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# TRACE FOSSILS FROM THE BALTOSCANDIAN ERRATIC BOULDERS IN SW POLAND

**Alina CHRZĄSTEK & Kamil PLUTA**

*Institute of Geological Sciences, Wrocław University; Maksa Borna 9, 50-204 Wrocław, Poland*
*e-mails: alina.chrzastek@uwr.edu.pl, kamil.pluta@ing.uni.wroc.pl*

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**Abstract:** Many well preserved trace fossils were found in erratic boulders and the fossils preserved in them, occurring in the Pleistocene glacial deposits of the Fore-Sudetic Block (Mokrzeszów Quarry, Świebodzice outcrop). They include burrows (*Arachnostega gastrochaenae*, *Balanoglossites* isp., ?*Balanoglossites* isp., ?*Chondrites* isp., *Diplocraterion* isp., *Phycodes* isp., *Planolites* isp., ?*Rosselia* isp., *Skolithos linearis*, *Thalassinoides* isp., root traces) and borings ?*Gastrochaenolites* isp., *Maeandropolydora* isp., *Oichnus* isp., *Osprioneides kampto*, ?*Palaeosabella* isp., *Talpina* isp., *Teredolites* isp., *Trypanites weisei*, *Trypanites* isp., ?*Trypanites* isp., and an unidentified polychaete boring in corals. The boulders, Cambrian to Neogene (Miocene) in age, mainly came from Scandinavia and the Baltic region. The majority of the trace fossils come from the Ordovician Orthoceratite Limestone, which is exposed mainly in southern and central Sweden, western Russia and Estonia, and also in Norway (Oslo Region). The most interesting discovery in these deposits is the occurrence of *Arachnostega gastrochaenae* in the Ordovician trilobites (?*Megistaspis* sp. and *Asaphus* sp.), cephalopods and hyolithids. This is the first report of *Arachnostega* on a trilobite (?*Megistaspis*) from Sweden. So far, this ichnotaxon was described on trilobites from Baltoscandia only from the St. Petersburg region (Russia). *Arachnostega* on a trilobite (*Asaphus*), a cephalopod and hyolithids is from Russia or Estonia. Another interesting ichnotaxon is *Balanoglossites*, which also was encountered in the erratic boulders from the Ordovician Orthoceratite Limestone of Sweden. So far, this ichnotaxon was known only from Russia (St. Petersburg region). Some rare borings (e.g., *Osprioneides kampto*, ?*Palaeosabella* isp.) also were found in glacial erratics of Silurian stromatoporoids, excellent outcrops of which are located in Gotland (Sweden) and Saaremaa (Estonia). In addition, stromatoporoid/coral, coral/coral and some new fossil associations are reported. The material studied probably was transported from the N, the NE, and less commonly from the NW.

**Key words:** Pleistocene deposits, Fore-Sudetic Block, Roztoka-Mokrzeszów Graben, ichnology, *Arachnostega*, *Osprioneides*, *Balanoglossites*.

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## INTRODUCTION

In the SW Poland, especially in the Fore-Sudetic Block (Mokrzeszów Quarry, Świebodzice outcrop), many glacial erratic boulders, Cambrian to Neogene in age, occur in Pleistocene sands and tills (Fig. 1). They originated in Baltoscandia (Salamon *et al.*, 2013 and references therein) and probably were transported and deposited during the Middle Polish Glaciation (Saalian Glaciation, see Marks, 2004; Marks *et al.*, 2016). The most interesting are glacial erratic boulders of sedimentary rocks, because of their rich body and trace fossil content.

The erratic boulders studied contain diverse trace fossils, in some cases new for the source areas. The most interesting discovery is *Arachnostega* in the pygidium of the trilobites ?*Megistaspis* sp. (probably from Sweden) and *Asaphus* sp. (from the St. Petersburg region of Russia, or from Estonia). So far, only Mikuláš and Dronov (2010, p. 63) described this trace fossil from Baltoscandia on the mould of an unidentified trilobite in the Obukhov Formation (the trilobite *Asaphus raniceps – Asaphus striatus* Zone, Tab. 1), Kunda Regional Stage (St. Petersburg region), but this ichnogenus was unknown on arthropods in Estonia and Sweden. *Arachnostega* found in hyolithids (this study), might come from the St. Petersburg region (Russia), where it was reported only in cephalopods and trilobites. The next interesting and rare Palaeozoic boring is *Osprioneides kampto*, encountered both in ?Ordovician bryozoans and Silurian erratic blocks. There are only a few reports of the occurrence of this trace fossil in Baltoscandia. Moreover, *Maeandropolydora* isp. found in the boulders studied was so far unknown in Scandinavia and the Baltic region.

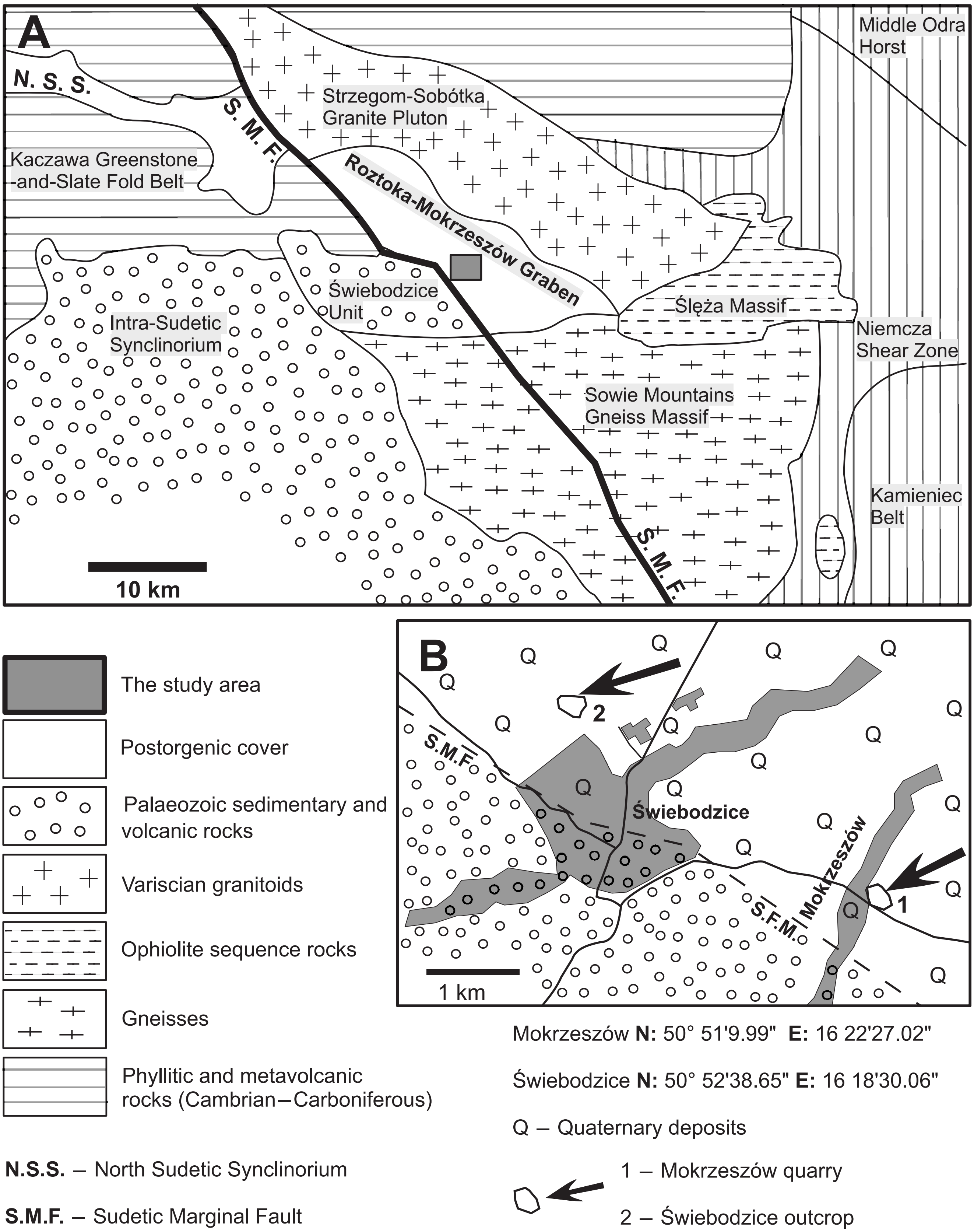
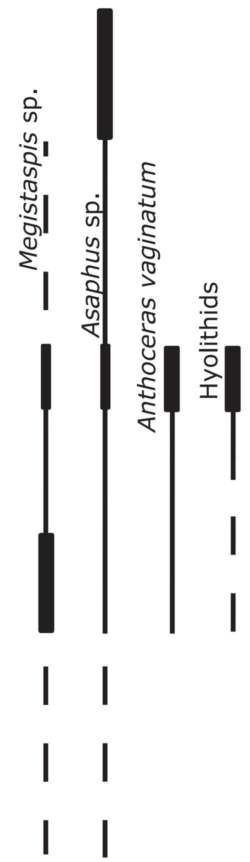



**Fig. 1.** Location of the Roztoka Mokrzeszów Graben in the Sudetes Mountains (**A**) and the Świebodzice outcrop and the Mokrzeszów Quarry (**B**).

**Table 1.**

Chronostratigraphic table of the Middle Ordovician in Baltoscandia with abundance peaks of trilobites (*Asaphus*, *Megistaspis*), cephalopod (*Anthoceras vaginatum*) and hyolithids. Global stages after Bergström *et al*. (2009), trilobite zonation after Bergström *et al*. (2013) and Pärnaste *et al*. (2013). Abundance peaks of individual invertebrate groups after Kröger (2012, 2013), Bergström *et al*. (2013), Pärnaste *et al*. (2013), Kröger and Rasmussen (2014), and Lindskog *et al*. (2015).

| Global series | Global stages | | Baltoscandian stages | Trilobite zones |
|---|---|---|---|---|
| Middle Ordovician | Darriwilian | Dw2 | Aseri | *A. kowalewskii/ A. intermedius/ A. cornutus/ A. latisegmentatus* |
| | | | Kunda | *A. sulevi/ M. gigas* |
| | | | | *M. obtusicauda* |
| | | | | *A. vicarius* |
| | | | | *A. raniceps* |
| | | Dw1 | | *A. expanus* |
| | | | Volkhov | *A. lepidurus/ M. limbata* |
| | Dapingian | Dp3 | | *M. simon/ Asaphus broeggeri* |
| | | Dp1-2 | | *Megistaspis polyphemus* |




Interesting discoveries in the glacial erratic boulders of North Germany and Lower Silesia already were studied by German geologists in the nineteenth century (e.g., Emmrich, 1839, 1844; Roemer, 1861, 1885). Some trace fossils were reported first from erratic boulders, e.g. the early Cambrian *Tubichnus angulatus* in NE Germany (Rügen Island, Western Pomerania) and S Sweden (Öland Island) by Hoffmann *et al*. (2016 and references therein).

In addition, some coral/coral and stromatoporoid/coral intergrowths as well as rare or new fossil associations, such as crinoid/stromatoporoid, brachiopod/bryozoan, brachiopod/coral and coral/microconchid, also were noted in the glacial erratic blocks studied in SW Poland. Some of them were bored by *Trypanites*.

Most of the trace fossils were found in the Mokrzeszów Quarry. This is partly due to the poor exposure of the Pleistocene deposits at Świebodzice, now completely flooded, by comparison with the very well exposed deposits in the Mokrzeszów Quarry.

The newly collected trace fossils are now in the Geological Museum of the University of Wrocław (samples MGUWr-6593s–MGUWr-6622s). Some specimens are in the private collection of Józef Kawałko at Świebodzice.

The aim of this paper is to report on and describe all of the ichnotaxa found in the erratic boulders at the study sites. The probable source areas of the boulders were indicated on the basis of the trace fossils, the associated body fossils and the lithology. A large number of the trace fossils are from the Ordovician Orthoceratite Limestone. The colour of the limestones, reddish or grey, and their skeletal fossil content (e.g., the trilobites ?*Megistaspis* sp., and *Asaphus* sp., or the cephalopod *Anthoceras vaginatum* Schlotheim, 1820) allow recognition of the possible source areas, i.e., Sweden, Estonia or Russia. However, it is important to note that the distribution of their outcrops at present and during the glaciation period might have been slightly different. For instance, some exposures might have been eroded or become covered with post-glacial sediments, while others appeared at the surface only recently. The determination of the source area of the glacial erratic boulders also indicates the direction of ice-sheet movement.

