of a bunch of 5–15 bulb-shaped structures and associated tubes. A central tube, which looks like a narrow shaft, continues downward into this structure. The bunch is 20–25 cm long and 15–20 cm wide. The bulbs are up to 7.0–9.0 cm in diameter; their tube is 1 cm wide. Some cross-sections of individual bulbs of *Asterosoma*, showing concentric structures (3.0–9.0 cm in diameter), were also noticed (walls B, C, Figs 7A, 9A, C). Questionable specimen assigned to ?*Asterosoma* (Fig. 9D) is probably a fragment of *Asterosoma*, which is visible as a section across the two bulbs. The diameter of individual bulbs is up to 2 cm, the length of the entire structure is 8.5 cm. A poorly preserved, concentric structure is observed inside bulbs, as well as in the other questionable cross-sections, presented in Figure 7A, B.

Remarks: The cross-sections of *Asterosoma* (Figs 7A, B, 9A, C) are very similar to those reported by Chamberlain (1978, figs 8–10), Bromley and Uchman (2003, fig. 5A), Olivero and López-Cabrera (2005, fig. 5A, B, D, E) and Carmona *et al.* (2008, fig. 3/2). They show concentrically laminated bulbs, which consist of laminae surrounding a central tube.

Asterosoma is interpreted as a fodinichnion of detritus- or deposit-feeders (Pemberton *et al.*, 2001; Neto de Carvalho and Rodrigues, 2007). Some authors suggested crustaceans, such as crabs or lobster-like animals (glypheoids, anomurans, brachyurans) as possible producers of *Asterosoma* (Häntzschel, 1975; Głuszek, 1998). Annelids or polychaete worms are also proposed (Pemberton *et al.*, 2001). This ichnogenus is indicative mainly of the *Cruziana* ichnofacies (MacEachern *et al.*, 2007, 2012), though it can appear also in the *Skolithos*, *Zoophycos* and *Nereites* ichnofacies (Knaust, 2017). *Asterosoma* occurs in various environments, from paralic to deep marine, but is especially common in shallow-marine, shoreface deposits (Bromley and Uchman, 2003; Rindsberg and Martin, 2003; Knaust, 2017 and references therein). It is known from the Cambrian to Recent (Häntzschel, 1975; Dashtgard and Gingras, 2012).

Bergaueria Prantl, 1945
?*Bergaueria* isp.
Figs 9E, 12H

Material: One specimen on the upper bedding plane of a sandstone bed (wall C).

Description: Vertical trace, hemispherical at the base to short and cylindrical in the upper part, smooth, unlined or thinly lined. The width is nearly the same as the height or slightly greater, i.e. 3.5 cm. The base shows an apical, shallow depression with a few fragmentarily preserved and poorly visible, radial ridges (Fig. 9E). Burrow fill is structureless.

Remarks: The study trace fossil seems to be closely related to *Bergaueria*, but a poor state of preservation prevents detailed and undoubtful assignment. It shows some similarities to the specimen described by Alpert (1973; pl. 1, fig. 1) and Stachacz (2016, fig. 5.18a–f) in having a small depression and faint ridges. *Bergaueria* is interpreted as a dwelling or resting trace (domichnion, cubichnion) of sea anemones (Pemberton *et al.*, 1988; Pickerill, 1989; Pacześna, 2010). It is typical of the *Skolithos* and the *Cruziana* ichnofacies (Alpert, 1973). *Bergaueria* is a common hypichnion in softground siliciclastic deposits of beaches, tidal flats and shallow-marine to deep-sea settings (Knaust, 2017). This ichnotaxon is abundant in the lower shoreface, though it can appear from the upper offshore to the middle shoreface (Plink-Björklund, 2008; Nagel *et al.*, 2013; Bayet-Goll *et al.*, 2015a, b). *Bergaueria* ranges from the Ediacaran to Recent (Mángano and Buatois, 2016; Knaust, 2017).

Conichnus Männil, 1966
Conichnus conicus Männil, 1966
Figs 7A, 9F, G, 10A–C

Material: Five specimens visible on the sandstone quarry (walls B and C).

Description: Vertical, conical, smooth structures with rounded bases, 20–30 cm deep and up to 10 cm in diameter, indistinctly to thinly lined, oval in outline. In some cases, these structures display cone-in-cone chevron lamination (Fig. 10A, C). They taper gradually from the top to the base (see Figs 9F, 10B).

Remarks: *Conichnus* is generally regarded as a resting and/or dwelling structure (Pemberton *et al.*, 2001). Owing to the different behaviours of trace makers, it is also interpreted as an escape structure (Martini *et al.*, 1995; Curran, 2007; Mayoral *et al.*, 2013) or equilibrichnion (Savrda *et al.*, 1998; Abad *et al.*, 2006). In some cases, distinction of *Conichnus* from escape (fugichnia) and dewatering structures is difficult (cf. Buck and Goldring, 2003). The specimens studied seem to be equilibrichnia (Fig. 10C) or fugichnia (Figs 9F, 10A) and ?domichnia (Fig. 10B). The specimens studied do not differ from *Conichnus*, described by Mayoral *et al.* (2013, fig. 6D–G), Knaust (2017, fig. 5.42c; 5.43a, c–d) and Patel *et al.* (2018, fig. 3a–c). *Conichnus* is considered to have been produced by sea anemones (Pemberton *et al.*, 2001; Pacześna, 2010; Mata *et al.*, 2012). It is indicative of the *Skolithos* ichnofacies (MacEachern *et al.*, 2007, 2012) in shallow-marine environments (Pollard *et al.*, 1993; Curran, 2007), mainly in well-oxygenated, fully marine, shoreface settings (Dashtgard *et al.*, 2012; Pemberton *et al.*, 2012; Desai and Saklani, 2015). It ranges from the lower Cambrian to Recent (Zonneveld *et al.*, 2001; Savrda, 2002).

Curvolithus Fritsch, 1908
Curvolithus simplex Buatois, Mángano, Mikuláš and Maples, 1998
Fig. 10D

Material: One specimen on the upper sandstone surface in wall B.

Description: A horizontal, flattish, straight to slightly winding, unbranched, smooth burrow, 1.2 cm wide and 9 cm long. The upper surface is trilobate with a cental lobe, which is wider than marginal ones. It is separated from the marginal lobes by shallow furrows. The central lobe is 0.6 cm wide, while the marginal ones are 0.3 cm wide.

Remarks: *Curvolithus* is interpreted as a locomotion trace (repichnion) of gastropods, worm-like polychaetes, oligochaetes, nemerteans and holothurians (Fürsich and Heinberg, 1983; Greb and Chesnut, 1994; Buatois *et al*., 1998). The flatworms (Platyhelminthes) are also suggested as possibly producers (Lockley *et al*., 1987; Seilacher, 2007; Buatois *et al*., 2016a). It belongs to the *Cruziana* ichnofacies sensu Seilacher, 1967 or the *Curvolithus* subichnofacies sensu Lockley *et al*. (1987). The latter is typical for a deltaic-influenced nearshore setting (Baucon and Neto de Carvalho, 2008). Although *Curvolithus* is reported from various marine environments, it is common in sandy, marginal- and shallow-marine environments with significant input of sand but little reworking (Buatois *et al*., 1998; Hofmann *et al*., 2011). This ichnogenus can occur also in the upper offshore (Maples and Suttner, 1990). *Curvolithus* appears from the Ediacaran to Holocene (Lockley *et al*., 1987; Crimes, 1992).

***Cylindrichnus* Toots in Howard, 1966**
***Cylindrichnus* isp.**
Figs 7A–C, 10E

Material: Several specimens preserved on the sandstone wall B.

Description: The current specimens occur as broad, bow-shaped structures, which are formed by two vertical shafts with conical openings on the surface, connected by a horizontal tunnel (Fig. 7C). Individual, slightly curved cylindrical tunnels, which are slightly funnel-shaped in the upper part and tapering downwards are also common (Figs 7A–C, 10E). The tunnels are filled with concentrically laminated sediment. The burrow is oriented mostly vertically or obliquely in the proximal part, being curved downwards and showing more horizontal course in the distal parts. Broadly arcuate U-shaped structures are wider than deep. In some cases, tunnels may overcross (Fig. 7A, C), but usually they are separated and unbranched. Additionally, cross-sections of cylindrical tunnels occur as circular to ellipsoidal spots with concentric rings (Figs 7A, C, 10E). The individual, cylindrical tunnels 1.5–2.0 cm in diameter and up to 20 cm deep. In lateral view, the length of the U-shaped bow structures is up to 30–40 cm.

Remarks: The presence of U-shaped bow structures and fragments preserved as curved tunnels with conical upper parts tapering downwards (cf. Ekdale and Harding, 2015, fig. 7) indicates assignment to *Cylindrichnus*. However, poorly observed, concentric lining inside the burrows made their assignment doubtful in some cases (Fig. 7A). Some specimens observed in Figure 7B might indicate ?*Schaubcylindrichnus* Frey and Howard, 1981, owing to the presence of a bundle of thickly lined tunnels and circular cross-sections, lighter than the host rock (Fig. 7B; see Knaust, 2017, fig. 5.125). The current specimens also slightly resemble other burrows, such as *Skolithos*, *Rosselia* and bivalve traces from the ichnofamily Siphonichnidae (cf. Knaust, 2015). The vertical or subvertical shafts of *Cylindrichnus* can be mistaken for *Skolithos* (Fig. 10E) and their funnel-shaped upper apertures are similar to *Rosselia*, while cross-sections resemble *Siphonichnus* or *Laevicyclus* (Fig. 7A, C; see also Knaust, 2015, 2017). *Cylindrichnus* is regarded as a domichnion (Knaust, 2017). Trace makers are suspension- (filter-feeding) and surface deposit-feeders, polychaete worms – terebellids (Dashtgard *et al*., 2008; Ekdale and Harding, 2015). C*ylindrichnus* characterizes the distal *Skolithos* and the *Cruziana* ichnofacies (Knaust, 2017). It usually appears from the middle shoreface to middle offshore (abundant in the lower shoreface), especially in storm deposits with HCS structures, between the fair-weather and the storm-wave bases (Goldring *et al*., 2002; Baucon *et al*., 2015; Knaust, 2017). *Cylindrichnus* is known from early Cambrian to Holocene (cf. Knaust, 2017 and references therein).

***Dactyloidites* Hall, 1886**
***Dactyloidites ottoi* Geinitz, 1849**
Fig. 10F, G

Material: Three well-preserved specimens in a positive epirelief on the upper bedding plane (wall C, Fig. 10G).

Description: Two fan-shaped spreiten structures, radiating from a central point, which form almost complete rosettes (240–270°). Each rosette consists of 11–12 radial elements, which are subhorizontal, protrusive, vertical spreiten. One fragmentary, incomplete rosette (palmate-like spreiten structure), which is composed of 7 radial elements also occurs. Individual radial elements, up to 0.6 cm wide, are not constant in length (from 0.5 to 2.5 cm). Entire structures (rosettes) are 4.0–5.5 cm wide. A few primary radial elements of each rosette bifurcate, producing secondary radial elements in the outermost part of the radial structures (Fig. 10F).

Remarks: The presence of the fully radial shape of the study specimen and numerous radial elements of different lengths indicate assignment to *Dactyloidites ottoi* Geinitz, 1849 (see Fürsich and Bromley, 1985; Wilmsen and Niebuhr, 2014). Ethologically, it is a fodinichnion (Fürsich and Bromley, 1985). Gardening also is proposed for *Dactyloidites peniculus* D'Alessandro and Bromley, 1986 (see Uchman and Pervesler, 2007). The potential trace makers were worm-like organisms, which systematically reworked the sediment in search of food, or crabs (Gibert *et al*., 1995, and references therein).

It is typical of the distal *Skolithos* and proximal *Cruziana* ichnofacies (see Wilmsen and Niebuhr, 2014). This ichnospecies is a good palaeoenvironmental indicator, which occurs in specific, palaeoenvironmental conditions (e.g., nutrient-rich, shallowing-upward cycles or settings of reduced salinity). It is typical of shallow-water, nearshore to deltaic, siliciclastic settings (Fürsich and Bromley, 1985; Agirrezabala and Gibert, 2004). *Dactyloidites ottoi* is especially common in the lower shoreface settings, between fair- and storm-wave base (Lazo *et al*., 2008; Mayoral *et al*., 2013; Wilmsen and Niebuhr, 2014). *Dactyloidites ottoi* Geinitz, 1849 is a relatively rare form, known from ?Triassic, Jurassic to Neogene (Wilmsen and Niebuhr, 2014).