## GEOLOGICAL SETTING OF THE AREA

The Mokrzeszów Quarry and the Świebodzice outcrop are situated in the Fore-Sudetic Block of the Roztoka-Mokrzeszów Graben (Żelaźniewicz *et al*., 2011). This geological unit is bounded by the Strzegom-Sobótka Granite Pluton, Sowie Mountains Gneiss Massif, Świebodzice Unit and the Kaczawa Greenstone-and-Slate Fold Belt (Fig. 1). The Roztoka-Mokrzeszów Graben, situated along the Sudetic Marginal Fault, started to subside during the latest Oligocene to Early Miocene (Jarosiński *et al*., 2009 and references therein).

The Mokrzeszów Quarry is situated in the southern part of the Roztoka-Mokrzeszów Graben, 1.5 km from the Sudetic Marginal Fault, whereas the Świebodzice outcrop is 1.5 km to the north of Świebodzice (Fig. 1). The Roztoka-Mokrzeszów Graben is filled with Neogene and Pleistocene deposits, which are 200–400 m and 30–50 m thick, respectively (Krzyszkowski and Bowman, 1997; Niedzielski and Migoń, 2005).

In the Mokrzeszów Quarry, sands predominate in the lower part, while gravel intercalations are common in the middle and upper parts. These deposits are subdivided into five units showing differences in lithology (Salamon *et al*., 2013). Krzyszkowski (2013) reported erratic blocks from several centimetres to 1.0–1.5 m in diameter, in some cases larger, 35–45% of which are "Baltic limestone", and 23–39% are Scandinavian crystalline rocks. Less common are Mesozoic sandstones and limestones, as well as local granites.

The Mokrzeszów Quarry (Fig. 1) dates back to 1920, but discoveries of fossils there (known as Nieder Kunzendorf bei Freiburg in the older literature) were reported much earlier (Emmrich, 1839; Salamon *et al*., 2013 and references therein). It is still a very rich palaeontological site (Pluta, 2013). The quarry yields well preserved macrofossils (e.g., sponges, trilobites, corals, stromatoporoids, bryozoans, molluscs, brachiopods, echinoderms, graptolites, and vertebrate remains) and trace fossils (Pluta, 2013). The holotypes of the trilobites *Odontopleura ovata* Emmrich, 1839 and *Leonaspis mutica* Emmrich, 1844 are from erratic blocks at this site (see also Bruton, 1967). Only recently, Calner *et al*. (2006) reported the first *Odontopleura ovata* in Scandinavia (Sweden, Gotland). As well, Silurian graptolites from the quarry were mentioned by Urbanek (1966) and studied by Radzevičius *et al*. (2010).

The Pleistocene deposits, exposed in the SW Poland, were assigned to the Middle Polish Glaciation (Saalian, see Marks, 2004; Marks *et al*., 2016) by Dyjor and Kuszell (1977), Jahn (1981) and Badura *et al*. (1992). However, Czubla (2013) suggested that they are referable to the South Polish Glaciation (Elsterian).

The sequence studied is interpreted as coarse-grained delta deposits (Salamon *et al*., 2013 and references therein). Czubla (2013) also analyzed the transport directions of the erratic material, mostly the Scandinavian crystalline boulders. This author suggested that the Öland region, Sweden, is the source area for the "red Baltic limestone" (Ordovician Orthoceratite Limestone). Earlier, Jahn (1981) noted the N and NE directions of movement of the ice sheet in Lower Silesia. Górska-Zabielska (2008) reported that sedimentary, especially Palaeozoic erratics, come mainly from the bottom of the Baltic Sea area, as well as Götaland, Öland and the Baltic countries, whereas the Cretaceous blocks were derived from the SW Baltic region.

A large part of the glacial erratic boulders in SW Poland (Mokrzeszów Quarry, Świebodzice outcrop) come from the Ordovician Orthoceratite Limestone, outcrops of which are located mainly in northern, central and southern Sweden (e.g., Öland), Norway (Oslo Region), East Baltica (e.g., Estonia) and in the St. Petersburg region of western Russia. These deposits are known also from deep boreholes in N Poland and from the Pleistocene erratics in northern Germany and northern Poland (Kröger, 2004 and references therein; Eriksson, 2010). Numerous erratic blocks studied are composed of Silurian stromatoporoids, which are known from excellent outcrops in Saaremaa (Estonia) and Gotland (Sweden) or neighbouring areas (see Sandström and Kershaw, 2002, 2008).

The Ordovician Orthoceratite Limestone, which consists of mainly bioclastic limestones or calcareous shales, slightly dolomitized and containing glauconite grains (Mikuláš and Dronov, 2005, 2010; Meidla *et al*., 2008; Eriksson, 2010), belongs mainly to the Volkhov and Kunda regional stages, which are Floian to Darriwilian in age (Tab. 1). These limestones are grey, brownish or red in colour, depending on the rising oxygenation of the sediment (Kröger, 2004; Histon, 2012). The reddish limestones occur mainly in Sweden, whereas light-grey or yellowish-grey limestones are in Estonia and Russia. These deposits are known also as the Endoceras Limestone (Oslo area), Vaginatenkalk in the eastern Baltica and the Vaginatum Limestone in Sweden (see Kröger, 2012; Kröger and Rasmussen, 2014). Their name is reference to the abundance of large, orthoceraconic cephalopods, including orthocerids, endocerids and actinoceratids (see Kröger, 2004). Trilobites (asaphids), echinoderms (especially cystoids) and molluscs (e.g., hyolithids) also occur in abundance, in addition to the very common nautiloids (Benner *et al*., 2004; Eriksson *et al*., 2013).

## SYNOPSIS OF TRACE FOSSILS

Seventeen ichnogenera, nine referable to burrows and eight to borings, were found in the glacial erratic boulders studied. They occur mainly in the Ordovician Orthoceratite Limestone (*Arachnostega*, *Balanoglossites*, *Planolites*) and in the Silurian stromatoporoids (*Osprioneides*, ?*Palaeosabella*, *Trypanites*). *Chondrites*, *Diplocraterion*, *Phycodes*, ?*Rosselia*, *Skolithos* and *Thalassinoides* were found in boulders made up of Palaeozoic rocks, whereas ?*Gastrochaenolites*, *Maeandropolydora*, *Oichnus*, *Talpina*, *Teredolites* occurred in boulders of Mesozoic-Cenozoic rocks.

### Burrows

*Arachnostega* Bertling, 1992
*Arachnostega gastrochaenae* Bertling, 1992
Figs 2A–H, 3A, B

**Material:** Six specimens: two on the pygidia of the trilobites: ?*Megistaspis* (10–13 cm long; Fig. 2A–E; MGUWr-6593s), one on a pygidium of *Asaphus* sp. (4 cm long; Fig. 2F; MGUWr-6594s), one specimen on a cephalopod (16 cm long; Fig. 3A; MGUWr-6595s) and two on hyolithid conchs (45–72 mm long; Fig. 3B; private collection of J. Kawałko) found in Ordovician Orthoceratite Limestone erratic boulders: reddish (Fig. 2A–E) and grey (Figs 2F, 3A, B) in the Mokrzeszów Quarry. The sixth specimen was noticed on the pygidium of the trilobite *Asaphus expansus* (5.5 cm ong; Fig. 2G, H), from the collection of the Geological Museum of the Wrocław University (MGUWr-129s), found in the glacial erratic boulders near Oleśnica (Sadowice, formerly Sadewitz), probably by Roemer (1861).
**Description:** Net-like structure, composed of straight or slightly curved, ramified tunnels at the surfaces of pygidia of the Ordovician trilobites ?*Megistaspis* sp. and *Asaphus*, and on cephalopod and hyolithid moulds. In some cases, the tunnels are widened slightly at junctions, typical for this ichnogenus. The tunnels are oval or elliptical in cross-section, 0.1–1.5 mm, mainly 1.0 mm wide.
**Remarks:** *Arachnostega* usually is interpreted as a feeding structure of the category fodinichnia, produced by detritus- or deposit-feeding polychaetes (Bertling, 1992). However, Fatka *et al*. (2011) considered it also as a domichnion.
This ichnotaxon was recognized in Baltoscandia, in the Middle–Upper Ordovician (Darriwilian–Katian) deposits of Russia (Mikuláš and Dronov, 2005, 2010) and Estonia (Vinn *et al*., 2014b; Chrząstek and Pluta, 2017 and references therein). In Russia, it was found on a cephalopod and a trilobite, whereas in Estonia it occurred on bivalves, gastropods, cephalopods, hyolithids and cystoids. On the basis of the associated lithology, the specimens found in the trilobite ?*Megistaspis* probably are from Sweden, while those in *Asaphus*, the cephalopod and hyoliths are from Russia (St. Petersburg region) or Estonia. The range of *Arachnostega* is from the Cambrian (Fatka and Kozak, 2014) to Recent (Bertling, 1992). It is common in the Mesozoic and Cenozoic. Palaeozoic *Arachnostega* was reported mainly from the Cambrian and Ordovician of the Czech Republic (Bruthansová and Kraft, 2003; Fatka *et al*., 2011, 2015), Spain and Portugal (Gil Cid and Lebron Moreno, 2010) and Argentina (Aceñolaza *et al*., 2003).

*Balanoglossites* Mägdefrau, 1932
*Balanoglossites* isp.
Fig. 3C–H

**Material:** Five blocks with several specimens in erratic boulders, composed of the reddish Ordovician Orthoceratite Limestone from the Mokrzeszów Quarry, which contain trilobites and large endocerids (up to 24.5 cm long; Figs 3C–F; MGUWr-6596s–6598s). Two specimens, determined as ?*Balanoglossites* isp. (MGUWr-6599s, MGUWr-6600s; Fig. 3G, H), are probably from Devonian limestones with brachiopods (Spiriferida).
**Description**: Branched, unlined tunnels with circular or elliptical cross-sections, 2–12 mm in diameter, which display blind-ending side branches and terminations. They plunge into the rock at least up to 20–40 mm and show openings, which are 5–10 mm wide. Some of the tunnels are U-shaped.
In the possibly Devonian limestone, ?*Balanoglossites* appears as irregular, branched tunnels, 3–5 mm in diameter, visible in cross-section (Fig. 3G, H), segments of which are 25–40 mm long between branches.
**Remarks:** *Balanoglossites* is regarded as a combined feeding and dwelling structure (fodinichnion/domichnion) of worm-like animals (Knaust and Costamagna, 2012). The tracemaker of *Balanoglossites* was probably an eunicid polychaete, which had the ability to bioerode and burrow the sediment (see Knaust, 2008; Knaust and Dronov, 2013).
*Balanoglossites* was described from the Ordovician Orthoceratite Limestone of western Russia (St. Petersburg region) by Knaust and Dronov (2013). The lithology of the boulders, in which *Balanoglossites* occurs, indicates Sweden as an area of origin. According to A. Dronov (pers. comm., 2014), this ichnogenus occurs there. It ranges from the ?Middle Cambrian (Ekdale *et al*., 2012) to the Neogene (Schäfer *et al*., 1996), but it is most common in the Ordovician, even more than in the Triassic (see Knaust and Dronov, 2013).

*Chondrites* Sternberg, 1833
?*Chondrites* isp.
Fig. 4A–C

**Material:** One specimen on a parting surface (Fig. 4A, B; housed in the private collection of J. Kawałko) and one in cross-section (Fig. 4C; MGUWr-6601s), both in probably Lower Palaeozoic limestones.
**Description**: A complex, root-like burrow system of mostly vertical or inclined, regularly branching, unlined tunnels, which are open to the surface. The tunnels are circular and elliptical in cross-section, 2–3 mm in diameter and 20–50 mm long, without crossings. Their fill is darker than the host rock.
**Remarks:** The specimen studied (Fig. 4A, B) shows some similarities to *Chondrites affinis* Sternberg, 1833, described by Uchman *et al*. (2012) as having straight to slightly curved tunnels (which never cross) and rounded terminations of these tunnels. By comparison with *Chondrites affinis*, the tunnels of the specimen described are narrower (2–3 mm instead of 4–5 mm in width) and they do not show the characteristic twigs in the branched tunnels, which run outward from the centre (compare Uchman *et al*., 2012). The specimen studied does not consist of ramified tunnels that form a dendritic network, characteristic of this ichnogenus but has a number of main shafts open to the surface (cf. Bhattacharaya and Banerjee, 2014). For these reasons, it should be assigned only tentatively to the ichnogenus *Chondrites*.

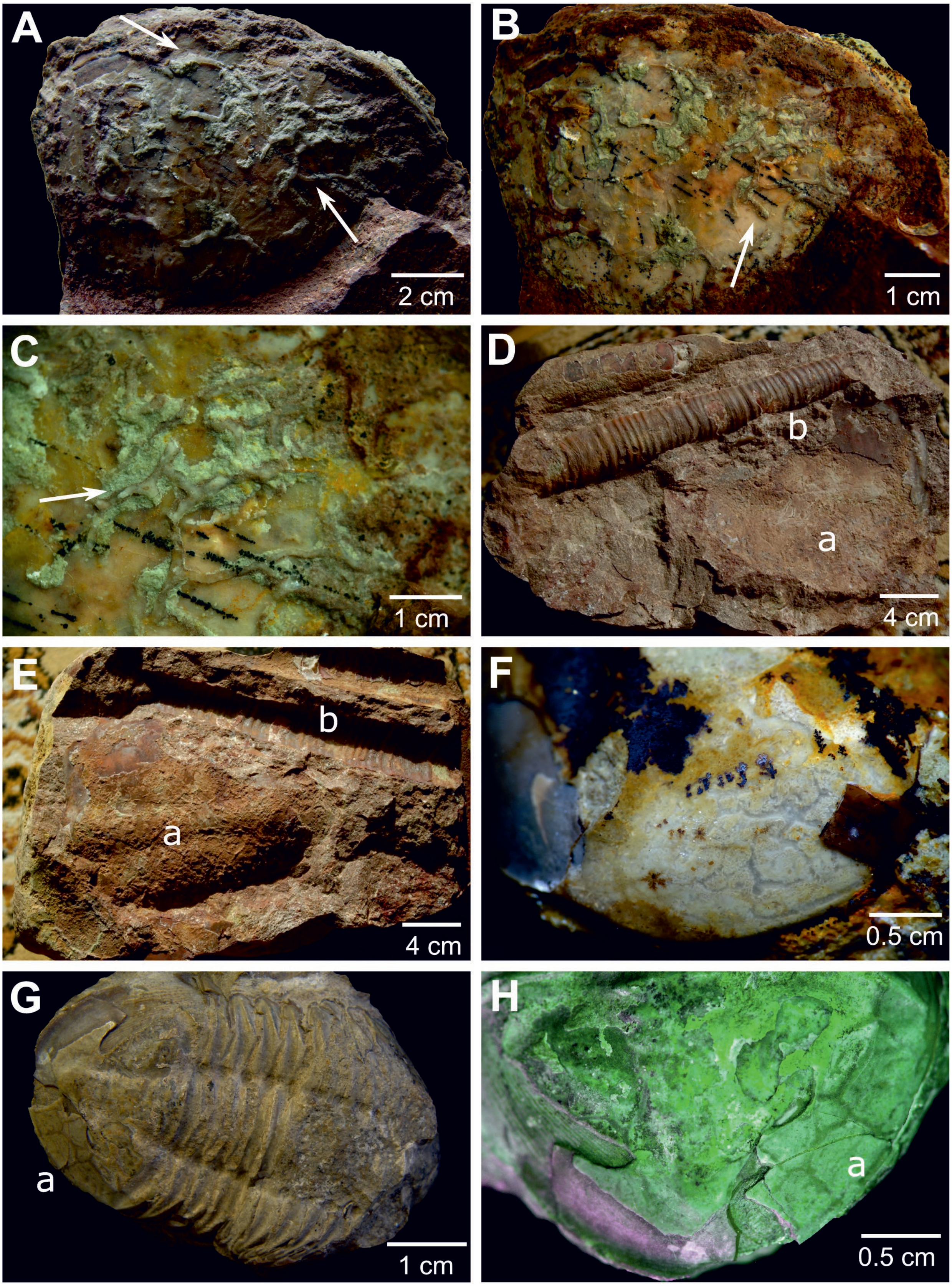



**Fig. 2.** *Arachnostega gastrochaenae* on pygidium of the trilobites ?*Megistaspis* and *Asaphus*, erratic blocks built of the Ordovician Orthoceratite Limestone. **A–C.** On the trilobite ?*Megistaspis*, Mokrzeszów Quarry (private collection of J. Kawałko). **D, E.** On the trilobite ?*Megistaspis* (a); cephalopod *Anthoceras vaginatum* (b), Mokrzeszów Quarry; MGUWr-6593s. **F.** On pygidium of *Asaphus* sp., Mokrzeszów Quarry; MGUWr-6594s. **G, H.** *A. gastrochaenae* (a) on pygidium of the trilobite *Asaphus expansus* (MGUWr-129s, specimen found by Roemer in 1861 in erratic boulders; Sadowice, near Oleśnica (formerly Sadewitz by Oels), the same specimen. Arrows indicate *Arachnostega*, on the pygidium of *Megistaspis* sp.

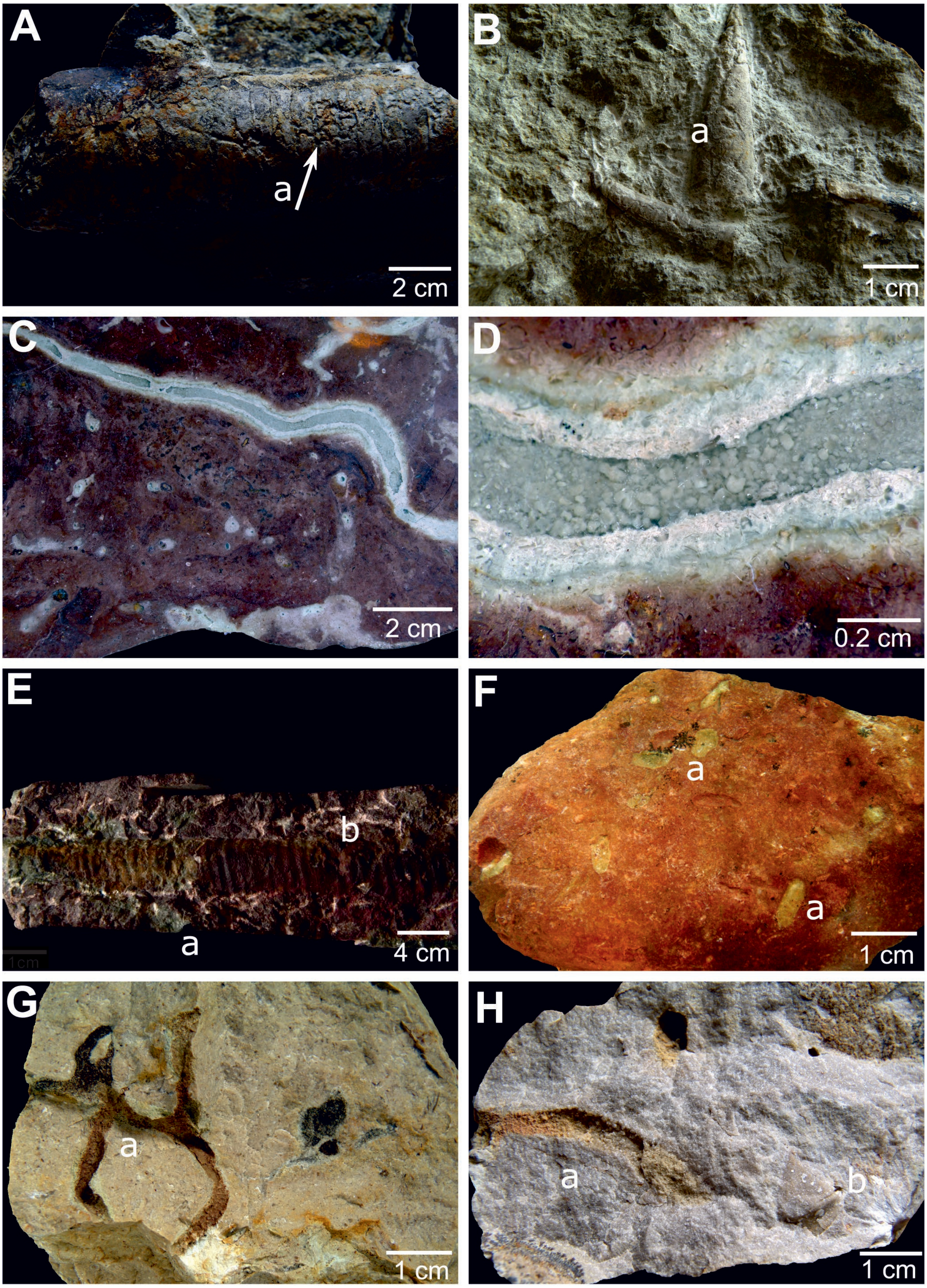



**Fig. 3.** *Arachnostega* on other fossils and *Balanoglossites*. **A.** *A. gastrochaenae* (a) on a cephalopod, Mokrzeszów Quarry; MGUWr-6595s; arrow is pointing *Arachnostega*. **B.** *A. gastrochaena* (a) on hyolithids, Mokrzeszów Quarry (private collection of J. Kawałko). **C, D.** *Balanoglossites* isp. in the Ordovician Orthoceratite Limestone, Mokrzeszów Quarry; MGUWr-6596s. **E.** *Balanoglossites* (a) and the cephalopod *Anthoceras vaginatum* (b) in the Orthoceratite Limestone; MGUWr-6597s. **F.** Openings of the *Balanoglossites* isp. (a) seen on the surface of an erratic boulder composed of Orthoceratite Limestone, Mokrzeszów Quarry; MGUWr-6598s. **G, H.** ?*Balanoglossites* isp. (a) and a spiriferid brachiopod (b) in the Devonian limestone erratic boulders (MGUWr-6599s-MGUWr-6600s).

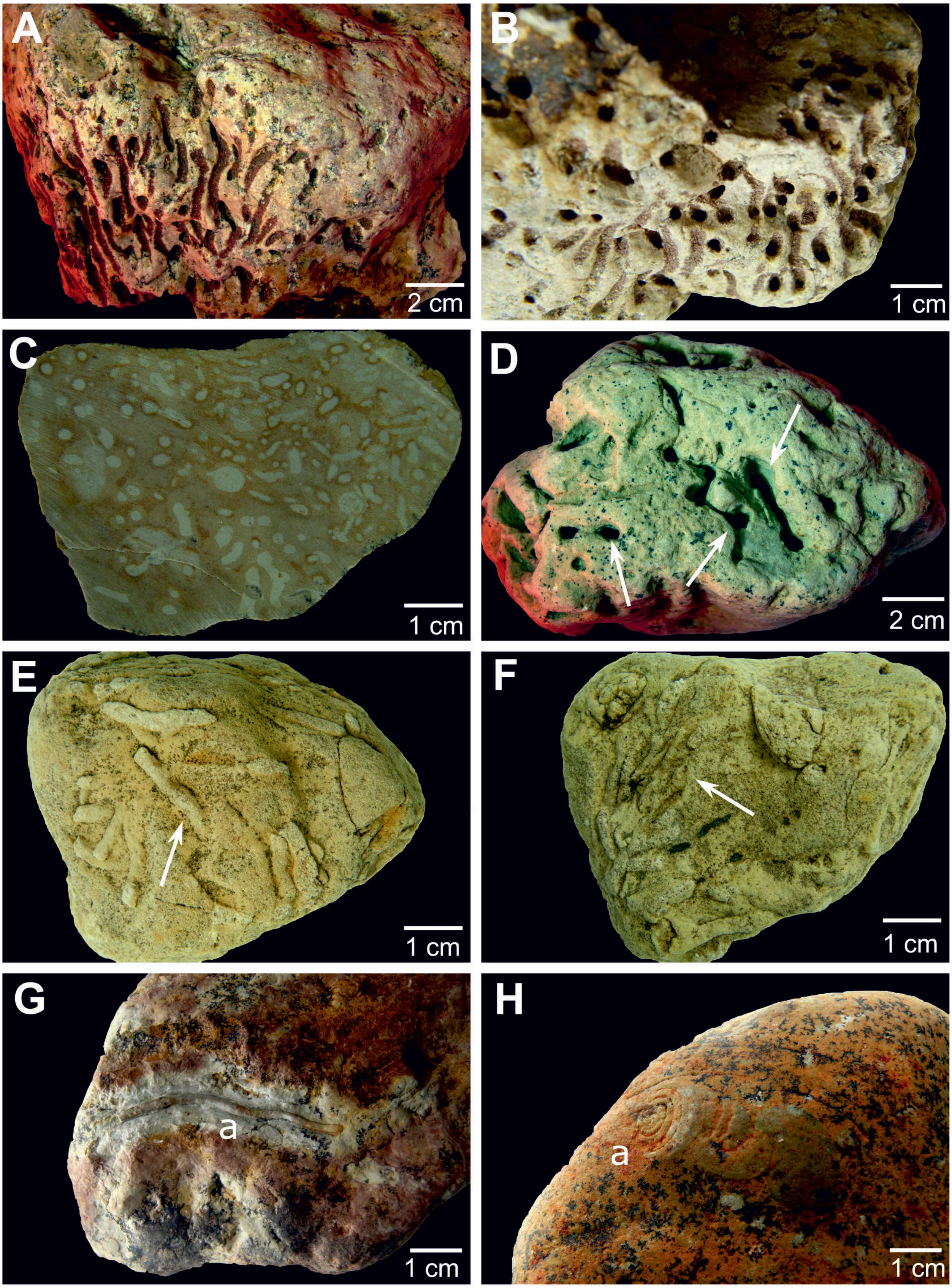



**Fig. 4.** Burrows in Lower Palaeozoic erratic boulders. **A, B.** ?*Chondrites* isp. in Lower Palaeozoic limestone erratic boulder, Mokrzeszów Quarry. **C.** ?*Chondrites* isp. in the cross-section, limestone erratic boulder, Mokrzeszów Quarry, MGUWr-6601s. **D.** *Diplocraterion* isp., the pair of the openings; ?Cambrian sandstone block, Mokrzeszów Quarry. **E, F.** *Phycodes* isp. in a ?Cambrian sandstone erratic boulder; Mokrzeszów Quarry. **G.** *Planolites* isp. (a) in a glacial erratic boulder of the Ordovician Orthoceratite Limestone; Mokrzeszów Quarry. **H.** ?*Rosselia* isp. (a) in a Lower Palaeozoic (?Cambrian) sandstone erratic boulder; Mokrzeszów Quarry. Specimens A, B, D–H housed in the private collection of J. Kawałko. Arrows indicate the burrows *Diplocraterion* (D) and *Phycodes* (E, F).