***Diplocraterion* Torell, 1870**
***Diplocraterion parallelum* Torell, 1870**
Figs 7A, 10H, I

Material: One specimen, very well preserved (wall C, Fig. 10H) and three specimens, poorly and fragmentarily preserved, observed on the vertical sandstone surfaces (wall B, Fig. 10I).

Description: *Diplocraterion parallelum* occurs as a vertical, U-shaped burrow with parallel limbs of constant thickness and spreiten connecting the arms. The basal part, slightly curved is also observed. It is always perpendicular or subvertical in relation to the bedding plane. Protrusive spreiten mainly have been recognized. The structure presented in Figure 10H is 26 cm high and 8 cm wide. Some poorly preserved specimens, described as ?*Diplocraterion parallelum* also occur (Fig. 10I). These structures are up to 14 cm long, and up to 10 cm wide.

Remarks: The study specimens show a close affinity to *Diplocraterion parallelum* in having U-shaped structures with protrusive spreiten. The questionable specimen, presented in Figure 10H, appears also as a U-shaped burrow with spreiten and arms diverging in the upper part, which is typical of this ichnospecies (see Fürsich, 1974a). However, owing to the poor state of preservation, the latter specimen is determined as ?*Diplocraterion parallelum*. *Diplocraterion* can be interpreted as a dwelling or equilibrium structure (domichnion, equilibrichnion) of suspension-feeding organisms (Bromley, 1996; Pemberton *et al*., 2001) or filter-, detritus-feeders and even benthic predators (see Uchman and Gaździcki, 2006). Mainly polychaetes (annelids) and crustaceans (amphipods; Cornish, 1986; Bromley, 1996; Rodríguez-Tovar and Pérez-Valera, 2013) are considered to be the trace makers. The modern analogues of marine *Diplocraterion*-type burrows are made by the amphipod *Corophium valutator* (Pemberton *et al*., 2001) and by the filter-feeding polychaete *Polydora ligni* (Hauck *et al*., 2009). *Diplocraterion* is most typical of the stiffground *Skolithos* ichnofacies (MacEachern *et al*., 2007, 2012) and the firmground *Glossifungites* ichnofacies (Rodríguez-Tovar *et al*., 2007). It is especially common in the middle shoreface setting, though it can appear from the foreshore to the lower shoreface (the distal end of the *Skolithos* ichnofacies; Pemberton *et al*., 2001, 2012), even to offshore (Knaust, 2017). Its stratigraphical range is from the Cambrian to Quaternary (Cornish, 1986; Gradziński and Uchman, 1994).

?*Diplocraterion* isp.

Figs 7A, 11A

Material: One U-shaped burrow and two questionable specimens observed on the sandstone wall B.

Description: A narrow, long U-shaped burrow with spreiten, 14 cm long and 4 cm wide. The marginal tubes are slightly converging in the upper part of the burrow. Two small, U-shaped specimens, probably ?*Diplocraterion* isp., each 3.5 cm long and 1.5 cm wide, are also visible.

Remarks: The study specimen shows some typical features for the ichnogenus *Diplocraterion*, such as U-shaped morphology and spreiten between the tubes. Owing to the poor state of preservation, it was assigned to ?*Diplocraterion* isp. It is most similar to *Diplocraterion habichi* Lissón, 1904 (now *Tisoa habichi* Lissón, 1904; see Knaust, 2019, fig. 6D) in having a U-shaped, narrow structure, with diverging arms and well-developed spreiten, especially in the lower part of the burrow (see Abbassi, 2007). Two small specimens presented in Figure 11A are also U-shaped spreite-like burrows and might be assigned to ?*Diplocraterion* isp.

Gyrochorte Heer, 1865

Gyrochorte isp.

Fig. 11B

Material: One negative hyporelief in a bed in wall B.

Description: A straight to slightly winding, horizontal, unbranched burrow, composed of two parallel grooves, almost the same width, with a median ridge between them in a negative hyporelief (and consequently, in a positive epirelief, two convex lobes, with a median furrow). It seems, on the basis of the preserved grooves, that lobes (in a positive epirelief) might have been rather gently vertical flanks, instead of steep ones. In transverse cross-section, a current burrow resembles "w"-shaped morphology in a negative hyporelief and "m"-shaped morphology in a positive epirelief (double arches with depression in the middle). The whole structure is 4 mm wide, up to 2 mm deep. The median ridge is 1.0–1.5 mm high above the bedding plane, while visible length attains 6 cm.

Remarks: The current specimen, which is a bilobate trace fossil, is not well preserved, but the occurrence of two grooves with a median ridge (negative hyporelief), allows assignment of the trace fossil to *Gyrochorte* (cf. Gibert and Benner, 2002, fig. 1C; Fürsich *et al*., 2017, fig. 3B). Internal transverse lamination (oblique spreiten), which is common for this ichnogenus, is not observed at the surface of the grooves, probably owing to the poor state of preservation. The current specimen differs significantly from the other locomotion trace fossil *Archaeonassa fossulata* Fenton and Fenton, 1937, which also possesses a pair of grooves and a central ridge in a negative epirelief (compare Buatois and Mángano, 2016, fig. 2.8g, h), in having a narrower central zone, instead wider ones (compare Buckman, 1994; fig. 2B). *Gyrochorte* is a pascichnion (Heinberg and Birkelund, 1984) or a fodinichnion-pascichnion (Schlirf, 2003). Recently, Wetzel *et al*. (2020) proposed sequorichnial behaviour for some *Gyrochorte* producers. Trace maker of *Gyrochorte* was a deposit- or detritus-feeder, a worm-like organism, probably an annelid (Heinberg, 1973; Gibert and Ekdale, 2002). Gastropods and crustaceans also have been suggested (Gibert and Benner, 2002; Chen *et al*., 2011). *Gyrochorte* characterizes mainly the *Cruziana* ichnofacies (MacEachern *et al.*, 2007, 2012). The study ichnotaxa typically occurs in sandy facies in moderate-energy, nearshore (marginal-marine) and shallow-marine, storm-influenced palaeoenvironments (Gibert and Benner, 2002; Baucon and Neto de Carvalho, 2016). It is known from the Ordovician to the Pliocene (Gibert and Benner, 2002).

Gyrophyllites Glocker, 1841

Gyrophyllites aff. *kwassizensis* Glocker, 1841

Fig. 11C–E

Material: One specimen preserved as hypichnion, and the second as negative epirelief (walls A, C respectively).

Description: One of the current specimens (Fig. 11C, D) occurs as a star-shaped burrow, horizontal to the bedding plane, which is composed of a few rays (4–?6), radiating from a central point (probably an axial tube), but this part of the trace fossil is poorly preserved. Four curved, petaloid (oval to subcircular), unbranched lobes are well-preserved. The outer margins of the rays are well marked (in the form of convex rings). It seems that the lobes can overlap. The diameter of the whole structure is 4 cm. Each ray is 1.0–1.3 cm wide and 1.65–2.25 cm long, while the central shaft is 0.9 cm wide. The second specimen, which resembles an isolated disc (Fig. 11E), occurs as a rimmed structure, surrounded by a convex arc (0.3 cm wide). Moreover, the outer margins of individual lobes (?6–7) are slightly convex. The entire structure is 3.5 cm wide.

Remarks: The study specimens, preserved as radial structures (rosetted), show close similarity to the ichnogenus *Gyrophyllites* Glocker, 1841 (see Fürsich and Kennedy, 1975; text-fig. 3) in having horizontal, unbranched, swollen, leaf-like lobes, radiating from a central shaft (cf. Uchman, 1998), which can overlap. The study specimens shows a close affinity to *Gyrophyllites kwassizensis* Glocker, 1841 in having partially marked, an elevated outer margin (irregularly circular; Fig. 11C–E), which seems to rim the structure (cf. Strzeboński and Uchman, 2015, fig. 7A). Moreover, some specimens of *G. kwassizensis* have the outer margin of individual lobes in form of a concave arc, as in the study specimen (Fig. 11C, D; see also Strzeboński and Uchman, 2015, fig. 8A, F). The study specimen (Fig. 11C, D) differs from *G. kwassizensis* in having a smaller quantity of petaloid lobes in a rosette (4–?6, 7–15 respectively), which are rather oval (subcircular), instead of elongate and narrower. However, probably some lobes in a study specimen (Fig. 11C, D) could be absent because of erosion. Owing to the poor state of preservation, which does not allow precise assignation, the current specimen was described as *Gyrophyllites* aff. *kwassizensis*. The current specimen (Fig. 11C, D) seems to slightly resemble the newly recognized ichnospecies *Gyrophyllites cristinae* Muñoz, Mángano and Buatois, 2019 that is characterized by the presence of only one level of five to six petaloid, non-overlapping lobes, which are smooth and oval to subcircular (cf. Muñoz *et al*., 2019, fig. 4). The main difference is the lack of one distinctly smaller lobe, what is a common feature of *G. cristinae*. Moreover, the presence in the current specimen slightly curved, overlapping lobes, is absent in *G. cristinae*. The specimen in Figure 11E, which occurs as a rimmed structure (rosette), is preserved in a negative epirelief, as usually is the case for specimens related to *G. kwassizensis* (cf. Strzeboński and Uchman, 2015). The current specimen shows resemblances to *G. rehsteineri* Fischer-Ooster, 1858 (now *G. kwassizensis*, see Uchman, 1998), described by Fürsich *et al*. (2013, fig. 127), Knaust *et al*. (2014, fig. 9l), Strzeboński and Uchman (2015, fig. 7A) and Hammersburg *et al*. (2018, fig. 13/6) in having lobes with a rounded margin in a distal part. Moreover, the individual lobes are straight or gently curved, as in the case of *G. kwassizensis* and can overlap (compare with Strzeboński and Uchman, 2015, fig. 6A, D). The presence of clusters (concave rays), probably radiating from a central point, might indicate assignment not only to *Gyrophyllites*, but also to *Asterosoma.* Głuszek (1998; see also Hammersburg *et al*., 2018) concluded that *Asterosoma* von Otto, 1854 strongly resembles *Gyrophyllites*, especially where it is observed in a horizontal section, e.g., on a bedding plane. The discussed specimen (Fig. 11C, D) shows more resemblance to *A. radiciforme* von Otto, 1854, which has a star-like arrangement of bulbs (Häntzschel, 1975; Olivero and López Cabrera, 2005; Seilacher, 2007), instead of a dichotomous to fan-like pattern of branching bulbs, typical of *A. ludwigae* Schlirf, 2000 (see also Neto de Carvalho and Rodrigues, 2007). However, the presence of slightly curved, overlapping lobes with convex-up outer margins and the convex arc, which seems to rim the rosettes, makes the assignation of the current specimens to *Gyrophyllites* certain.

Gyrophyllites is regarded as a fodinichnion of detritus- or shallow deposit-feeders, worm-like trace makers, mostly polychaetes (Strzeboński and Uchman, 2015). Other suggested producers are crustaceans (amphipods, decapods), bivalves and fish (Muñoz *et al*., 2019). It characterizes the *Cruziana* and *Nereites* ichnofacies (Strzeboński and Uchman, 2015; Muñoz *et al*., 2019). *Gyrophyllites* appears in fine-grained, nutrient-rich storm beds (shoreface-offshore), usually below fair-weather wave base (cf. Muñoz *et al*., 2019) or in the deep sea (Strzeboński and Uchman, 2015). *Gyrophyllites kwassizensis* is known from the Cambrian (Hammersburg *et al*., 2018).

***Macaronichnus* Clifton and Thompson, 1978**
***Macaronichnus segregatis* Clifton and Thompson, 1978**
Fig 11F

Material: Several specimens, preserved in high density on the sandstone surface (walls B, C).

Description: *Macaronichnus* occurs as horizontal, subhorizontal or rarely oblique, cylindrical burrows, which are circular in cross-section, 5 mm in diameter, from a few millimetres to 20 mm long. The burrows are filled with sediment that is lighter than the surrounding rock, while the outer burrow margin (so-called mantle) is composed of darker mineral grains. They are mostly unbranched, except for some rare cases, and follow a straight or slightly meandering course. The specimens studied occur usually in groups of several individual tunnels.