*Chondrites* was regarded as a feeding structure belonging to the category fodinichnia (Häntzschel, 1975; Frey and Howard, 1990). More recently, it is considered to be a chemichnion (see Rindsberg, 2012). Candidates for trace-maker are among the deposit-feeding sipunculids, polychaetes, anthoptiloid sea pens, arthropods (e.g., Osgood, 1970; Pickerill *et al*., 1984).

In Baltoscandia, *Chondrites* is known from the Ordovician of the St. Petersburg region, Russia (Dronov, 2011; Dronov *et al*., 2002), the Upper Ordovician of the Oslo region, Norway (Hanken *et al*., 2016), and from the Upper Triassic of Bornholm, Denmark (Nielsen *et al*., 2015). It ranges from the Ediacaran (McCann and Pickerill, 1988; Buatois and Mángano, 2011), through the Cambrian to Recent (Häntzschel, 1975; Seilacher, 2007).

*Diplocraterion* Torell, 1870
*Diplocraterion* isp.
Fig. 4D

**Material:** Several specimens, visible in the same sandstone sample (probably Cambrian), housed in the private collection of J. Kawałko).
**Description:** Endichnial, U-shaped structures, mostly visible as paired circular or dumbbell-like openings. They are 12–27 mm, mostly 15 mm wide. One vertical U-shaped spreiten structure is visible. It shows parallel limbs, perpendicular to the bedding plane, 60 mm long. Only protrusive spreiten have been recognized. The marginal tunnel is 5 mm wide.
**Remarks:** The study specimen is very similar to the *Diplocraterion* reported by Prothero (2004, fig. 19.4F) from southern Sweden. This ichnogenus is interpreted as a dwelling or equilibrium structure (Häntzschel, 1975; Bromley, 1996; Pemberton *et al*., 2001), produced by suspension-, detritus- or filter-feeding organisms, mainly polychaetes or amphipod crustaceans (Fürsich, 1974; Cornish, 1986; Gradziński and Uchman, 1994; Pemberton *et al*., 2001; Hanken *et al*., 2016).

*Diplocraterion* was described from the lower Cambrian of south-central Sweden by Torell (1870), Westergård, (1931) and Jensen (1997) and from southern Sweden (Scania) and Denmark (Bornholm) by Nielsen and Schovbso (2011). Bromley and Hanken (2003) and Hanken *et al*. (2016) reported this ichnogenus from the lower Cambrian and Upper Ordovician of Norway. It is known from Cambrian to Recent (Cornish, 1986; Gradziński and Uchman, 1994).

*Phycodes* Richter, 1850
*Phycodes* isp**.**
Fig. 4E, F

**Material:** The specimens studied are preserved in a full relief in the Lower Palaeozoic sandstone erratic boulder (private collection of J. Kawałko).
**Description:** Broom-like bundle of four-seven horizontal tubes, showing two-three branches. The tubes originate from nearly the same point of a thick, single stem. The tubes are about 5 mm in diameter and up to 30 mm long.
**Remarks:** *Phycodes* generally is interpreted as a structure produced by deposit-feeding organisms (fodinichnia), mostly annelids (Osgood, 1970; Häntzschel, 1975; Fillion and Pickerill, 1990).

In Baltoscandia, this ichnogenus was reported from the lower Cambrian of Sweden by Jensen (1997) and Jensen and Grant (1998) and from the Ordovician of the St. Petersburg region, Russia by Dronov (2011). Knaust (2004) described this burrow from the Cambrian-Ordovician deposits of SW Norway. Generally, *Phycodes* is known from the lower Cambrian to the Miocene (Han and Pickerill, 1994) and is common in the Lower Palaeozoic. Recently, this ichnogenus was described also from the Pliocene (Belaústegui and Muñiz, 2016).

*Planolites* Nicholson, 1873
*Planolites* isp.
Fig. 4G

**Material:** Several specimens occur in erratic blocks of the Ordovician Orthoceratite Limestone (private collection of J. Kawałko).
**Description:** A straight or slightly undulating, smooth, unlined, cylindrical burrow, elliptical or circular in cross--section, 3 mm in diameter, at least 70 mm long. Lithology of the fill differs from the host rock.
**Remarks:** *Planolites* is interpreted as a pascichnion of deposit feeders produced by various organisms, mostly polychaetes (Pemberton and Frey, 1982; Keighley and Pickerill, 1995).

In Baltoscandia, this ichnogenus was reported from the Ordovician of the St. Petersburg region, Russia (Dronov *et al*., 2002; Dronov, 2011). It is known from the late Proterozoic to Holocene (Häntzschel, 1975; McCann and Pickerill, 1988).

*Rosselia* Dahmer, 1937
?*Rosselia* isp.
Fig. 4H

**Material:** One specimen, collected from a Lower Palaeozoic sandstone erratic boulder (private collection of J. Kawałko).
**Description:** The specimen studied is visible in a transverse cross-section as an oval structure, about 20 mm wide, and continues into the rock as partly visible on the side. It shows a central shaft and alternating, concentric, sandy and muddy laminae. The shaft is 5 mm in diameter. The concentric, sandy and muddy laminae are 2 mm and 0.5–1.0 mm thick, respectively.
**Remarks:** The specimen studied resembles the upper part of *Rosselia*, which is characterized by a funnel or spindle shape and concentric, internal lamination. It is regarded as a fodinichnial-domichnial (Nara, 1995) and equilibrichnial structure (Nara, 2002).

*Rosselia* was produced by suspension or detritus feeders, most probably terebellid polychaetes (Nara, 1995, 2002). Sea anemones also have been considered as the possible producers (Uchman and Krenmayr, 1995). *Rosselia* has been reported from the lower Cambrian of south-central Sweden by Jensen (1997) and from the Upper Ordovician of Estonia (Vinn and Toom, 2016 and references therein). It ranges from the Cambrian to the Holocene (Nara and Haga, 2007).

*Skolithos* Haldeman, 1840
*Skolithos linearis* Haldeman, 1840
Fig. 5A, B

**Material:** Several specimens (MGUWr-6606s-MGUWr--6607s), preserved in the Lower Palaeozoic sandstone erratic boulders (probably Cambrian).
**Description:** Straight, smooth, vertical and unbranched cylindrical burrow, perpendicular to the bedding planes, circular or elliptical in cross-section, at least 65 mm long and 2–2.5 mm in diameter. The fill is structureless.
Marine *Skolithos* is a dwelling burrow (domichnion) of suspension-feeding annelids or phoronids (Alpert, 1974; Buckman, 1996).

In Baltica, *Skolithos* was reported from the lower Cambrian of southern-central Sweden by Jensen (1997; and references therein). Nielsen and Schvobso (2011) described this ichnogenus from the lower Cambrian of Bornholm, Denmark, while Vinn and Wilson (2013) from the Silurian of Saaremaa, Estonia. This ichnogenus is common in the Lower Palaeozoic, mostly Cambrian, where it forms piperock (Droser, 1991). It ranges from the late Precambrian to Recent (Häntzschel, 1975; Fillion and Pickerill, 1990).

*Thalassinoides* Ehrenberg, 1944
*Thalassinoides* isp.
Fig. 5C

**Material**: One specimen in a Palaeozoic sandstone block (private collection of J. Kawałko).
**Description**: *Thalassinoides* appears as cylindrical, flattened tunnels, 2.0 cm wide, elliptical in cross-section. This burrow exhibits Y-shaped branching and crossings of the tunnels.
**Remarks:** *Thalassinoides* is regarded as a domichnion/fodinichnion or even an agrichnion produced mostly by thalassinidean shrimps (Myrow, 1995; Bromley, 1996; Ekdale and Bromley, 2003). Frey *et al*. (1984), Neto de Carvalho *et al*. (2007) and Neto de Carvalho (2016) proposed also crabs and lobsters.

From Baltoscandia, *Thalassinoides* was described by Cherns *et al*. (2006), together with *Asaphus* sp. (its possible tracemaker), and by Ekdale and Bromley (2003) from the Ordovician of Sweden. It is known from the Cambrian (Myrow, 1995) to Recent (Ekdale and Bromley, 2003).

Root traces (rhizoliths)
Fig. 5D

**Material:** A few blocks (20 x 30 cm) of dark brown sandstones (probably Mesozoic-Cenozoic in age), containing fossil wood, some plant or root traces, Mokrzeszów Quarry (MGUWr-6615s).
**Description:** Straight or slightly curving, smooth, occasionally branched tunnels, resembling roots. They are 5–50 mm long and 1–6 mm wide. Some of them show a delicate ornamentation in the form of horizontal wrinkles. Additionally, *Trypanites* (1 mm wide, 15–20 mm long) occurs in the same blocks.
**Remarks:** Similar root traces were described from Upper Triassic continental sandstones in Baltoscandia (Bornholm, Denmark) by Knaust (2015).

**Borings**

*Gastrochaenolites* Leymerie, 1842
?*Gastrochaenolites* isp.
Fig. 5E

**Material:** One specimen in a bivalve shell, Mokrzeszów Quarry (private collection of J. Kawałko).
**Description:** Broad, unornamented, drop-like cavity, which is circular in transverse section, 15 mm deep and up to 2 mm wide. The upper neck-like part is eroded.
**Remarks:** *Gastrochaenolites* is regarded as a dwelling structure (domichnion), produced by suspension-feeding gastrochaenid, lithophagid, pholadid and mytilid bivalves (Warme, 1975; Kelly and Bromley, 1984). Recent coralliophillid gastropods (closely related to Muricidae, see Oliverio and Mariottini, 2001) and some sipunculan worms also have been suggested as the potential tracemakers of *Gastrochaenolites* (Bromley, 2004). It may occur also as a burrow (Mikuláš *et al*., 2003).

*Gastrochaenolites* was described from the Lower–Middle Ordovician of Baltoscandia (Sweden, Norway, Estonia, Russia) by Ekdale and Bromley (2001), Ekdale *et al*. (2002), Dronov *et al*. (2006) and Vinn and Wilson (2010c). The specimen studied was found in a probably Jurassic *Gryphaea* shell. *Gastrochaenolites* ranges from the Early Ordovician to Recent (Kelly and Bromley, 1984), more commonly in the Jurassic (Wilson and Palmer, 2006).

*Maeandropolydora* Bromley and D'Alessandro, 1983
*Maeandropolydora* isp.
Fig. 5F, G

**Material:** Borings preserved in two valves of the *Gryphaea* shells, Mokrzeszów Quarry (private collection of J. Kawałko).
**Description:** Long, straight or sinuous, shallow, cylindrical borings, usually unbranched, 0.5–1.5 mm in diameter. One shell is almost completely bioeroded, especially the right valve (Fig. 5G).
**Remarks:** *Maeandropolydora* is interpreted as the domichnion of suspension-feeding organisms, probably polychaetes (Bromley and D'Alessandro, 1983; Taylor and Wilson, 2002).

This ichnogenus is commonly preserved on the shell surfaces, usually bivalves, especially oysters (Parras and

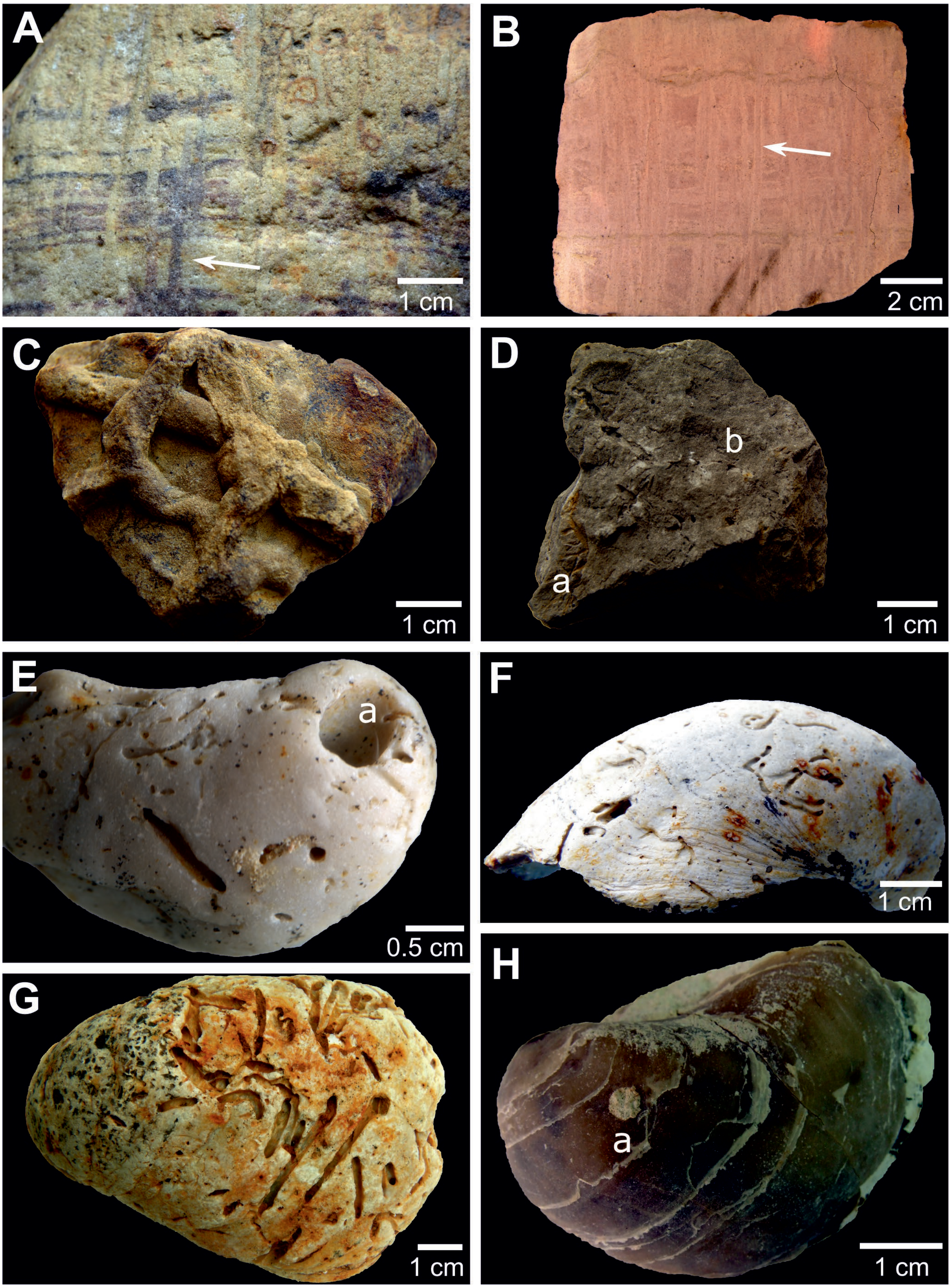



**Fig. 5.** Burrows in Palaeozoic rocks and borings in Mesozoic-Cenozoic shells and root traces. **A, B.** *Skolithos linearis*, ?Cambrian sandstone block; Mokrzeszów Quarry; MGUWr-6606s-6607s; arrows are pointing vertical burrows ascribed to *Skolithos*. **C.** *Thalassinoides* isp. in Palaeozoic sandstone erratic boulder; Mokrzeszów Quarry. **D.** Root traces bored by *Trypanites*; root traces (a), *Trypanites* (b) in the ?Mesozoic-Cenozoic sandstone erratic boulders; Mokrzeszów Quarry; MGUWr-6615s. **E.** ?*Gastrochaenolites* isp. (a) in the *Gryphaea* shell; Mokrzeszów Quarry. **F, G.** *Maeandropolydora* isp. in the *Gryphaea* shells; Mokrzeszów Quarry. **H.** *Oichnus* isp. (a) in a Mesozoic bivalve shell; Mokrzeszów Quarry, MGUWr-6602s. Specimens C, E–G housed in the private collection of J. Kawałko.

Casadío, 2006; Santos and Mayoral, 2008). The specimen studied was found on *Gryphaea* shells (probably Jurassic). *Maeandropolydora* ranges from the ?Silurian/Devonian to Recent, commonly in the Mesozoic and Cenozoic, mainly in the Jurassic and Cretaceous (Taylor and Wilson, 2003; Bromley, 2004).

*Oichnus* Bromley, 1981
*Oichnus* isp.
Figs 5H, 6A, B

**Material:** One specimen in a Mesozoic bivalve (MGUWr--6602s; Fig. 5H; Mokrzeszów Quarry) and three specimens in Miocene gastropod shells (MGUWr-6603s-6604s; Fig. 6A, B; Świebodzice outcrop).
**Description:** Small, circular or subcircular holes, perpendicular to the shell surface, 3-4 mm in diameter. They do not pass through the shells, but terminate within the shell as a flat-bottom depression.
**Remarks:** The specimens studied were found in a bivalve shell (Mesozoic) and gastropods (probably Miocene) in the Mokrzeszów Quarry and the Świebodzice outcrop, respectively. *Oichnus* was reported from Upper Cretaceous corals in Sweden (Sørensen and Surlyk, 2011).

Wisshak *et al*. (2015) noted that *Oichnus* is not a junior synonym of *Sedilichnus*, as presented by Zonneveld and Gingras (2014). *Oichnus* is interpreted as a praedichnion (Bromley, 1981), which was produced in the Cretaceous and Cenozoic by predatory gastropods of the families Naticidae and Muricidae (Taylor *et al*., 1983; Mallick *et al*., 2014 and references therein) in shells belonging to different taxa (Bromley, 1981; Klompmaker *et al*., 2016). According to Bromley (1993, 2004) and Todd and Harper (2010), octopods can make drill-holes closely similar to those of muricaceans.

*Oichnus* is known from the Cambrian to Recent (Wilson, 2007) and is common in the Cenozoic (Kowalewski *et al*., 1998; Harper, 2003). According to Bromley (2004) and Buatois *et al*. (2016), it also occurs in the Ediacaran.

*Osprioneides* Beuck and Wisshak, 2008
in Beuck *et al*., 2008
*Osprioneides kampto* Beuck and Wisshak
in Beuck *et al*., 2008
Fig. 6C–F

**Material**: Borings in two stromatoporoid blocks (Fig. 6C, D; MGUWr-6605s) and in a large (8 x 8.5 cm) bryozoan (Fig. 6E, F; private collection of J. Kawałko); Mokrzeszów Quarry.
**Description:** Numerous, large, unbranched, single-entrance, straight or slightly undulating in course, deep clavate cavities with oval cross-sections, up to 22–24 mm long, 10–18 mm deep, and 3–6 mm in diameter. The borings studied are vertical or subparallel to the external surface of the stromatoporoids and the bryozoan. They lack any scratch traces. In some cases, the borings cross each other and usually show a tapered to hemispherical terminus.
**Remarks:** *Osprioneides* is regarded as a domichnion of a suspension-feeder, most likely polychaetes (Beuck *et al*., 2008).

It was found in the Lower Silurian (Sheinwoodian) stromatoporoids and tabulate corals of Saaremaa (Estonia) by Vinn and Wilson (2010a) and in the Silurian (lower Wenlock) of Gotland (Sweden) by Beuck *et al*. (2008). Vinn *et al*. (2014a) found this ichnogenus for the first time in the Late Ordovician (Sandbian) bryozoans of Estonia. Chrząstek and Pluta (2017) also have reported these borings from the Upper Ordovician bryozoans of Estonia. The specimens studied come from Silurian stromatoporoids (Sweden or Estonia) and an ? Upper Ordovician bryozoan (?Estonia). *Osprioneides kampto* occurs only in the Ordovician (Vinn *et al*., 2014a) and Silurian, from the Llandoverian to the Ludlovian (Beuck *et al*., 2008).

*Palaeosabella prisca* McCoy, 1855
?*Palaeosabella* **i**sp.
Fig. 6D

**Material:** A few specimens (MGUWR-6605s) in two stromatoporoid blocks, preserved in glacial erratic boulders; Mokrzeszów Quarry.
**Description:** Straight, vertical drill-holes, circular in a cross-section in the upper part of stromatoporoids, 3–7, mainly 5 mm in diameter. The terminus, which is slightly enlarged distally, is partially visible.
**Remarks:** *Palaeosabella* is regarded as a "worm" boring (Cameron, 1969; Bromley, 2004). Furlong and McRoberts (2014) proposed the name *Clionoides* Fenton and Fenton, 1932 instead *Palaeosabella* McCoy, 1855. The ichnotaxon studied is similar to *Trypanites*, but differs from it by having a terminus, which is enlarged distally (see Bromley, 2004; Wilson and Palmer, 2006; Tapanila and Hutchings, 2012).

*Palaeosabella* was mainly described from Silurian stromatoporoids and corals of Sweden (Gotland) and Estonia (Saaremaa) by Beuck *et al*. (2008) and Vinn and Wilson (2010a, 2012a). This ichnotaxon also was reported by Wyse Jackson and Key (2007) from Ordovician bryozoans in Estonia. The specimen described was found in the glacial erratic boulders, in stromatoporoids, probably Silurian in age and originating in Sweden (Gotland) or Estonia (Saaremaa). *Palaeosabella* is distributed mainly in the Palaeozoic, but its stratigraphical range is from the Late Ordovician (Taylor and Wilson, 2003) until Recent (Bromley, 2004).

*Talpina* Hagenow, 1840
*Talpina* isp.
Fig. 6G

**Material:** One specimen in the rostrum of a belemnite, Mokrzeszów Quarry (private collection of J. Kawałko).
**Description:** Network of straight or gently undulating tunnels on the surface or very shallowly below surface of a belemnite, rarely branching, circular to semi-circular in cross-section, 3–4 mm in diameter.