Remarks: The specimens studied show close similarity to *Macaronichnus*, due to segregation of mineral grains, typical for this ichnogenus (Bromley *et al*., 2009). They are most similar to *Macaronichnus segregatis degiberti* in having partly oblique to vertically oriented burrows and larger dimensions (see Rodríguez-Tovar and Aguirre, 2014; Knaust, 2017). Previously, similar specimens from the Idzików Quarry were considered by Wojewoda and Raczyński (1997, fig. 38D) to be coprolites. Vertebrate coprolites, which were reported from the Lower Idzików Beds (Stary Waliszów) by Brachaniec and Wieczorek (2016), also could have a sinusoidal to slightly curved course (compare Luo *et al*., 2017). Moreover, the current burrows slightly resemble invertebrate coprolites, which also might be "string-shaped" (see Knaust, 2020, fig. 2), though in comparison to the specimens studied, they have smaller sizes. However, the segregation of mineral grains, which was observed in cross-section of the current specimens (darker mineral grains are situated along the outer margins of burrows, while the core is composed of lighter grains), certainly indicate assignment to *Macaronichnus segregatis*.

The current ichnogenus is assigned to fodinichnia (Clifton and Thompson, 1978), pascichnia (Rodríguez-Tovar and Aguirre, 2014) or sequorichnia, a new ethological behaviour proposed by Nara and Seike (2019) for some *Macaronichnus* trace makers. It characterizes both the *Skolithos* and *Cruziana* ichnofacies (MacEachern *et al*., 2007, 2012; Buatois and Mángano, 2011). Trace makers are ophelid polychaetes (cf. Clifton and Thompson, 1978; Nara and Seike, 2004), e.g., *Ophelia limacina*, *Euzonus mucronata*, *Travisia japonica* (Seike, 2007; Dafoe *et al*., 2008; Seike *et al*., 2011). The producers used to feed on the microbes on quartz grains (cf. Uchman and Krenmayr, 2004; Knaust, 2017 and references therein). In shallow-marine environments, *Macaronichnus* is common in foreshore and shoreface settings (cf. Pemberton *et al*., 2001). It is known from early Cambrian to Cenozoic (Knaust, 2017).

Ophiomorpha Lundgren, 1891

Ophiomorpha nodosa Lundgren, 1891

Figs 11G, 12A, B

Material: Several specimens, tunnels and their openings, preserved on the sandstone walls A–C.

Description: *Ophiomorpha nodosa* appears mainly as single, isolated, tubular shafts or a boxwork, composed of tubular burrows. The burrows are in some cases branched and usually exhibit a Y-shaped branching pattern. They are mostly vertical or inclined, rarely horizontal. Fragments of the burrows, visible on the rock surface, are up to 25 cm long and 1.0–2.0 cm wide. The burrow wall is built of predominantly dense, knobby sand pellets (up to 1 cm long), regularly spaced along the wall, perpendicular to the long axis of the trace fossil (see Fig. 11G). The burrow fill is mainly structureless and similar to the surrounding matrix. *Ophiomorpha* is mostly elliptical, rarely circular in cross-sections.

Remarks: The current specimens can be assigned to *Ophiomorpha nodosa* in having a characteristic pelleted wall and swollen chambers (turn arounds), typical of trace fossils from the so-called "*Ophiomorpha* group" (see Frey *et al*., 1978; Uchman, 1995; Seilacher, 2007). Niebuhr and Wilmsen (2016) suggested that *Ophiomorpha saxonica* Geinitz, 1842 (earlier *Spongites saxonicus* Geinitz, 1842 or *Thalassinoides saxonicus*, Kennedy, 1967) should be used instead of *Ophiomorpha nodosa* Lundgren, 1891 (see also Fürsich, 1973; Schlirf, 2000, 2005; Rindsberg, 2018). However, *Spongites saxonicus* was recommended for burrows with pellets up to 1 cm long, having several, usually large swollen chambers (see Geinitz, 1842).

Ophiomorpha nodosa is interpreted as a domichnion or domichnion/fodinichnion (Frey *et al*., 1978; see also Uchman and Gaździcki, 2006). The trace makers of *Ophiomorpha* are interpreted as deposit- and/or suspension-feeders to farmers (Bromley, 1996). *Ophiomorpha* is produced by decapod crustaceans, mainly callianassid shrimps; however, crayfish and crabs also are considered as producers (Frey *et al*., 1978; Gibert *et al*., 2006). *Ophiomorpha* is characteristic of the *Skolithos* and the *Cruziana* ichnofacies (Frey and Seilacher, 1980). It is most common in shallow-marine and marginal-marine settings (foreshore and shoreface; Frey *et al*., 1978; Curran, 1985; Curran and White, 1991; Goldring and Pollard, 1995), although *Ophiomorpha* occurs also in offshore settings (Frey, 1990; Frey and Howard, 1990), in deep sea (Uchman, 1991, 1992) and in non-marine settings (Merill, 1984). *Ophiomorpha nodosa* Lundgren, 1891 predominates in shallow-marine settings, whereas the other ichnospecies *O. annulata* (Książkiewicz, 1977), or *O. rudis* (Książkiewicz, 1977) occur in deep-sea settings (Uchman, 2009; Leaman *et al*., 2015). This ichnogenus is known from the Permian to the Holocene (Frey *et al*., 1978), but according to Anderson and Droser (1998), the oldest finds come from the Pennsylvanian.

Ophiomorpha isp.

Figs 9G, 10F, 11H, 12C–G

Material: Some tunnels and several openings (Figs 9G, 10F) and some questionable specimens observed on the sandstone walls A–C (Figs 12C–G).

Description: Straight to slightly sinuous, cylindrical, unbranched, unlined or thinly lined burrows, which are oriented vertically or rarely horizontal to the bedding plane. Tunnels and cross-sections (openings) have poorly preserved walls, without clearly visible pellets (Figs 10F, 11H). Additionally, some questionable specimens are preserved; one on the sole of the bed as a slightly curved tunnel (Fig. 12C). The other burrows (vertical or inclined to the bedding plane) have a meniscate filling (Fig. 11D–F). The individual tunnels are up to 45 cm long (see Fig. 12E), while their openings are usually 1.0–2.0 cm, rarely up to 3.0 cm wide (Fig. 10F). The meniscate laminae in the trace fossil tentatively assigned to ?*Ophiomorpha* isp. are 0.4 cm (Fig. 12D) or 0.4–0.7 cm apart (Fig. 12E, F). Moreover, one horizontal hypichnion, described as ?*Ophiomorpha* isp. (Fig. 12G), consists of a horizontal, unbranched, lined cylinder (12 cm long, 2.0 cm wide), terminating in a wide chamber (17 cm long and 10 cm wide). The cross-section of the chamber seems to be circular to subellipsoidal. Swollen chambers, up to 17 cm in length and 10 cm in width, also are observed at the end of the cylindrical tunnels (Fig. 12G), as well as numerous openings.

Remarks: Some of the burrows studied are poorly preserved (probably owing to erosion) and do not have the clearly visible pelleted lining, characteristic and diagnostic for *Ophiomorpha nodosa* (Frey *et al*., 1978). For this reason, they were assigned to *Ophiomorpha* isp. (Figs 9G, 10F, 11H). The cross-sections of cylindrical tunnels, observed in Figure 10F, owing to their large diameter (up to 3 cm) and elongated shape, might belong to ?*Thalassinoides*. However, it seems that these openings show more resemblances to *Ophiomorpha* (e.g., ?*Ophiomorpha irregulaire* Frey, Howard and Pryor, 1978; Frey *et al*., 1978). They possess elliptical cross-sections, up to 3.0 cm wide, and poorly preserved pellets, creating "flame-like structures" at the top and on the sides of the burrows (compare Boyd *et al*., 2012 and references therein, fig. 5). That elongated shape, as well as the "flame-like structures" extending from the burrow margin in *Ophiomorpha* might be explained as resulting from compaction (cf. López Cabrera and Olivero, 2014).

Other specimens, which occur as mostly vertical shafts with meniscate structures, typical of ophiomorphids (but not diagnostic for *Ophiomorpha*; compare Fürsich, 1973, fig. 2D; Frey *et al*., 1978; Rindsberg, 2018, fig. 1) are determined as ?*Ophiomorpha* isp. (Fig. 12D–F). However, the presence of menisci and a distinct wall in a questionable trace fossil (Figs 12E, F) also might indicate *Beaconites* Vialov, 1962. The specimen shown in Figure 12F, which occurs as a vertical, sharply lined and meniscate cylindrical burrow, is most similar to *Beaconites capronus* Howard and Frey, 1984 (formerly *Ancorichnus capronus*, Howard and Frey, 1984) in having a poorly preserved, chevron-shaped cross-section of its backfill, which consists of strongly arcuate menisci (compare Boyd and McIlroy, 2017, fig. 9). *B. capronus* typically exhibits horizontal or subhorizontal burrows, but in some cases also vertical shafts (cf. Boyd and McIlroy, 2017). The other specimens (Fig 12E), which exhibit backfill, characterized by thin and gently arcuate menisci, show more similarity to *Beaconites coronus* Frey, Pemberton and Fagerstrom, 1984 (Frey *et al*., 1984b). However, several other ichnospecies show meniscate infill as well (compare Bromley, 1996; Knaust, 2018). *Ophiomorpha* with meniscate infill of the tunnel was reported by Gibert *et al*. (2012; fig. 5D) and Chrząstek (2013a, figs 7F, 8B). The study specimens have a distinct wall and for this reason they differ from *Taenidium* Heer, 1877, which is unlined (Keighley and Pickerill, 1994). They also do not show similarity to *Ancorichnus* Heinberg, 1974, owing to their vertical orientation and lack of an outer mantle, instead of a wall (cf. Keighley and Pickerill, 1994).

Another questionable specimen (Fig. 12G) can be assigned to *Ophiomorpha* Lundgren, 1891 in having a chamber, which might have been a turning chamber (swollen chamber) typical of ophiomorphids. The main difference is the lack of a characteristic pelletal wall and a diameter and length of this chamber too large in comparison to the chambers usually reported in *Ophiomorpha*. However, the trace fossil studied also shows some similarities to *Macanopsis* Macsotay, 1967 described by Muñiz and Mayoral (2001, figs 6, 7) and Neto de Carvalho and Baucon (2010, fig. 1b), which also possess a wide, elongated, horizontal chamber. The main difference is the lack of a vertical, cylindrical tunnel (upper shaft), which seems to be horizontal. Additionally, though the dimension of the trace fossils is not the most important and diagnostic feature, the current specimen shows a length (average 17 cm) and a width (up to 13 cm) of the horizontal chamber, which is similar to the dimensions seen in *Macanopsis* (compare Muñiz and Mayoral, 2001). Moreover, the study burrow shows also some similarities to the rosary-shaped trace fossil *Rosarichnoides sudeticus* Chrząstek, Muszer, Solecki and Sroka, 2018, which also belongs to the "*Ophiomorpha* group" sensu Uchman (1995), in having a large chamber and a cylindrical tunnel (see Chrząstek *et al*., 2018).

Palaeophycus Hall, 1847
?*Palaeophycus* isp.
Fig. 12H

Material: A few specimens, preserved on the upper bedding plane (Fig. 12H; wall C), which co-occur with ?*Bergaueria* isp. and an ?almond-shaped burrow (Fig. 12H).

Description: Horizontal, straight or slightly curved, unbranched, cylindrical burrow, which is slightly elliptical in cross-section. In some specimens, on the upper part of cylindrical burrows, a central furrow appears. The filling of the burrow is similar to the host rock. It is 0.6 cm wide, while the total visible length is up to 12 cm. The questionable, almond-shaped burrow is 1.3 cm long and 0.9 cm wide.