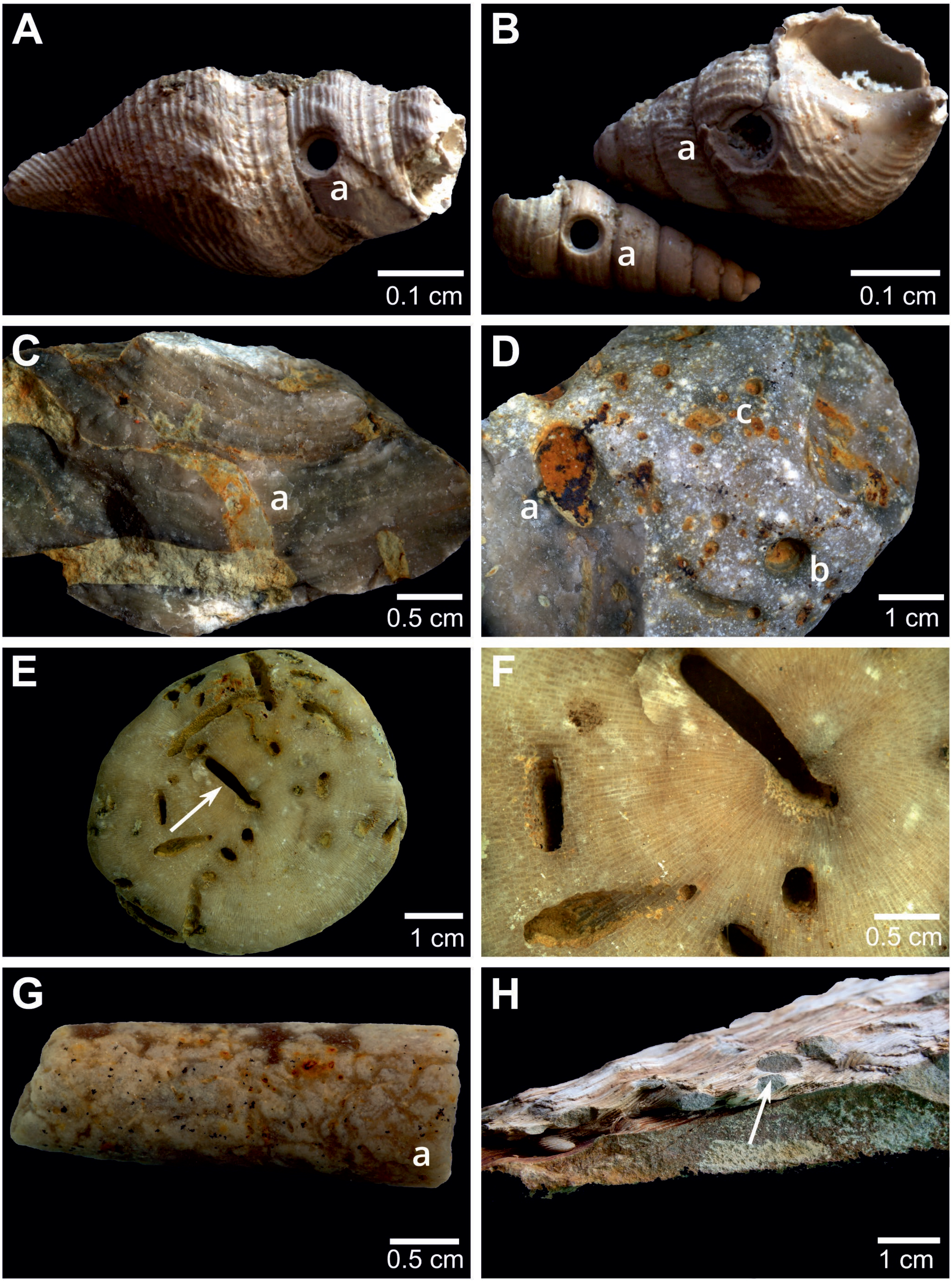



**Fig. 6.** Borings in Palaeozoic, Mesozoic and Cenozoic fossils and wood. **A, B.** *Oichnus* isp. (a) in Miocene gastropod shells; Świebodzice outcrop, MGUWr-6603s-6604s. **C.** *Osprioneides kampto* (a) in a Silurian stromatoporoid; Mokrzeszów Quarry (MGUWR-6605s). **D.** *Osprioneides kampto* (a), ?*Palaeosabella* isp. (b) and *Trypanites* isp. (c) in a Silurian stromatoporoid; Mokrzeszów Quarry; MGUWr-6605s. **E, F.** *Osprioneides kampto* in an ?Upper Ordovician bryozoan; Mokrzeszów Quarry. **G.** *Talpina* isp. (a) in the rostrum of a belemnite (Cretaceous); Mokrzeszów Quarry. **H.** *Teredolites* isp. in a piece of wood (Jurassic–Miocene?); Mokrzeszów Quarry. Specimens E–H housed in the private collection of J. Kawałko. Arrows indicate the borings *Osprioneides* (E) and *Teredolites* (H).

**Remarks:** Owing to the poor state of preservation of the boring, the branching pattern is not clearly visible, but it seems that lateral branches occur on one side, which is typical of *Talpina* (see Uchman *et al*., 2016). According to some authors (e.g. Bromley, 2004), *Conchotrema* Teichert, 1945 is a junior synonym of *Talpina* von Hagenow, 1840. Uchman *et al*. (2016) distinguished and described both ichnogenera *Talpina* and *Conchotrema*, whereas Wisshak *et al*. (2017) rediscovered the type material of *Talpina* (from the Hagenow, 1840 collection). From an ethological point of view, *Talpina* is a domichnion produced by suspension-feeding phoronid worms (Bromley, 2005; Tapanila and Hutchings, 2012; Zonneveld and Bistran, 2013).

From Baltoscandia, *Talpina* was described by Neumann *et al*. (2008) from echinoid spines in Denmark. The belemnite bearing the specimen studied is probably Cretaceous in age. *Talpina* is known from the Devonian to Recent (Taylor and Wilson, 2003) and is abundant in the Jurassic (Bromley, 2004).

*Teredolites* Leymerie, 1842
*Teredolites* isp.
Figs 6H, 7A

**Material:** Eight specimens in a piece of fossil wood (Mesozoic–Cenozoic), which is 13 cm long and 6 cm wide; Mokrzeszów Quarry (private collection of J. Kawałko).
**Description:** Clavate borings, in which the neck region passes gradually into the chamber part. They are circular or elliptical in cross-section, 22 mm long and 4–6 mm in diameter. Their surface may show faint bioglyphs in the form of parallel rings and grooves, which encircling the individual tubes (see Kelly and Bromley, 1984; Kumar *et al*., 2011).
**Remarks:** *Teredolites* is a domichnion (Savrda and Smith, 1996) or a fodinichnion, produced by wood-boring bivalves (Bromley *et al*., 1984; Kelly, 1988), mostly in the families Teredenidae and Pholadidae (Evans, 1999). *Teredolites* is known from the Pliensbachian (Jurassic) to Recent (Buatois *et al*., 2016 and references therein).

*Trypanites* Mägdefrau, 1932
*Trypanites weisei* Mägdefrau, 1932
Figs 5D, 7B–H, 8, 9E

**Material**: Many specimens in Palaeozoic corals (MGUWr--6611s-6612s; Figs 8A, B, D and H), Mesozoic coral ?*Thamnasteria* sp. (MGUWr-6614s; Fig. 8E), bryozoans (MGUWr-6613s; Fig. 8C), stromatoporoids (MGUWr--6609s-6610s; Figs 7D–H, 9E), belemnites (Fig. 8F), ammonites (Fig. 8G), bones of the lizard ?*Platecarpus* sp. (MGUWr-6608s; Fig. 7C) as well as in the Silurian/Devonian (?) erratic limestone blocks (Fig. 7B) and Mesozoic-Cenozoic sandstones (MGUWr-6615s; Fig. 5D). The specimens studied were found in the Mokrzeszów Quarry, with the exception of the Mesozoic corals (Świebodzice outcrop). Specimens visible in Figs 7B, 8F and G are housed in the private collection of J. Kawałko.
**Description:** A straight or slightly curved, unlined, unbranched, vertical, cylindrical boring with a single, circular aperture (opening to the surface) and a circular cross-section. The base of the boring is blind, and has a tapered to rounded terminus. The boring is up to 10 mm long. It is 0.5–1.0 mm in diameter in stromatoporoids, 2.0–2.5 mm in corals and 6 mm in the bone. Some questionable specimens, mainly preserved in corals (Figs 8A, B, D) and belemnites (Fig. 8F) or ammonites (Fig. 8G), due to their poor preservation were recognized as *Trypanites* isp., whereas this one in the bone (Fig. 7C), owing to its large dimensions, as ?*Trypanites* isp.
**Remarks:** *Trypanites* is a domichnion (Pemberton *et al*., 2001), produced possibly by polychaetes, sipunculids, phoronids or cirripeds (Pickerill *et al*., 1984; Pemberton *et al*., 1988). It was described from Baltoscandia from Ordovician-Silurian hardgrounds and tabulate corals, bryozoans and stromatoporoids of Estonia, Russia, Sweden (Dronov *et al*., 2002; Wyse Jackson and Key, 2007; Beuck *et al*., 2008; Mikuláš and Dronov, 2010; Vinn and Wilson, 2010a, 2012a, b). *Trypanites* is known from the Cambrian to Recent (Pemberton *et al*., 1988; Taylor and Wilson, 2003). It is common in Palaeozoic, especially from the Late Ordovician to Silurian and is also abundant in the Mesozoic and Cenozoic (Tapanila *et al*., 2004a; Wilson and Palmer, 2006; Wilson, 2007).

Polychaete borings
Fig. 8H

**Material**: One specimen in a Palaeozoic coral (*Heliolites* sp.), Mokrzeszów Quarry (private collection of J. Kawałko).
**Description**: Straight, slightly curving line, 15 mm long, with two clavate cavities, drop-like in shape at both ends. The diameter of swellings (cavities) is about 3 mm, whereas diameter of a cylindrical tunnel about 0.2 mm. The shape of this boring resembles the microboring *Flagrichnus*, interpreted as the work of fungi, in having a sack-shaped cavity (compare Wisshak and Porter, 2006; figs 2–4). It differs from this in the lack of thin galleries, extending deep into the substrate. In the specimen studied, a connecting line is almost horizontal, parallel to the surface of *Heliolites*. On the other hand, this boring might has been slightly inclined, owing to preservation in cross-section. Additionally, the dimensions of the boring studied is much larger than *Flagrichnus* (M. Wisshak, pers. comm., 2014). Other microborings produced by algae and fungi, such as *Rhopalia* and *Saccomorpha* (see Molinu *et al*., 2015), respectively, also show a net of cavities (knobs or club-shaped sacks), connected by cylindrical tunnels or narrow necks. As in the case of *Flagrichnus*, the macroboring studied differs from these microborings in its pattern of morphology, lack of galleries and much larger dimensions. Most probably, the specimen studied was produced by polychaete worms, which may form circular holes 0.5–2 mm in diameter that penetrate up to several centimetres into a coral skeleton (Glynn and Manzello, 2015). The specimen studied differs from other polychaetes borings (*Talpina*, *Trypanites*) in having cavities, a lack of branches, and a different shape. It co-occurs with *Trypanites*.

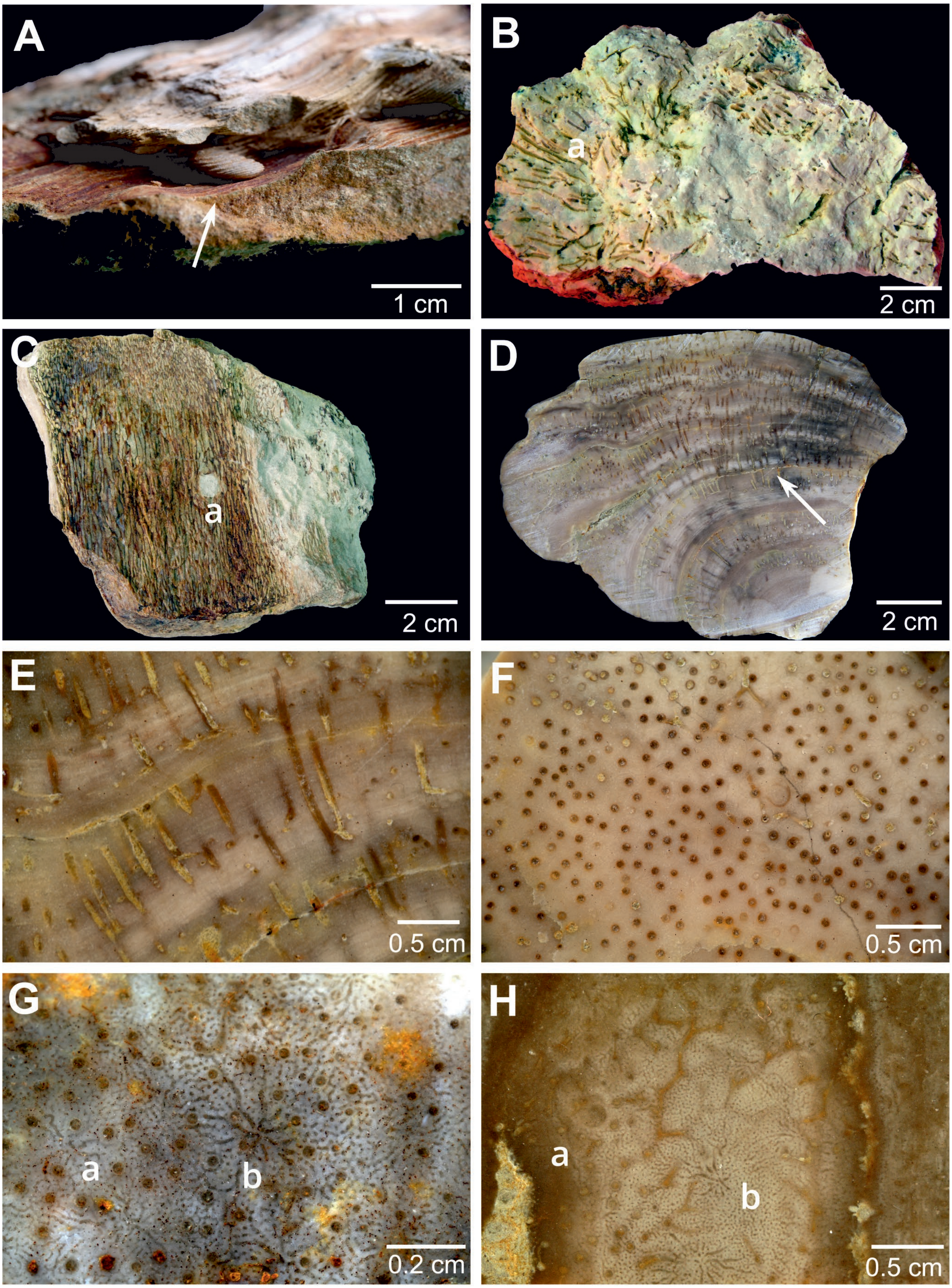



**Fig. 7.** Borings in rocks, bone, wood and stromatoporoids. **A.** *Teredolites* isp. in a piece of wood (Jurassic–Miocene?); Mokrzeszów Quarry. **B.** *Trypanites weisei* in the ?Silurian-Devonian limestone erratic boulder; Mokrzeszów Quarry. **C.** ?*Trypanites* isp. (a) in the Mesozoic reptile (lizard) bone of ?*Platecarpus* sp.; Mokrzeszów Quarry; MGUWr-6608s. **D–H.** *Trypanites* isp. (a) in Silurian stromatoporoids; b – astrorhizae; Mokrzeszów Quarry; MGUWr-6609s-6610s. Specimens A, B housed in the private collection of J. Kawałko. Arrows indicate the borings *Teredolites* (A) and *Trypanites* (D).

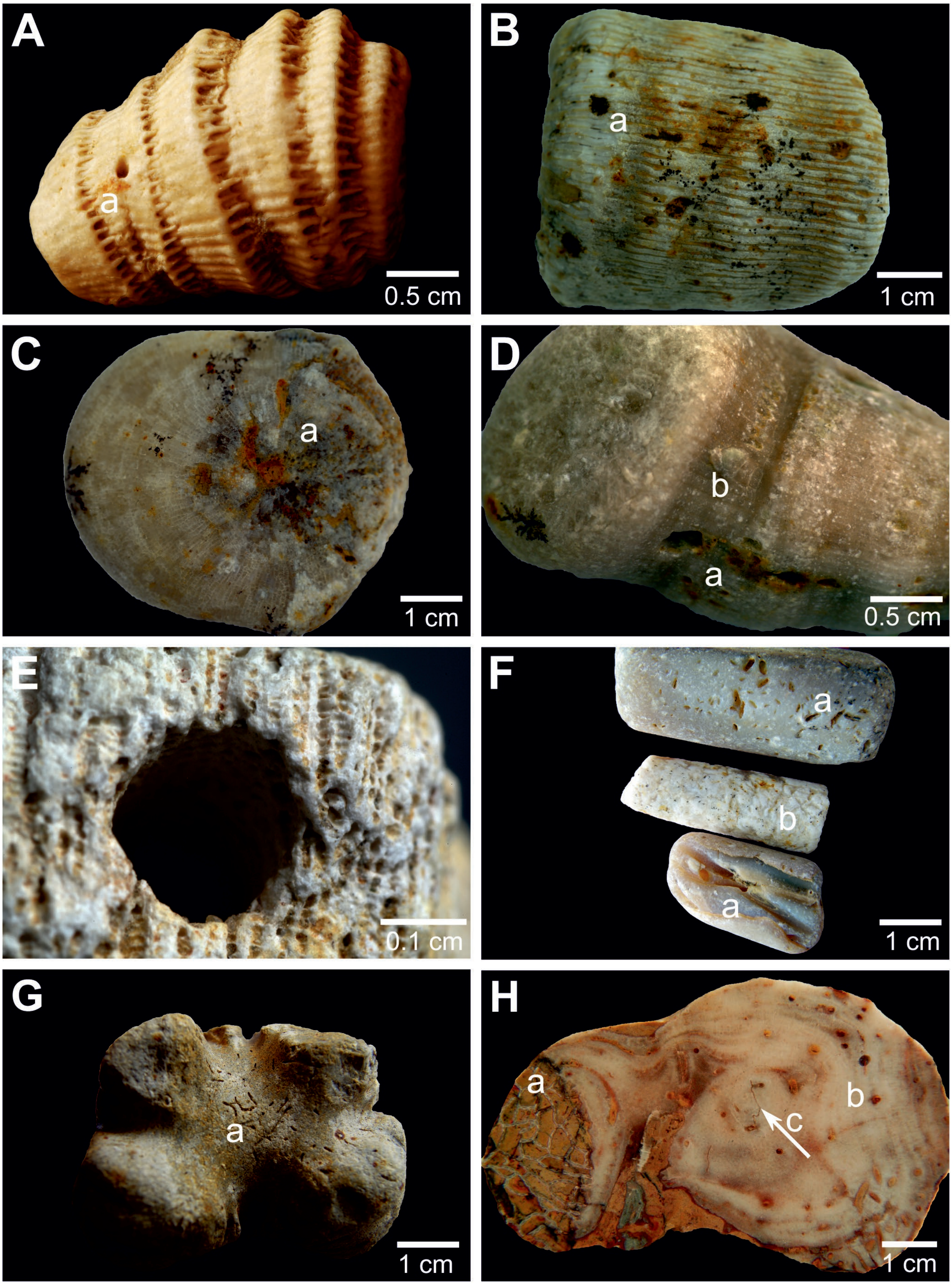



**Fig. 8.** *Trypanites* in corals, bryozoans, belemnites, ammonites. **A.** *Trypanites* isp. (a) in a Lower Palaeozoic coral; Świebodzice outcrop; MGUWr-6612s. **B.** *Trypanites* isp. in Palaeozoic rugose coral (a); Mokrzeszów Quarry. **C.** *Trypanites* isp. in Palaeozoic bryozoan (a); Mokrzeszów quarry; MGUWR-6613s. **D.** *Trypanites* isp. in Palaeozoic rugose coral (a); microconchid (b); Mokrzeszów Quarry. **E.** ?*Trypanites* isp. in Jurassic coral (?*Thamnasteria* sp.); Świebodzice outcrop; MGUWr-6614s. **F.** *Trypanites* isp. (a) and *Talpina* isp. (b) in the rostrum of a Cretaceous belemnites (a); Mokrzeszów Quarry. **G.** *Trypanites* isp. in the internal mould of the Mesozoic ammonite (a), Mokrzeszów Quarry. **H.** Coral intergrowths *Halysites* sp. (a) and *Heliolites* sp. (b) with polychaete boring (c); Mokrzeszów Quarry; arrow indicates the polychaete boring in *Heliolites* sp. Specimens B, D, F–H housed in the private collection of J. Kawałko.

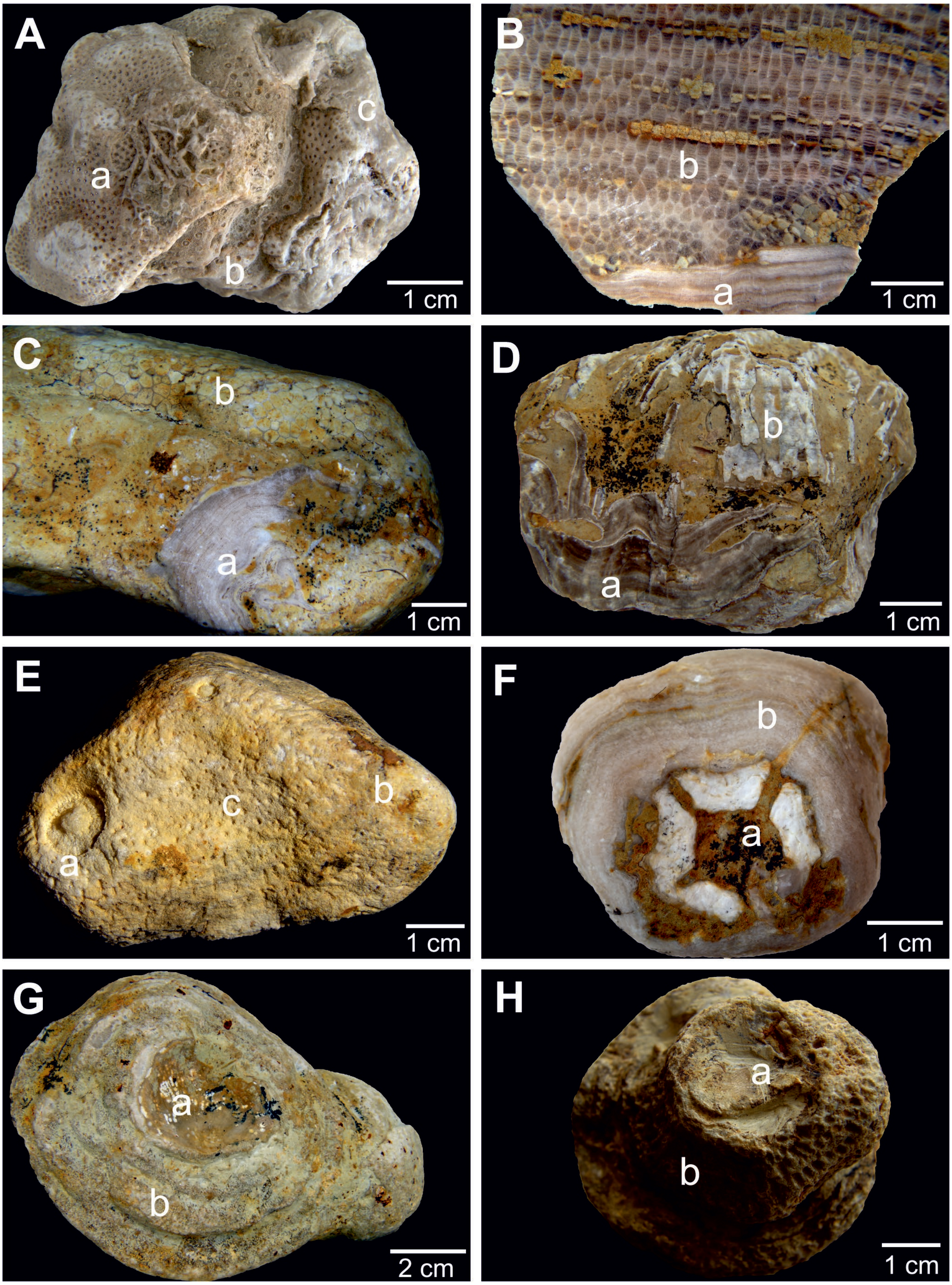



**Fig. 9.** Fossil associations. **A.** *Aulopora*/*Heliolites*/stromatoporoid intergrowth on a rugose coral; a – *Aulopora*; b – *Heliolites*; c – stromatoporoid; Świebodzice outcrop, MGUWr-6616s. **B, C.** Corals (*Favosites*)/stromatoporoid intergrowth; a – stromatoporoid, b – *Favosites*; Mokrzeszów Quarry, MGUWr-6617s-6618s. **D.** Coral (*Halysites*)/stromatoporoid intergrowth; a) – stromatoporoid, b – *Halysites*; Mokrzeszów Quarry, MGUWr-6619s. **E.** Rugosa/stromatoporoid association (symbiosis); a – Rugosa; b – stromatoporoid; c – the boring *Trypanites*; Mokrzeszów Quarry, MGUWr-6620s. **F.** Crinoid/stromatoporoid association; a – crinoid, b – stromatoporoid; Mokrzeszów Quarry, MGUWr-6621s. **G.** Bryozoan/brachiopod association; a – brachiopod, b – bryozoan; Mokrzeszów Quarry, MGUWr-6622s. **H.** Coral/brachiopod association; a – brachiopod, b – coral; Mokrzeszów Quarry (private collection of J. Kawałko).