Remarks: The specimen studied is most similar to *Palaeophycus*, because of the presence of wall and the filling, which is the same as the surrounding rock. However, owing to the poor state of preservation, it is determined as ?*Palaeophycus* isp. The current specimen shows some similarities to *Palaeophycus imbricatus* Torell, 1870, in having a central furrow on the upper part of a cylindrical burrow (cf. Jensen, 1997, figs 46A, 47D). It also shows some resemblance to a bivalve burrow, e.g., *Protovirgularia* M'Coy, 1850, in having in some cases, a trapezoidal shape of the cylindrical burrow and slightly triangular cross-section, but differs in lack of the ribs, arranged in a chevron-shaped pattern (cf. Fernandez *et al*., 2010). The questionable, ?almond-shaped burrow (Fig. 12H) might resemble *Lockeia* James, 1879 but owing to the poor state of preservation, the assignation is doubtful. *Palaeophycus* is regarded as a dwelling burrow of suspension-feeding organisms or predators (Pemberton and Frey, 1982) or a domichnion/fodinichnion (Jensen, 1997; Knaust, 2017). In shallow-marine settings, the possibly producers are mostly polychaetes or other worm-like invertebrates (Pickerill *et al*., 1984; Keighley and Pickerill, 1995). *Palaeophycus* is a eurybathic form and appears both in shallow- and deep-marine settings (e.g., Knaust, 2017 and references therein), mostly in the *Skolithos*, *Cruziana* and the *Glossifungites* ichnofacies (Frey and Seilacher, 1980; MacEachern *et al*., 2007, 2012). In shallow-marine siliciclastic deposits, it is more common in the lower shoreface to the lower offshore (Pemberton *et al*., 2001, 2012; Buatois and Mángano, 2011; Mayoral *et al*., 2013). *Palaeophycus* occurs from Ediacaran to Recent (Häntzschel, 1975; Mángano and Buatois, 2016).

Rhizocorallium Zenker, 1836
?*Rhizocorallium* isp.
Fig. 13A, B

Material: Two hypichnia (walls A, C).

Description: Straight, subhorizontal, U-shaped burrows with spreite structure, 4.0–15.0 cm wide and 12–20 cm long, which are horizontal or oblique to the bedding. The marginal tunnel is poorly and only partially observed (Fig. 13B). The tubes are elliptical in cross-sections. Spreiten between the arms are fragmentarily preserved (Fig. 13A).

Remarks: The specimens studied are similar to *Rhizocorallium* in having a U-shaped spreite structure and a partially marked marginal tube, which enclose spreiten, but owing to the poor state of preservation, they are determined as ?*Rhizocorallium* isp. Probably, this is *R. commune* Schmidt, 1876, which is parallel or slightly inclined to the bedding plane (compare Knaust, 2013, fig. 5.117; Zhao *et al*., 2020; Fig. 13B). *Rhizocorallium* is interpreted mainly as a fodinichnion, less commonly as a domichnion (Knaust and Costamagna, 2012; Knaust, 2013) or even recently as an agrichnion (gardening and storage behaviour; see Zhang *et al*., 2016; Zhao *et al*., 2020). Their trace makers are deposit feeders, worm-like animals, possibly polychaetes or decapod crustaceans (Fürsich, 1974b; Knaust, 2007). *Rhizocorallium commune* is a softground burrow and appears in the *Cruziana* ichnofacies, while *R. jenense* characterizes the *Glossifungites* ichnofacies, typical of firmgrounds (Knaust, 2013). *Rhizocorallium* is common in shallow-marine, siliciclastic deposits, usually in the lower shoreface-offshore settings (Pemberton *et al*., 2001, 2012; Rodríguez-Tovar and Pérez-Valera, 2008; Chrząstek, 2013b and references therein). It is known from the early Cambrian to the Holocene (Knaust, 2013; Zhang *et al*., 2016 and references therein).

Rosselia Dahmer, 1937
Rosselia isp.
Figs 7A, C, 9G, 13C–F

Material: Five specimens, almost complete preserved (walls B and C).

Description: The current specimens are preserved in full relief, as isolated, vertical or slightly inclined, funnel-shaped burrows, tapering downwards, with a central tube, filled with sandy sediment, surrounded by concentric, muddy lamination. The internal lamination is fragmentary but poorly preserved (Fig. 13C, D, F). The burrows are lined, circular to oval, rarely slightly elongated in cross-section. They are rarely branched, in the form of secondary successive branching (Y-shaped; Fig 13C). In the upper part, the study specimens have a single swelling, while their distal parts are rather horizontal and have smaller diameters (Fig. 13D). It is 4 cm wide and 20 cm long. The branching is up to 12 cm long.

Remarks: The occurrence of a single, bulb-like swelling with internal, concentric lamination in the proximal parts of the study burrows indicates assignment to *Rosselia* (see Nara, 1997, figs 2, 3, 5; Knaust, 2017, fig. 5.120g). Moreover, a vertical or oblique orientation and funnel shape of burrows, tapering downwards, also might be evidence of *Rosselia* (compare Uchman and Krenmayr, 1995, fig. 4D). The study specimens are similar to *Asterosoma*, which also appears as vertical shaft with bulbs that have concentric lamination, but differ from it by lacking a single bulb-like swelling in the proximal part of the vertical, lined burrow (compare Uchman and Krenmayr, 1995; Hoffmann and Grimmberger, 2011, fig. 8, p. 108; see also Knaust, 2017). The Y-shaped branching, which is observed in Figure 13C may be evidence of *Asterosoma*, but *Rosselia* also occasionally has preserved branches (cf. Knaust, 2017, fig. 5.120a, c), caused by erosion, when the trace maker tries to find a new connection to the sediment surface (cf. Uchman and Krenmayr, 1995; Fierling, 2007; compare Campbell *et al*., 2016, fig. 1). Some of the study burrows show a close affinity to *Cylindrichnus* (Fig. 13D, E), in having a similar conical upper part of the burrows, which tapers downwards (cf. Uchman and Krenmayr, 1995; Knaust, 2017). Especially the lower part of *Rosselia* shows a similarity to *Cylindrichnus* (cf. Uchman and Krenmayr, 1995; Fig. 13D). The specimen in Figure 13F also is slightly similar to the bivalve burrow *Siphonichnus ophthalmoides* (Jessen, 1950) (Knaust, 2015, fig. 7B), in having a vertical tube, but it differs in the lack of a preserved, laminated, meniscate mantle. *Rosselia* is regarded as a fodinichnial-domichnial structure of deposit-feeders, worm-like organisms, probably annelids or predators, and sea-anemones (Uchman and Krenmayr, 1995 and references therein). Equilibrichnion is also indicated (Buatois *et al*., 2016b; Knaust, 2017 and references therein). It is characteristic of the distal *Skolithos* and *Cruziana* ichnofacies in low- to moderate-energy settings (Uchman and Krenmayr, 2004), especially from the lower shoreface to the upper offshore (Uchman and Krenmayr, 1995). It is also common in the middle shoreface (Buatois and Mángano, 2011; Pemberton *et al*., 2012). It is known from the Cambrian to the Holocene (Uchman and Krenmayr, 1995; Nara and Haga, 2007).

Scolicia group
Scolicia de Quatrefages, 1849
?*Scolicia* isp.
Figs 7A, C, 9G, 13C, E, G

Material: One specimen, preserved in a perpendicular cross-section (Fig. 13C) and two questionable specimens (Fig. 13E, G), walls B, C.

Description: The current specimen (Fig. 13C) appears as a horizontal, sinuous trace fossil with ?bilobate backfill, which consists of alternating, sandy and muddy laminae. It is preserved in a cross-section, which has an oval (heart-like) shape. The outline of the individual laminae (menisci) resembles the general outline of the burrow. The upper part of the burrow (margin) is slightly concave (convex-upward) with a middle part, which seems to be concave-downwards. The others are poorly preserved specimens (Fig. 13E, G) probably exhibit an elliptical cross-section of laminated backfill. It seems that in the lower part of the cross-section, a structure resembling string is present (Fig. 13G). The study specimens are 6–10 cm in width and in up to 9 cm in length (deep).

Remarks: The study specimens show resemblances to *Scolicia* in having a laminated (meniscate) backfill, an oval to heart-like shape and a concave-upward upper part of the trace (cf. Knaust, 2017, figs 5.130, 5.135). Owing to a very poor state of preservation and not observed strings (only at the base is a structure, which might resemble string, Fig. 13G), the current specimens were assigned to ?*Scolicia* (Fig. 13C) or cf. *Scolicia* (Fig. 13E, G). The study specimens differ from other trace fossils, belonging to the *Scolicia* group (cf. Uchman, 1995), e.g., *Bichordites* Plaziat and Mahmoudi, 1988, in lacking a distinctly bilobate structure in its upper part and an internal, central core (cf. Uchman and Krenmayr, 1995, fig. 7). The current specimen, observed in

Figure 13C, is slightly similar to *Asterosoma*, which also has a laminated internal structure in cross-section (compare Carmona *et al*., 2008, fig. 3/2), but differs in the lack of a concave and slightly bilobate, upper part of the burrow.

Scolicia is regarded as a fodinichnion (Knaust, 2017) or a pascichnion (Uchman, 1995). Trace makers of *Scolicia* were echinoids (cf. Smith and Crimes, 1983; Uchman and Krenmayr, 1995 and references therein). *Scolicia* characterizes the *Cruziana*, *Zoophycos* and *Nereites* ichnofacies (MacEachern *et al*., 2007; Knaust, 2017). In shallow-marine deposits, it is common lower-shoreface settings (Carmona *et al*., 2020). It is known from Late Jurassic to Recent (Uchman, 1995).

***Teichichnus* Seilacher, 1955**
***Teichichnus* isp.**
Figs 9G, 13H, I

Material: One specimen on the upper bedding plane (Fig. 13H) in wall C.
Description: A vertical, unbranched, trough-like structure (with an arcuate shape), which appears as patches of stacked laminae (concave-up spreiten), which are observed on the vertical sandstone wall (Fig. 13I). The individual, cylindrical, horizontal burrow, which occurs on the upper bedding plane (Fig. 13H), constitutes an upper part of *Teichichnus*. It is 14 cm long, while width between the two cylindrical tunnels (each up to 0.5 cm wide) is 4.5 cm (Fig. 13H). The vertical development of spreite, which is observed on the vertical sandstone wall, reaches up to 10 cm (Fig. 13I).
Remarks: This specimen shows similarity to *Teichichnus* described by Castelltort *et al*. (2011), in having well-developed spreiten, observed on the vertical wall. Most often, it is interpreted as a fodinichnion (Häntzschel, 1975; Buckman, 1996; Fürsich, 1998; Locklair and Savrda, 1998). This trace fossil also was considered to be an equilibrichnion (Bromley, 1996; Gibert *et al*., 2011). Potential producers represent different behaviours, including deposit- and suspension-feeding, gardening and equilibrium movement (Knaust, 2018). The trace makers are probably worm-like animals or arthropods (trilobites, crustaceans; Pickerill *et al*., 1984; Pemberton *et al*., 2001; Uchman *et al*., 2013). Echiurans, holothurians, sipunculids and bivalves also have been suggested as potential producers of *Teichichnus* (Knaust, 2018 and references therein). This ichnogenus is a marine trace fossil with a predominance in the shallow-marine environments (lower shoreface-offshore) but also can appear in marginal- and deep-marine settings (compare Pemberton *et al*., 2001; Knaust, 2017, 2018 and references therein). It is known throughout the Phanerozoic (Häntzschel, 1975; Buckman, 1996). *Teichichnus* was described from the Cambrian (Loughlin and Hillier, 2010), specifically from the Fortunian (Mángano and Buatois, 2016).

***Thalassinoides* Ehrenberg, 1944**
***Thalassinoides* isp.**
Fig. 14A

Material: Two well preserved specimens and a poorly preserved boxwork, observed on the vertical sandstone wall C.
Description: Cylindrical, unlined, flattened tunnels, elliptical in cross-section, which exhibit a Y-shaped branching pattern (Fig. 14A). The burrows are up to 12 cm long and 6.0 cm wide (between branching arms). The individual tunnels are 1.5–2.0 cm wide. The boxwork consists of Y-shaped tunnels, which are up to 4.0 cm wide.
Remarks: The described specimens show similarities to *Thalassinoides suevicus* (Rieth, 1932), especially in having a Y-shaped branching pattern. *Thalassinoides* is considered to be a domichnion (Myrow, 1995), a fodinichnion (Bromley, 1996) or an agrichnion (Ekdale and Bromley, 2003). The trace makers are mainly crustaceans: thalassinidean shrimps, crabs, lobsters, cerianthid sea anemones, and enteropneust acorn worms; fishes also are suggested as potential producers (Frey *et al*., 1984a; Myrow, 1995; Ekdale and Bromley, 2003; Chen *et al*., 2011). In the case of non-marine occurrences, crayfish are possible producers (Kim and Kim, 2002; Neto de Carvalho, 2016). Modern analogues of the trace makers are *Callianassa*, *Mecochirus*, *Glyphea*, *Haploparia*, ?*Atherfieldastacus* (Neto de Carvalho *et al*., 2007, 2016; Yanin and Baraboshkin, 2013; González-León *et al*., 2017 and references therein). *Thalassinoides* is a common constituent of the *Cruziana* ichnofacies (MacEachern *et al*., 2007) and may occur in softgrounds, firmgrounds or even hardgrounds (Myrow, 1995). This facies-crossing ichnogenus is common in shallow-marine (Archer and Maples, 1984; Pemberton *et al*., 2001; Rodríguez-Tovar *et al*., 2008) and less frequently in deep-sea deposits (Uchman, 1998). *Thalassinoides* is known from the Cambrian (Mikuláš, 2000) to Recent (Yanin and Baraboshkin, 2013), commonly from the Ordovician (Sheehan and Schiefelbein, 1984; Jin *et al*., 2012).

Escape structures (fugichnia)
Fig. 7A–C

Material: A few specimens on the walls B, C.
Description: Vertically oriented, straight, conical burrows in planar-laminated sandstones or structureless ones. The fill is commonly slightly bioturbated but in some cases, the poorly preserved primary lamination is observed partially (Fig. 8F). Escape structures are 14–24 cm long and 6.0–10.0 cm wide at the broadest part of the burrow (Fig. 7A, B). Two specimens occur below hummocky cross-stratification (HCS structure; Fig. 7A, B). One is described as questionable escape structures (?fugichnia), while the other probably as *Cylindrichnus* isp. (Fig. 7B).
Remarks: The structures studied show some similarities to escape traces, described by Bromley and Uchman (2003; fig. 11A–D). The escape traces were constructed by several kinds of invertebrates (Hasiotis, 2004). These structures can occur in continental or shallow-marine environments with episodic, rapid-sedimentation events (Hasiotis, 2004; Patel *et al*., 2018). In Figure 7A and B, the escape structures are interpreted as made by crustaceans or other invertebrates. They occur just beneath hummocky cross-stratification, which records a storm event. According to Buatois and Mángano (2011) and Jones *et al*. (2018), fugichnia are usually are found in middle- to lower-shoreface settings (see also Pemberton *et al*., 2012).

Unidentified burrows

Fig. 14B–H

Material: Some questionable hypichnia (wall A) and burrows on the lower (wall B) and upper (wall C) bedding plane in fine-grained sandstones.

Description: The first of the study specimens (Fig. 14B, C), consists of a partly visible, cylindrical tunnel (in a distal part) and a wider, U-shaped chamber (in proximal part). The chamber (14 cm long, 10 cm wide) shows a braid-like, internal structure and convex margin, which resembles a marginal tube. The other specimens are preserved as circular to elliptical, spreite-like structures, with a slightly convex upper, wider part (Fig. 14D, E) and poorly and fragmentarily preserved, convex margins (?tubes; 12–20 cm long, 4.5–15 cm wide). It seems that one spreite-structure continues in the next similar structure (Fig. 14E). The next doubtful specimen (Fig. 14F) occurs as a circular-shaped trace fossil – a convex mound with a central depression, 4 cm wide and 1.5 cm high. Other burrows are preserved as epireliefs of heart-like shaped (6 cm long, 5 cm wide; Fig. 14G) and circular (1.5 cm wide) or elongated, cylindrical tunnels (3.5 cm long; Fig. 14H).

Remarks: The current U-shaped, spreite-like structure (Fig. 14B, C) might have been ?*Rhizocorallium*, but precise assignation for this specimen is difficult. It resembles *Rhizocorallium* in having a U-shaped structure and possibly spreiten between its marginal convex edges (?marginal tube), but differs from it in the presence of a cylindrical tunnel at the end of this structure. The next specimens preserved as circular to elliptical, spreite-like structures, described above (Fig. 14D, E), are here listed in open nomenclature. However, they might have been cross-sections across the *Asterosoma* bulbs (compare *A. coxii*; Seilacher, 2007 or Knaust, 2017, fig. 5). *Asterosoma coxii* occurs as a bunch of bud-shaped structures, extending from a stem which is oblique to the bedding (cf. Leszczyński, 2018, fig. 27D). The specimen shown in Figure 14F might be interpreted as ?*Schaubcylindrichnus* Frey and Howard, 1981. It is similar in shape (a convex mound with a central depression), but differs from this ichnogenus in having a larger diameter of this structure, especially high in the marginal wall (compare Löwemark and Hong, 2006, fig. 5a–d; Carmona *et al*., 2008, fig. 7/1–2; Löwemark and Nara, 2013, fig. 5.4). Moreover, the current specimen might resemble also cylindrical bivalve traces from the ichnofamily Siphonichnidae (cf. Knaust, 2015), which comprises burrows, consisting of a subvertical tube with passive fill and an active lining or mantle. In cross-section, these burrows occur as elliptical or circular sections (cf. Knaust, 2015, fig. 1, 3B; Knaust, 2017, fig. 5.141). The study specimens show the greatest degree of resemblance to *Siphonichnus* Stanistreet, le Blanc Smith and Cadle, 1980 (Stanistreet *et al*., 1980, fig. 15), which is attributed to the activity of siphon-bearing, endobenthic bivalves (nuculids, tellinids) with deposit-feeding behaviour (cf. Knaust, 2015). *Siphonichnus* appears as an oval to circular, ring-like “eye” mound (cf. Knaust, 2015, fig. 8A, F). It has also some similarities to *Laevicyclus* Quenstedt, 1879, which appears as circular relief with a central depression at the bottom of the bed (see Knaust, 2015, fig. 4E). The specimen studied also shows some similarity to the specimens described by Hagadorn *et al.* (2002, fig. 3F, appendix 4H) and Hammersburg *et al.* (2018, fig. 22.4–5) and interpreted as probably the trace fossil (resting trace) of a cnidarian jellyfish or a sea anemone. According to the authors mentioned above, the literature presents some examples of jellyfish specimens, preserved as concave rings. However, jellyfish, which are regarded as the so-called “soft fossils” commonly leave an imprint in the sediment. The next specimens (Fig. 14G, H) are preserved as tunnels, heart-like or circular in shape and elongated, that might be the trace fossils of unknown producers, maybe crustaceans.

ASSOCIATED BODY FOSSILS

In the Idzików Conglomerate Member, some accompanying fossils were also recorded, e.g., bivalves and the decapod crustaceans (Fig. 8A–D).

Neithea (*Neithea*) *quadricostata* **(**family Pectenidae Rafinesque, 1815 see Dhondt, 1973; Fig. 8B**)** is a common bivalve in the Cretaceous of Saxony (Germany), the Bohemian Basin (Czech Republic), the North Sudetic Basin (Poland) and the Anglo-Paris Basin (see Tröger, 2003; Fig. 2). This genus was reported from the Cenomanian–Coniacian of the southern Germany (Bavaria) by Wilmsen *et al*. (2010) and Schneider *et al.* (2011, 2013). It is regarded as a Tethyan bivalve (Nagm and Boualem, 2019). According to the authors cited, the widely distributed genus *Neithea* is an important palaeogeographic indicator for understanding the relationship between the Tethyan realm and other provinces (see also Iba *et al*., 2011). *Neithea* (*Neithea*) *quadricostata* Sowerby, 1814, formerly *Vola quadricostata* or *Pecten quadricostatus*, was found by Stürm (1901, p. 90) and Geinitz, 1843 (taf. 3/14–15) in Idzików. This genus was also reported by Andert (1934, Taf. 9/13–16) from the Sudetes. *Neithea* is usually found in neritic settings (Sanders, 1998; Andrade *et al*., 2004).

Cardium (*Protocardium*) *hillanum* (family Cardiidae Lamarck, 1809; Fig. 8A) was often reported from different localities, e.g., in Europe, Asia, Africa and Mexico (see Wade, 1926). It occurs from Late Triassic to Late Cretaceous (Schneider *et al*., 2011). *Cardium* (*Protocardium*) *hillanum* (formerly *Protocardia hillana*) was found by Andert (1934, taf. 12/21–22) in Idzików. Previously, this bivalve species was described from the study area by Geinitz (1843, Taf. 2/10-11) and Stürm (1901, taf. 7/2). *Cardium* (*Protocardium*) is a globally distributed genus of shallow-water, infaunal, suspension-feeding bivalves, which were particularly widespread in Jurassic and Cretaceous deposits, mainly in the Northern Hemisphere (see Griffin and Varela, 2012), in Tethyan and Boreal realms (Schneider *et al*., 2010, 2011). This bivalve is typical of the shoreface-offshore settings, being regarded mainly as clearly fully marine taxon (e.g., Woods and Jones, 1996) or less common as indicator of slightly brackish conditions (Schneider *et al*., 2010).

Pholadomya sp. (family Pholadomyidae Gray, 1847; an unidentified specimen, which was assigned to *Pholadomya* by the present author; Fig. 8C) shows some resemblances to the specimen described by Lazo (2007, figs 3, 4, 6) and

Griffin and Varela (2012, fig. 5N), in having a characteristic, posteriorly elongated shell with strong radial ribbing. It ranges from the Mississippian (early Carboniferous) to Recent. During the Early Cretaceous, *Pholadomya* reached a cosmopolitan distribution (Lazo, 2007, fig. 9). It occurs in the North Temperate, Tethyan and South Temperate realms (warms, temperate and subtropical climates). This genus was reported by Geinitz (1843, taf. 1/28–30), Stürm (1901, taf. 8/9) and Andert (1934, taf. 15/3–7) from the Sudetic Upper Cretaceous. Fürsich *et al*. (1995) suggested that *Pholadomya* occurs in fully marine conditions (normal marine salinity). According to Lazo (2007, fig. 8), *Pholadomya* usually appears in well-oxygenated, soft to firm, sandy, bioclastic substrates of the shoreface to inner-shelf environments.

The crustacean *Callianassa elongata* (Fritsch, 1867) (MGUWr-1560s; Fig. 8D) was found by Stürm (1901, taf. 3/3) at Idzików, where it was also reported by Jerzykiewicz (1971). Additionally, *Callianassa antiqua* von Otto, 1854 (MGUWr-3752s-1) was found in the study area. Decapod remains usually are encountered in open, shallow-marine environments (Weimer and Hoyt, 1964; Schneider *et al*., 2011; Ossó *et al*., 2018).

PALAEOENVIRONMENTAL INTERPRETATION BASED ON TRACE-FOSSIL ASSEMBLAGES

Ethologically, the trace-fossil assemblage studied, comprising 18 ichnogenera, 24 ichnospecies, represents a wide spectrum of ethological categories, produced by deposit-, detritus-, suspension-feeders and scavengers. Domichnia or equilibrichnia (*Arenicolites* isp., *Conichnus conicus*, *Diplocraterion parallelum*, *Rosselia*) and domichnia/fodinichnia (*Ophiomorpha nodosa*, *Ophiomorpha* isp., ?*Palaeophycus* isp., *Rosselia*) dominate. Fodinichnia (*Asterosoma* isp., *Cylindrichnus* isp., *Dactyloidites ottoi*, *Gyrophyllites* aff. *kwassizensis*, *Teichichnus* isp., *Thalassinoides* isp., ?*Rhizocorallium* isp.) are common, while repichnia (*Curvolithus simplex*), pascichnia (*Gyrochorte* isp., *Macaronichnus segregatis*, ?*Scolicia* isp.) and domichnia/cubichnia (?*Bergaueria* isp.) are rare.

In the Idzików section, shallow-tier trace fossils (up to 15 cm deep, see Fig. 17; cf. Rodríguez-Tovar *et al*., 2017; Dorador *et al*., 2019) co-occur with mid-tier trace fossils (up to 50 cm). Deep-tier trace fossils (below 50 cm deep) are represented only by *Ophiomorpha*.

In the upper Coniacian sandstones and conglomerates of the Idzików Conglomerate Member in the Idzików Quarry, trace fossils are abundant and show moderately high diversity. In the lower part of the section, burrows made by deposit- and detritus-feeders predominate, while traces of suspension- or filter-feeding organisms are more common in the upper part.

Generally, the trace-fossil assemblage recognized indicates a mixture of the impoverished, proximal *Cruziana* ichnofacies that characterizes settings below the fair-weather wave base (lower shoreface) and the archetypal and distal *Skolithos* ichnofacies, which indicates deposition above fair-weather wave base (i.e. foreshore – proximal lower-shoreface *vide* Pemberton *et al*., 2012). The results of the ichnological and sedimentological analyses are shown in Figures 5, 15–17 and Table 1.

Ichnoassociation IA1 (*Ophiomorpha-Cylindrichnus*)

Characteristics: Ichnoassociation IA1 occurs in fine- and medium-grained sandstones that are exposed in the lower part of the section (Figs 5, 6, 7A, 9G). In the assemblage studied, a wide range of ethological categories occurs, such as fodinichnia, domichnia, equilibrichnia, cubichnia, repichnia and pascichnia. Fodinichnia and domichnia/fodinichnia (?*Asterosoma* isp., *Cylindrichnus* isp., *Dactyloidites ottoi*, *Gyrophyllites* aff. *kwassizensis*, *Ophiomorpha nodosa*, *Ophiomorpha* isp., ?*Palaeophycus* isp., ?*Rhizocorallium* isp., *Rosselia* isp., *Teichichnus* isp., *Thalassinoides* isp.) predominate over domichnia (?*Arenicolites* isp., *Conichnus conicus, Diplocraterion parallelum*) and domichnia/cubichnia (?*Bergaueria*). Equilibrichnia are represented by *Conichnus conicus*, *D. parallelum*, *Rosselia* isp. and *Teichichnus* isp. and repichnia by *Curvolithus simplex* and pascichnia by *Gyrochorte* isp. and ?*Scolicia* isp. Escape traces (fugichnia) are also present. Additionally, some unrecognizable or doubtful trace fossils left in open nomenclature, probably decapod burrows (shrimps or crabs), showing a variety of shapes, also appear in this ichnoassociation (Fig. 14B–H). Possibly, the producers of the trace fossils are deposit-, detritus- and suspension-feeders and passive predators. These deposits are moderately to highly bioturbated (BI = 0–4). The most abundant trace fossil is *Ophiomorpha nodosa*, while *Cylindrichnus* isp. is common (Tab. 1). Only *Dactyloidites ottoi*, *Gyrophyllites aff. kwassizensis*, ?*Rhizocorallium, Rosselia*, ?*Scolicia*, *Thalassinoides* are rare. Other ichnospecies of this ichnoassociation usually are represented by single occurrences (very rare; Tab. 1). Ichnodiversity and ichnodisparity are moderately high (17 ichnogenera, 18 ichnotaxa but only *Ophiomorpha* predominates, while *Cylindrichnus* is common) and there are thirteen different morphological designs (see Fig. 15) but only two morphological categories, especially maze and boxwork burrows (*Ophiomorpha*, *Thalassinoides*) and vertical, concentrically filled burrows (*Cylindrichnus*, *Rosselia*) predominate, while radial to rosette structures (*Dactyloidites*, *Gyrophyllites*), burrows with horizontal spreiten (?*Rhizocorallium*) and complex, actively filled, horizontal structures (?*Scolicia*) are rare. In the sandstones bearing IA1, shallow-tier trace fossils (Fig. 17) predominate, including ?*Bergaueria* isp., *Curvolithus simplex*, *Dactyloidites ottoi*, *Gyrochorte* isp., *Gyrophyllites* aff. *kwassizensis*, ?*Palaeophycus* isp., ?*Rhizocorallium* isp., *Rosselia* isp. and *Teichichnus* isp. Mid-tier trace fossils, represented by ?*Arenicolites* isp., *Asterosoma* isp., *Conichnus conicus*, *Cylindrichnus* isp., *Diplocraterion parallelum*, ?*Rhizocorallium* isp., ?*Scolicia* isp. and *Thalassinoides* isp., are also common. In the deep tier, only *Ophiomorpha*, which also characterizes the shallow and mid tiers (Fig. 17), is present.

Sedimentary structures: The bioturbated sandstones are mainly structureless. Hummocky cross-stratification, which is typical for settings between the fair-weather and storm wave bases (Dott and Bourgois, 1982; Duke, 1985), also was recognized (see also Wojewoda and Raczyński, 1997).

Sedimentary palaeoenvironment: The presence of common, horizontal, background traces, produced mainly by detritus- or deposit-feeders (*Dactyloidites*, *Gyrochorte*, *Teichichnus*, *Thalassinoides*), or doubtful burrows of secondary palaeoenvironmental significance (?*Asterosoma*, ?*Bergaueria*, ?*Rhizocorallium*), supports low- to moderate-energy conditions, typical of the fair-weather suite of the *Cruziana* ichnofacies. These burrows, especially *Dactyloidites*, ?*Rhizocorallium*, *Teichichnus*, and *Thalassinoides*, indicate a palaeoenvironment slightly beneath the fair-weather wave base in the distal lower-shoreface setting (Uchman and Krenmayr, 2004; Pervesler *et al*., 2011a, b; Knaust, 2013, 2018; Wilmsen and Niebuhr, 2014). Moreover, the occurrence of *Cylindrichnus*, *Rosselia* and *Scolicia* as well as *Gyrophyllites*, also indicates the lower shoreface as the possible palaeoenvironment (Uchman and Krenmayr, 1995; Pemberton *et al*., 2012; Ekdale and Harding, 2015; Muñoz *et al*., 2019). However, the appearance of mostly vertical trace fossils, produced by suspensions-feeders (*Arenicolites*, *Conichnus*, *Diplocraterion*, *Ophiomorpha*), and fugichnia gives evidence of the episodically higher-energy conditions (opportunistic suite), typical of the *Skolithos* ichnofacies (see Pemberton *et al*., 2001) in the proximal lower shoreface. Ichnogenera referred to them are especially common in the middle- and lower-shoreface environments (compare Pemberton *et al*., 2001, 2012). Moreover, the presence of *Cylindrichnus* in monoichnospecific assemblages, just below the HCS beds (Fig. 7A–D), commonly found in the lower shoreface, indicates occasional, high-energy, hydrodynamic events, e.g., related to storms (cf. Ekdale and Harding, 2015). Similar, the appearance of *Rosselia* might be evidence of higher-energy conditions during storm events (cf. Netto *et al*., 2014).

The HCS stratification clearly points to a storm origin for the sandstone beds (cf. Swift *et al*., 1983; Buatois *et al*., 2012), though it also has been reported from lacustrine, intertidal and estuarine deposits (cf. Dott and Bourgeois, 1982 and references therein). These diagnostic structures in storm deposits, usually occur between the fair-weather and storm wave bases and are especially common in the distal, lower shoreface and upper offshore (Immenhauser, 2009; Pomar *et al*., 2012).

In summary, the assemblage studied reflects a mixture of the proximal expression of the impoverished *Cruziana* ichnofacies, which is characteristic of the distal lower-shoreface, and the storm-related distal *Skolithos* ichnofacies, typical of the proximal lower-shoreface. According to the wave-dominated shoreface model, deposit-feeding organisms predominate in the lower-shoreface setting, while suspension-feeders and farming behaviours are subordinate (Pemberton *et al*., 2012) or minor (Pemberton *et al*., 2001). The presence of both deposit- and suspension-feeders indicates availability of food in suspension (water column) and in the sediment. The dominance of deposit-feeding behaviour, especially the occurrence of *Dactyloidites* (Fig. 10F) points to an occasionally nutrient-rich substrate.

Moreover, the occurrence of entirely marine trace fossils (e.g., *Asterosoma*, ?*Bergaueria*, *Conichnus*, *Gyrochorte*, ?*Rhizocorallium*, *Teichichnus*) and a moderately diverse trace-fossil assemblage, comprising a wide range of behavioural categories, points to a normal, marine and well-oxygenated setting (Savrda and Bottjer, 1986; MacEachern and Gingras, 2007; Savrda, 2007, Buatois and Mángano, 2011; Gingras *et al*., 2011). The occurrence of facies-crossing ichnogenera, connected with post-storm colonization of tempestites (opportunistic suite), might indicate a stressed environment.

The deposits studied, in which trace fossils of ichnoassociation IA1 (e.g., *Dactyloidites*, *Cylindrichnus*, *Gyrophyllites*, ?*Scolicia*, *Thalassinoides*, *Teichichnus*) appear, are recognized as storm deposits, which can be specified as transitional tempestites (cf. Aigner and Reineck, 1982; Einsele, 2000), typical of the lower-shoreface setting. The transitional tempestites, which occur below the fair-weather wave base and exhibit low abundance of HCS (see Bayet-Goll *et al*., 2015a and references therein, figs 3A, IA1, 6A), are present mainly in the lower part of the Idzików Quarry section (Figs 6A, 7A, 11F). Below the tempestite bed, there are fine-grained, massive or parallel- and cross-laminated sandstones without trace fossils, which are poorly exposed. Wojewoda and Raczyński (1997, fig. 38) interpreted this lowermost bed of the Idzików section (wall B, Fig. 6A) as bar deposits. Owing to the lack of trace fossils, ichnological analysis of these sandstones (Fig. 7E) is not possible. Only in the uppermost part of these deposits, just beneath the distinctly marked tempestite bed, *Curvolithus simplex* and *Gyrochorte* isp. were recorded (Figs 6A, 7E, 10D, 11B). Although the ichnotaxa mentioned are common in bar deposits, mostly in the lower-shoreface to upper-offshore settings (e.g., Fürsich and Heinberg, 1983; Heinberg and Birkelund, 1984; Gibert and Benner, 2002), it seems that they also might characterize the lowermost part of the tempestite succession (compare Figs 6A, 7E).

The trace-fossil assemblage, together with inorganic, sedimentary structures, indicate a low- to moderate-energy, shallow environment (lower shoreface), which can be affected by weak storms (the so-called storm-affected shoreface; see MacEachern and Pemberton, 1992; Dashtgard *et al*., 2012; Pemberton *et al*., 2012). The weakly storm-affected shoreface deposits are dominated by the occurrence of fair-weather suites of trace fossils with occasionally preserved, primary, sedimentary structures (see Dashtgardt *et al*., 2012) and by tempestites. The tiering of trace fossils also is well developed (Fig. 16).

In summary, the fine- and medium-grained sandstones, containing IA1 with a moderately diverse trace fossil assemblage, comprising a wide spectrum of ethological categories, moderate ichnodiversity and ichnodisparity (17 ichnogenera, 13 architectural designs respectively), the highest bioturbation index (BI = 0–4) and the presence of a complex tiering structure (shallow to deep tier, tiers 1–4), together with inorganic, sedimentary structures (HCS and parallel lamination), indicates deposition below or close to the fair-weather wave base in the lower-shoreface setting (Figs 15–17). Deposition took place under entirely marine and well-oxygenated conditions (fair-weather suite), interrupted by high-energy storm events (opportunistic suite). During deposition, mainly optimal ecological conditions for the trace makers prevail in soft, ocassionally rich in food substrate (e.g., *Dactyloidites, Gyrophyllites*) with episodically stressed conditions during storms.

Ichnoassociation IA2 (*Asterosoma-Conichnus*)

Characteristics: Trace fossils of this ichnoassociation occur in the middle and upper part of the fine-grained sandstone beds (Figs 6, 7A, 9G). It contains ?*Diplocraterion parallelum*, ?*Diplocraterion* isp. (domichnia/equilibrichnia), *Conichnus conicus* (domichnia, equilibrichnia, fugichnia), *Arenicolites* isp. (domichnia), *Ophiomorpha nodosa*, *Ophiomorpha* isp. and *Rosselia* isp. (domichnia/fodinichnia, equilibrichnia), complete, well-preserved specimens of *Asterosoma* (fodinichnia) (Figs 7A, 8H, 9A–C) and escape structures (fugichnia). Additionally, some trace fossils *Macaronichnus segregatis* and ?*Scolicia* isp. (pascichnia) also were observed (Figs 7A, C, 9G, 11F, 13C, E, G). Domichnia or domichnia/equilibrichnia distinctly predominate over fodinichnia. The trace-fossil assemblage is dominated by vertical burrows, produced by opportunistic suspension-, filter- and surface detritus-feeders or even carnivores. *Asterosoma*, *Conichnus*, *Macaronichnus* and *Ophiomorpha* are common trace fossils in this ichnoassociation, as well as fugichnia; *Arenicolites,* ?*Diplocraterion* and *Rosselia* are rare (Tab. 1). The bioturbation index (BI = 1–3), the ichnodisparity (7 different categories), and the ichnodiversity (8 ichnogenera, 10 ichnospecies) are moderately low (Fig. 15). Five architectural types predominate: horizontal, branched concentrically filled burrows (*Asterosoma*), vertical plug-shaped burrows (*Conichnus*), maze and boxwork burrows (*Ophiomorpha*), simple actively filled (massive) horizontal to oblique structures (*Macaronichnus*), and vertical single U-and Y-shaped burrows (*Arenicolites*, ?*Diplocraterion*; cf. Buatois *et al*., 2017).

Sedimentary structures: Planar lamination is common (Fig. 7A), especially in the uppermost part of sandstones of IA2, with HSC or remnants of this stratification (cf. Baniak *et al*., 2014).

Sedimentary palaeoenvironment: The dominance of vertical burrows of suspension feeders (*Arenicolites*, *Conichnus*, *Diplocraterion*, *Ophiomorpha*), which are abundant, over burrows of detritus- and deposit-feeders (*Asterosoma*, *Macaronichnus*, *Rosselia*, ?*Scolicia*) indicates moderate-high energy and moderate-high storm intensity, which maintain food mainly in suspension. However, the presence of fodinichnia indicates also food particles in a deposit during conditions of reduced energy (e.g., well preserved, whole specimens of *Asterosoma*, Figs 7A, 8A). *Arenicolites*, *Conichnus*, *Diplocraterion*, and *Ophiomorpha*, produced mostly by suspension feeders, as well as fugichnia, are common in the middle-shoreface setting (Buatois and Mángano, 2011; Frey and Dashtgard, 2011). *Asterosoma* and *Rosselia* are also commonly found in the middle shoreface (MacEachern and Bann, 2008; Buatois and Mángano, 2011; Pemberton *et al*., 2012), as well as *Macaronichnus*, especially in storm deposits (Pemberton *et al*., 2001; Uchman and Krenmayr, 2004). Echinoid burrows (e.g., ?*Scolicia*), which are very sparse in the study section, though more abundant in the lower shoreface-offshore (Knaust, 2017) are also reported from shallower settings, including the upper-middle shoreface (cf. Goldring *et al*., 2004). The trace makers of the trace fossils studied (e.g., *Arenicolites*, *Diplocraterion*) are commonly associated with high-energy deposition (Fürsich, 1974a; Šimo and Olsavšký, 2007; Mikuláš *et al*., 2013) and can tolerate repeated erosion and deposition (e.g., storm deposition, compare Knaust, 2017).

A decrease in bioturbation index (BI = 1–3), ichnodiversity and ichnodisparity in comparison to ichnoassociation IA1, points to a shallower setting. The trace-fossil assemblage characterizes the archetypal *Skolithos* ichnofacies, with some elements of the *Cruziana* ichnofacies, which indicates the middle-shoreface setting (Pemberton *et al*., 2001, 2012; Buatois and Mángano, 2011). Suspension feeders predominate over deposit feeders in the middle shoreface (Pemberton *et al*., 2012). The sandstones, in which appears the IA2 are reworked by opportunistic suspension-feeders (tempestite beds) and partly by deposit-feeders (bioturbated beds) in an open-marine environment, close to the fair-weather wave base. Sedimentary structures are well preserved, including parallel lamination (Fig. 7A), HSC (Fig. 7A) and probable remnants of this structure. Rapid sedimentation of tempestites (usually a decimetre thick, Fig. 7A–C) probably was responsible for the low ichnodiversity (see Fürsich *et al*., 2018). These beds contain *Arenicolites* or fugichnia (Figs 7A, C, 8F), typical of the archetypal *Skolithos* ichnofacies in the middle shoreface (earlier *Arenicolites* ichnofacies sensu Bromley and Asgaard, 1991; see also Bradshaw, 2010; Knaust, 2017). However, a post-event community, related to opportunistic colonization of storm beds in IA2, comprises a greater number of dwelling structures than in the tempestites, such as *Conichnus*, ?*Diplocraterion parallelum*, ?*Diplocraterion* isp., *Ophiomorpha nodosa* and *Ophiomorpha* isp. (Figs 7A, 9F, G, 17; cf. MacEachern *et al*., 1999). Additionally, inter-storm background suites (?fair-weather suites) contain also trace fossils of deposit- or detritus-feeders in a low-energy and nutrient-rich environment (*Asterosoma* isp.; Fig. 7A), typical of the *Cruziana* ichnofacies (cf. Pemberton *et al*., 2001; Neto de Carvalho and Rodrigues, 2007; Pearson *et al*., 2013).

According to Buatois and Mángano (2011), under decreased storm influence some burrows of the *Cruziana* ichnofacies (e.g., *Asterosoma*, *Rosselia*) can appear in the middle-shoreface deposits. However, Knaust (2017) postulated the occurrence of *Asterosoma* and *Rosselia*, both in the *Skolithos* and *Cruziana* ichnofacies. In fact, in proximal storm deposits in the middle-shoreface setting, *Asterosoma* is typical of the transition between the *Skolithos* and proximal *Cruziana* ichnofacies (cf. Pemberton *et al*., 2001; Pervesler and Uchman, 2004). Abundant *Asterosoma* (whole specimens preserved; Figs 7A, 8H, 9A–C) appears especially in the uppermost part of parallel-laminated sandstones and may indicate a lower influence of storms and high quantity of organic matter (Pemberton *et al*., 2001; Buatois and Mángano, 2011 and references therein). Moreover, the trace fossil *Macaronichnus* (Fig. 7A) in inter-storm suites also is observed and very sparse ?*Scolicia* (Fig. 13C). The fair-weather deposits were partially reworked and removed during erosion by high-energy storms, when the wave base was lowered (see Hampson and Storms, 2003; Fürsich *et al.*, 2018). Amalgamation of tempestites is common in the proximal middle-shoreface (see Einsele, 2000, fig. 3.5b; Pérez-López and Pérez-Valera, 2013; Bayet-Goll *et al.*, 2015a and references therein) as in sandstones in the range of IA2 (see Figs 7A, C, 8F). On the basis of the sedimentary structures preserved, especially HCS, the recurrence of tempestites (both background and post-storm suites) might be suggested (Fig. 7A). The abundance of HCS structures and the higher tendency for amalgamation of tempestites than in the range of IA1 indicates mostly proximal tempestites (cf. Aigner and Reineck, 1982; Bayet-Goll *et al.*, 2015a), which were deposited in a middle-shoreface setting (Fig. 7A).

The dominance of trace fossils, typical of opportunistic colonization after storm events (domichnia, opportunistic suite), such as *Asterosoma*, *Conichnus* points to well-oxygenated and entirely marine environment (see Ekdale and Mason, 1988; Pemberton *et al.*, 1992, 2001; MacEachern and Gingras, 2007). However, the impoverished trace-fossil assemblage, comprising predominantly burrows of opportunistic suspension-feeders (equilibrichnia/domichnia behaviour of trace makers), might indicate also an occasionally stressed environment during storms. The abundance of fugichnia (Fig. 7C) supports episodically shifting substrates and fluctuations in sedimentation rate and energy of the water (Rygel *et al.*, 2008; Knaust, 2017), when the buried organisms, the producers of the trace fossils, try to reach the new sediment-water interface (Bann and Fielding, 2004; Hasiotis, 2004).

In summary, the deposition of the sandstones studied (IA2) took place under moderate-high wave and current energy in the middle-shoreface setting of normal salinity and good oxygenation, interrupted by stressed conditions, connected with storm deposition. The depositional setting can be described as a storm-influenced shoreface (Dashtgardt *et al.*, 2012; Pemberton *et al.*, 2012), which is identified by the presence of characteristic laminated beds (tempestite beds, usually non-amalgamated; post-storm suites) to burrowed deposits (fair-weather suite; compare Rygel *et al.*, 2008; Pemberton *et al.*, 2012; Wesolowski *et al.*, 2018).

In general, the sandstones, in which the trace fossils of IA1 and IA2 occur, are recognized as transitional and proximal tempestites, which were deposited in the lower- to middle-shoreface setting. The ichnoassociation *Ophiomorpha-Cylindrichnus* (IA1) predominates in the lower part of the tempestite succession, while the ichnoassociation *Asterosoma-Conichnus* (IA2) from the middle to upper part (Figs 6A, 7A, 9G). However, the recurrence of transitional and proximal tempestites, reported earlier by Wojewoda (1997, fig. 20), is also observed (Fig. 7A). In the lower part of the tempestite bed, transitional tempestites (wall B, IA1) appear, followed by proximal tempestites (IA2) and transitional-proximal ones (IA1–IA2). From the middle part of the tempestite succession proximal tempestites (IA2) predominate.

Sedimentological and ichnological features of sandstones in the range of IA1 and IA2 point to an upward-shallowing tempestite sequence from the lower-shoreface (transitional tempestites) to middle-shoreface setting (proximal tempestites), from the weakly storm-affected shoreface to the moderately storm-affected shoreface (cf. Buatois and Mángano, 2011; Pemberton *et al.*, 2012) or from the storm-affected to the storm-influenced shoreface (cf. Dashtgard *et al.*, 2012). The increased number of HCS storm beds from IA1 to IA2 is also evidence of the progressive shallowing of the shoreface sequence (cf. MacEachern *et al.*, 1999; see Figs 15–17).

Ichnoassociation IA3 (*Ophiomorpha-Arenicolites*)

Characteristics: Ichnoassociation IA3 appears in the coarse-grained sandstones and gravels (Figs 6, 7A, D). Trace fossils of this ichnoassociation are dominated by domichnia, produced by suspension-feeders. In this assemblage, vertical or inclined burrows predominate, namely *Ophiomorpha nodosa*, *Ophiomorpha* isp., and *Arenicolites*. The bioturbation index (BI = 0–2) and ichnodiversity and ichnodisparity are low (3 ichnospecies, 2 ichnogenera and 2 different categories respectively; one taxon and one morphological category dominate; Fig. 15). The most abundant trace fossil, especially in the upper part of the Idzików section, is *Ophiomorpha*, while *Arenicolites* is rare (Figs 8E, 11G, H, 12A).

Sedimentary structures: Cross-stratification, reactivation surfaces (Fig. 7A, D) and parallel stratification (Fig. 7A) were observed in the coarse-grained sandstones (previously reported by Wojewoda, 1997, fig. 19 and Wojewoda and Raczyński, 1997, fig. 37). Ripple-marks in gravel also are common (presented earlier by Wojewoda and Raczyński, 1997, fig. 36; Wojewoda, 1997, fig. 18). In the upper part of the section (conglomerates), microcliffs and clast imbrication occur (see Wojewoda, 1997, fig. 5). Above the tempestite sequence (IA1–IA2) and gravel bed (Fig. 7E), a runnel erosional surface is present (Fig. 6).

Sedimentary palaeoenvironment: IA3 is dominated by the burrows of suspension feeders (*Arenicolites*, *Ophiomorpha*), which indicates concentration of nutrients in the water column. The low bioturbation index (BI = = 0–2), as well as the low ichnodiversity and ichnodisparity (Fig. 15) are interpreted as the result of high-energy conditions, which in some cases make the preservation of traces difficult. *Ophiomorpha nodosa*, which is the most common trace fossil in IA3, predominates in the foreshore-upper shoreface settings (cf. Curran, 1985, 2007; MacEachern and Hobbs, 2004) as well as *Arenicolites* (Pemberton *et al.*, 2012). Trace fossils of ichnoassociation IA1 are indicative of the archetypal *Skolithos* ichnofacies, which is characteristic for the foreshore to upper-shoreface settings, where suspension-feeders predominate, while deposit-feeders are rare (see ichnological-sedimentological model for shoreface in Pemberton *et al.*, 2012; Fig. 15). Associated trough cross-bedding in coarse-grained sandstones and ripple-marks in conglomerates also are indicative of the upper shoreface (Bann *et al.*, 2004; Dashtgard *et al.*, 2012; Buatois *et al.*, 2013). However, in the upper part of the Idzików Quarry section (conglomerates), planar lamination occurs, which might be interpreted as the result of swash and backwash processes (see Masselink and Short, 1993). Microcliffs and clast imbrication in conglomerates, typical of the foreshore setting, are also observed (Wojewoda, 1997; Pemberton *et al*., 2012).

The presence of *Ophiomorpha* and *Arenicolites* can indicate a normal marine, but a slightly brackish environment (mesohaline) is not excluded, because potential producers are able to tolerate fluctuations in salinity (Frey *et al*., 1978; Knaust, 2017; Hyžný *et al*., 2018). The current trace fossils usually occur in well-oxygenated settings (Ekdale and Mason, 1988; Pemberton *et al*., 2001, 2012; Buatois and Mángano, 2011).

On the basis of sedimentological analysis, the part of the section, in which IA3 appears, was interpreted as bar and beach deposits (Wojewoda, 1997; Wojewoda and Raczyński, 1997). According to the authors cited, cross-stratification and reactivation surfaces in coarse-grained sandstones indicate S and SE direction of bar migration (by a longshore palaeocurrent). Moreover, some conglomerates showing clast imbrication are diagnostic for a beach environment (cf. Wojewoda, 1997). The onshore migration of sandbars by nearshore currents take place typically in the upper shoreface during fair-weather periods (Dashtgard *et al*., 2012; Bayet-Goll *et al*., 2015b), where breaking waves are responsible for the formation of longshore bars (cf. Reineck and Singh, 1975; Greenwood and Davidson-Arnott, 1979; Jiang *et al*., 2018, fig. 1). It is caused by less favourable conditions for benthic organisms and is usually evidenced by sparsely distributed trace fossils, as evidenced by the low bioturbation index in IA3 (BI = 0–2; cf. MacEachern and Pemberton, 1992; Baniak *et al*., 2014; Isla *et al*., 2018). *Ophiomorpha* and *Arenicolites* are also characteristic of high-energy deposition, e.g., storm deposits or migrating sand bodies (cf. Baniak *et al*., 2014; Knaust, 2017). Reactivation surfaces (Figs 6, 7A, D) are also typical of bars (McCabe and Jones, 1977). The erosional structures and reactivation surfaces in a sandstone bed indicate short-term erosion, mainly by storms (Roy *et al*., 1994; Dashtgard *et al*., 2012). Additionally, the runnel erosional system, which was observed between deposits containing IA2–IA3 (Fig. 7E), indicates erosion of the beach and transport of sediments to the shoreface (cf. Melo Apoluceno *et al*., 2002 and references therein).

In summary, both sedimentary structures (cross-stratification, planar lamination, ripple-marks, reactivation surfaces), which were observed in the deposits studied and almost vertical trace fossils indicate an environment of shallow, regularly agitated, high-energy waters above the fair-weather wave base (upper shoreface-foreshore), under normal conditions of oxygenation and salinity.

The uppermost part of the Idzików Quarry section (above the beach deposits) was interpreted by Wojewoda (1997) as deltaic deposits (Fig. 6A). This part of the Idzików Conglomerate Member is difficult for ichnological study, owing to the scarcity (almost lack) of the trace fossils and terrain unavailability. Only in the lowest part of these deposits, at the transition between beach and delta deposits, a few specimens of *Ophiomorpha* isp. are present (Fig. 11H).

The Upper Idzików Beds of the Idzików Conglomerate Member were regarded by Wojewoda (1997) as a fan-delta system with narrow littoral-beach zones (see also Chrząstek and Wojewoda, 2011). Fan deltas (originally described by Holmes, 1965) are alluvial fans, prograding directly into a standing body of water (e.g., an entirely marine basin) from an adjacent highland (or the main fault margin, cf. Pollard *et al*., 1982, fig. 10; McPherson *et al*., 1987; Nemec and Steel, 1988; Liangqing and Galloway, 1991; Postma, 2003). In the study area, the fan-delta system was prograded out from the eastern margin of the Upper Nysa Kłodzka Graben, close to the East Sudetic Island (Wojewoda, 1997 and references therein). Sedimentologically, the coarse-grained deposits of the fan-delta show mainly clast imbrication and cross-stratification or parallel lamination (Sendra *et al*., in press and references therein). Ichnologically, fan deltas are not well recognized (cf. Buatois and Mángano, 2011). Owing to the dominance of coarse-grained sediments, prevailing high-energy conditions and sedimentation rates, connected with rapid sediment influx, fan-delta ichnoassemblages show reduced ichnodiversity and lowered values of bioturbation index (cf. Buatois and Mángano, 2011). The ichnology of shallow and deep fan deltas (Carboniferous, Jurassic, Cretaceous and Quaternary) recently was discussed by Hovikoski *et al*., 2019). In the coarse-grained shallow-marine fan deltas, the trace fossils of the *Skolithos* and *Cruziana* ichnofacies predominate (Ekdale and Lewis, 1991; Soegaard and MacEachern, 2003), while in deep-sea deltas (submarine) elements of the ?*Nereites* and *Zoophycos* ichnofacies also occur (Hovikoski *et al*., 2019). According to Buatois and Mángano (2011), *Thalassinoides* and *Ophiomorpha* seem to be the dominant components of the coarse-grained fan-delta ichnofaunas (see also Sendra *et al*., in press). Siggerud and Steel (1999), Soegaard and MacEachern (2003) and MacEachern *et al*. (2005) suggested also *Ophiomorpha* and additionally fugichnia as the main trace fossils in the fan-delta deposits. Furthermore, usually in more distal, fine-grained deposits of shallow-marine fan-deltas also there are e.g., *Ancorichnus*, *Arenicolites*, *Asterosoma*, *Curvolithus*, *Cylindrichnus*, *Diplocraterion*, *Palaeophycus*, *Planolites*, *Rosselia*, *Scolicia*, *Skolithos*, *Teichichnus* (Lockley *et al*., 1987; Ekdale and Lewis, 1991; Sendra *et al*., in press). Moreover, Gibert *et al*. (2007) also reported *Dactyloidites* from the Eocene fan-delta deposits of Spain.

Ichnological evidence of the conglomerates of the Idzików Quarry section shows the presence of opportunistic trace fossils (*Ophiomorpha*) of the *Skolithos* ichnofacies, typical of coarse-grained fan-deltas (Siggerund and Steel, 1999; Buatois and Mángano, 2011). Moreover, the occurrence of the majority of other trace fossils in more distal finer-grained deposits (*Arenicolites*, *Asterosoma*, *Curvolithus*, *Cylindrichnus*, *Dactyloidites*, *Diplocraterion*, *Palaeophycus*, *Rosselia*, ?*Scolicia*, *Teichichnus*, *Thalassinoides*) and fugichnia (*Skolithos* and *Cruziana* ichnofacies), frequently reported from fan deltas, was also recorded (cf. Ekdale and Lewis, 1991; Soegaard and MacEachern, 2003; Gibert *et al*., 2007; Hovikoski *et al*., 2019 and references therein; Sendra *et al*., in press). In summary, ichnological analysis of the Idzików Quarry section might indicate the development of a fan-delta system in the Upper Nysa Kłodzka Graben.

CONCLUDING REMARKS

On the basis of field work, a moderately diverse assemblage of the trace fossils was recognized in the Idzików Conglomerate Member of the Nysa Kłodzka Graben (Idzików Quarry). The trace fossils belong to 18 ichnogenera and 24 ichnospecies. Escape structures (fugichnia) and some unidentified burrows (in open nomenclature) also were found.

Domichnia and domichnia/cubichnia predominate in the ichnoassemblage studied (*Arenicolites*, ?*Bergaueria*, *Conichnus*, *Diplocraterion*, *Ophiomorpha*). Fodinichnia and domichnia/fodinichnia (*Asterosoma*, *Cylindrichnus*, *Dactyloidites*, *Gyrophyllites*, ?*Palaeophycus*, ?*Rhizocorallium*, *Rosselia*, *Teichichnus*, *Thalassinoides*) also are common. Pascichnia (*Gyrochorte*, *Macaronichnus*, ?*Scolicia*) and repichnia (*Curvolithus*) are rare. Equilibrichnia are represented by *Diplocraterion*, *Rosselia* and *Teichichnus.*

Detailed ichnological analysis of the Idzików Conglomerate Member indicates the presence of three trace-fossil assemblages (IA1–IA3), which are assigned to the *Skolithos* and the impoverished, proximal *Cruziana* ichnofacies and represent a progression from the distal lower shoreface to the foreshore (Pemberton *et al*., 2012; Figs 6, 15). The IA1 (*Ophiomorpha-Cylindrichnus*) assemblage characterizes the impoverished, proximal *Cruziana* ichnofacies and the distal *Skolithos* ichnofacies (lower shoreface). The IA2 (*Asterosoma-Conichnus*) assemblage is characteristic for the archetypal *Skolithos* ichnofacies, with some elements of the *Cruziana* ichnofacies (middle shoreface). The IA3 (*Ophiomorpha-Arenicolites*) also points to the archetypal *Skolithos* ichnofacies (upper shoreface-foreshore).

On the basis of sedimentological (the presence of hummocky cross-stratification, amalgamated beds) and ichnological evidence, the fine-grained sandstones are recognized as transitional-proximal tempestites. The current study is in agreement with previous sedimentological interpretations of the Idzików Conglomerate Member by Wojewoda (1997) and Wojewoda and Raczyński (1997) and adds precision to the palaeoenvironmental interpretation of these deposits. The current study shows, in general, the presence of transitional tempestites mainly in the lower part of the tempestite succession (IA1), while in the middle and upper part, proximal tempestites predominate (IA2). Moreover, occasionally, the recurrence of transitional and proximal tempestites was recorded in the lower and middle part of a tempestite bed (Fig. 7A). An increase in energy from the weakly storm-affected shoreface (IA1) up to the moderately storm-affected shoreface (IA2) is presumed.

The ichnoassociation IA3 (*Ophiomorpha-Arenicolites*), which appears in coarse-grained sandstones and conglomerates, indicates the upper shoreface-foreshore settings. These deposits were recognized as subtidal bar and beach deposits (Fig. 6). Additionally, Wojewoda and Raczyński (1997, fig. 38), interpreted the lowermost part of the Idzików Quarry section (fine-grained sandstones without trace fossils), lying below the tempestite succession, as bar deposits (Figs 6A, 7E).

In the Idzików section, the combined reappearance of tempestites, bar and beach deposits also are recognized (see Fig. 6); the phenomenon was reported earlier by Wojewoda and Raczyński (1997).

The integrated ichnological and sedimentological study shows that the palaeoenvironment of the sandstones and conglomerates of the Idzików Conglomerate Member was shallow-marine, well-oxygenated, of normal salinity, and under low-moderate to high hydrodynamic conditions. This is confirmed by the presence of typical marine ichnotaxa, e.g., *Asterosoma*, ?*Bergaueria*, *Conichnus*, *Teichichnus*, as well as the palaeoecological significance of the accompanying benthic assemblage of body fossils, namely bivalves and decapod remains, e.g., *Neithea*, *Cardium* (*Protocardium*), *Pholadomya* and *Callianassa*.

The presence of *Neithea*, which is regarded as a palaeogeographic indicator of the Tethyan Ocean (the so-called “Tethyan bivalve”; see Nagm and Boualem, 2019), indicates a good connection between the two provinces (Tethyan and Boreal realms) during the sedimentation of the Idzików Conglomerate Member.

The appearance of *Diplocraterion* isp. and *Ophiomorpha* isp. in the uppermost part of the Lower Idzików Member (Figs 3, 4, 14I, J) probably indicates that this part of the section might have been deposited in the lower-middle shoreface, like the tempestites of the Idzików Conglomerate Member (IA1–IA2).

The sandstones and conglomerates studied belong to a fan-delta system with littoral-beach zones (Upper Idzików Beds) and a succession of tempestites (lower part of the Idzików section; cf. Wojewoda, 1997). Palaeogeographic, tectonic, as well as sedimentological features of the deposits studied, e.g., the existence near the fault margin of the Upper Nysa Kłodzka Graben in close proximity to the East Sudetic Island, indicate the evolution of a fan-delta system (cf. Wojewoda, 1997).

Ichnological analysis revealed the occurrence in the Idzików Conglomerate Member of *Ophiomorpha*, which is regarded as the dominant trace fossil in coarse-grained fan-delta systems (cf. Buatois and Mángano, 2011 and references therein; Sendra *et al*., in press), as well as other ichnotaxa (e.g., *Arenicolites*, *Asterosoma*, *Curvolithus*, *Cylindrichnus*, *Dactyloidites*, *Diplocraterion*, *Gyrophyllites*, ?*Palaeophycus*, *Rosselia*, ?*Scolicia*, *Teichichnus*, *Thalassinoides*), common in fan-delta deposits (cf. Hovikoski *et al*., 2019 and references therein). Thus, the present ichnological study might be in agreement with the probable development of fan-deltas during sedimentation of Idzików Conglomerate Member in the Upper Nysa Kłodzka Graben.

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