## ASSOCIATED SKELETAL FOSSILS

Numerous coral/coral (*Halysites*/*Heliolites*; Fig. 8H) and stromatoporoid/coral intergrowths (*Favosites*, *Halysites*) (MGUWr-6617s-6619s; Fig. 9B–D) or stromatoporoid/Rugosa coral symbiosis (MGUWR-6620s; Fig. 9E) were also found in the Mokrzeszów Quarry and the Świebodzice outcrop. Some fossils, such as rugose and tabulate corals and bryozoans (in some cases bored by *Trypanites*) also were found in the study area (Fig. 8A–D). These organisms usually encrusted Silurian stromatoporoid or Ordovician--Silurian hardgrounds (Kershaw, 1987, 1990; Lebold, 2000). Additionally, rugose coral encrusted by a stromatoporoid and corals association (*Aulopora*, *Heliolites*) also was noted (MGUWr-6616s; Fig. 9A). On one specimen of coral, bored with *Trypanites*, the microconchid was found (coral/microconchid association, Fig. 8D). Many examples of different fossil associations were described from the Silurian stromatoporoid outcrops of Sweden (Gotland) and Saaremaa (Estonia) by Kershaw (1987), Kershaw and Mõtus (2016) and Vinn and Wilson (2016 and references therein). Stromatoporoid/Rugosa symbioses were reported from the Silurian of Baltoscandia (Estonia) by Vinn *et al*. (2015b), Vinn and Mõtus (2014) and Vinn and Toom (2017). Some new associations, such as crinoid/stromatoporoid (MGUWr-6621s; Fig. 9F) and brachiopod/bryozoan (MGUWr-6622s; Fig. 9G) and brachiopod/coral (Fig. 9H), which have not been reported so far from Baltoscandia, also were found in the Mokrzeszów Quarry. Recently, Zatoń *et al*. (2016) described the first microconchid-encrusted corals (Estonia, Saaremaa) and brachiopods (Sweden, Gotland). Earlier, microconchids were reported from Baltoscandia by Vinn and Wilson (2010b, 2012b, 2016) and Zatoń and Vinn (2011) from Silurian stromatoporoids and bryozoans of Estonia and Sweden.

## DISCUSSION

### Ordovician Orthoceratite Limestone

Most of the erratics studied originate in the Ordovician Orthoceratite Limestone, which crops out from Norway, across Sweden, Estonia to Russia (St. Petersburg region). These limestones differ in colour. They are red in Sweden, but grey or yellow-grey in Estonia or Russia (Kröger, 2004; Mikuláš and Dronov, 2010; Histon, 2012). They contain very well preserved, large fossils of cephalopods (mostly endocerids), trilobites and molluscs, especially hyolithids (Eriksson *et al*., 2013; Lindskog *et al*., 2015).

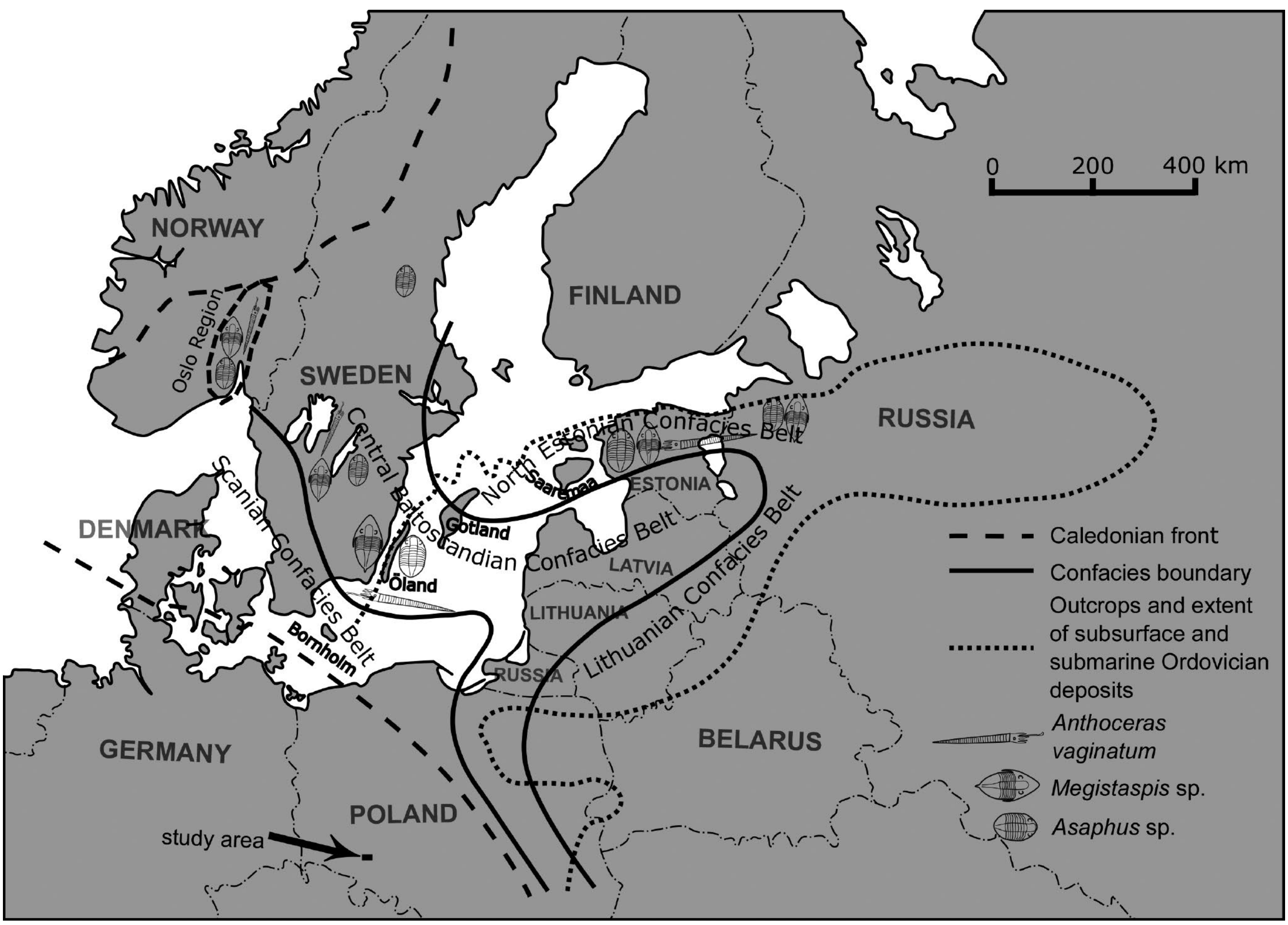



**Fig. 10.** Map of the Baltoscandian Confacies Belts and distribution of maximum occurrences of trilobites (*Asaphus*, *Megistaspis*) and cephalopod (*Anthoceras vaginatum*) during the Middle Ordovician in Baltoscandia. Confacies belts after Jaanusson (1982), chronostratigraphy after Bergström *et al*. (2009).

The Orthoceratite Limestone was formed in the Baltoscandian Basin, a shallow, epicontinental sea that covered the Scandinavia and Baltic region and is regarded as one of the largest Early Palaeozoic basins (Hints, 2000; Ainsaar *et al*., 2007; Eriksson, 2010). This basin extended from Norway (Oslo Graben) across southern Sweden (Öland) and Denmark (Bornholm) to the eastern Baltic countries and to the Moscow Basin, in western Russia (Benner *et al*., 2004; Dronov *et al*., 2011). The Baltoscandian platform, on which this basin was developed, is subdivided into SE-NW-oriented confacies belts: the Scanian Confacies Belt (outer ramp or basinal facies), the Central Baltoscandian Confacies Belt (intermediate facies) and the Estonian Confacies Belt (middle to inner ramp settings) (see Tinn *et al*., 2006; Eriksson, 2010: Kröger and Rasmussen, 2014; Fig. 10). These belts show differences in water depth, lithology and facies assemblages.

The Ordovician Orthoceratite Limestone is interpreted mainly as a shallow marine deposit, containing tempestites (Dronov, 2005). However, according to some other views, its environment was slightly deeper, even as much as 200–300 m (see Lindskog *et al*., 2014 and references therein). This view concerns mainly the western part of the Baltoscandian Basin. The limestones were deposited in cool waters, because these deposits do not contain coral-stromatoporoid reefs, typical of tropical conditions.

The Orthoceratite Limestone represents a stratigraphically condensed sequence, several metres thick (see Eriksson, 2010; Eriksson *et al*., 2012 and references therein). Numerous hardgrounds are described from these deposits, which contain numerous trace fossils, for example *Balanoglossites*, *Gastrochaenolites* and *Trypanites*? (Ekdale and Bromley, 2001; Dronov *et al*., 2002; Knaust and Dronov, 2013). The occurrence of the hardgrounds (Dapingian–Katian; see Vinn *et al*., 2015a) was connected with an extremely low, average rate of sedimentation during the Ordovician (see Dronov, 2005).

### The occurrence of *Arachnostega gastrochaenae*

In boulders from the Mokrzeszów Quarry, numerous, large endocerid cephalopods occur (*Anthoceras vaginatum* Schlotheim, 1820), as well as trilobites (*Megistaspis*, *Asaphus*, *Illaenus*). Some of them contain *Arachnostega*. The trilobites *Asaphus* and *Megistaspis* were very common during Early–Middle Ordovician in Baltoscandia (Pärnaste *et al*., 2013) and achieved large sizes (see Klug *et al*., 2015; Dronov *et al*., 2016). The Baltica was regarded as the *Asaphus* Province, especially during the Floian and Dapingian (Early–Middle Ordovician; see Pärnaste and Bergström, 2013). The asaphids are endemic to Baltica, owing to the dispersal of palaeocontinents in the Early Ordovician (see Fortey and Owens, 1997; Cocks, 2000). During this time, Baltica was separated from the other continents by wide oceans, i.e. the Tornquist Sea and the Iapetus Ocean; this caused endemism of fauna (Cocks and Fortey, 1982; Torsvik and Trench, 1991; Cocks and Torsvik, 2005).

According to Pärnaste and Bergström (2013), the abundance peak of *Megistaspis* took place in the late Dapingian (*M. limbata Zone*), but a number of the megistaspine species remained almost at the same level until the middle Darriwilian (*Asaphus raniceps* Zone), when it started to disappear by the Sandbian (the boundary between the Kunda and Asari regional stages; see Tab. 1). In the latest Dapingian – early Darriwilian time, *Megistaspis* occurred on both sides of Baltica (Estonia and Sweden), indicating an exchange of fauna (Cocks, 2001; Pärnaste and Bergström, 2013; Fig. 10). *Megistaspis* is particularly abundant in southern Sweden, Öland, common in Estonia, rare in central Sweden and almost absent in deeper water settings of the Oslo region (Hoel and Hoyberget, 2002; Fig. 10). This taxon predominates in the Central Baltoscandian Confacies Belt (Bergström *et al*., 2013). The second family, Asaphinae (*Asaphus expansus* Wahlenberg, 1821), is most common in north-west Estonia, common in the St. Petersburg region (Russia) and in Sweden (Öland), and it is less common in central Sweden (see also Cherns *et al*., 2006) and the Oslo region (Pärnaste and Bergström, 2013; Fig. 10). It is particularly abundant in the North Estonian Confacies Belt (Fig. 10). The abundance peaks were at the beginning of the Kunda Regional Stage and the Aseri Regional Stage (Tab. 1).

In the same erratic blocks, besides *Megistaspis*, the cephalopod *Anthoceras vaginatum* Schlotheim, 1820 occurs (Figs 2D, E), the species that gave rise to the name of the Orthoceratite Limestone in Sweden and Estonia (Vaginatum Limestone or Vaginatenkalk, see Kröger, 2004, 2012). *Anthoceras* mainly characterizes the *Anthoceras* Biofacies, distinguished in Baltoscandia (see Kröger and Rasmussen, 2014), which occurs mostly in Sweden, Öland (Central Baltoscandian Confacies Belt) and in northwestern Estonia, Tallinn (Fig. 10).

The oldest occurrence of *Anthoceras vaginatum* was noted in the lowermost Darriwilian from the *Megistaspis limbata* trilobite Zone (Kröger and Rasmussen, 2014). This taxon started to be the dominant cephalopod species near the base of *A. raniceps* Zone and above in the middle Darriwilian of the Kunda Regional Stage (see Kröger, 2012, 2013; Tab. 1).

In summary, *Arachnostega* in the reddish glacial erratic boulders on ?*Megistaspis* comes from Sweden, probably Öland (Fig. 2A–E). This is confirmed by the most common occurrence of the trilobite *Megistaspis*, as well as the associated fossil *Anthoceras vaginatum* in this area (Fig. 10). *Arachnostega* on the trilobites *Asaphus* sp. and *Asaphus expansus* in the grey limestone blocks might have its origin in Russia or Estonia (Fig. 2F–H). This is evidenced by the grey colour of the limestones, as well as by the occurrence of *Asaphus*, which is typical for these areas (Fig. 10). The limestones in erratic boulders with *Arachnostega* are probably Middle Ordovician (Kunda Regional Stage, *Asaphus raniceps* trilobite Zone) in age, owing to the abundance peak of the trilobites *Megistaspis* and *Asaphus*, and the endocerid *Anthoceras*.

In the Kunda Stage, other molluscs (gastropods, bivalves and hyoliths) also started to appear in abundance (Kröger and Rasmussen, 2014; Lindskog *et al*., 2015 and references therein). Besides *Arachnostega* on the pygidium of trilobites (?*Megistaspis*, *Asaphus*), this ichnotaxon was also

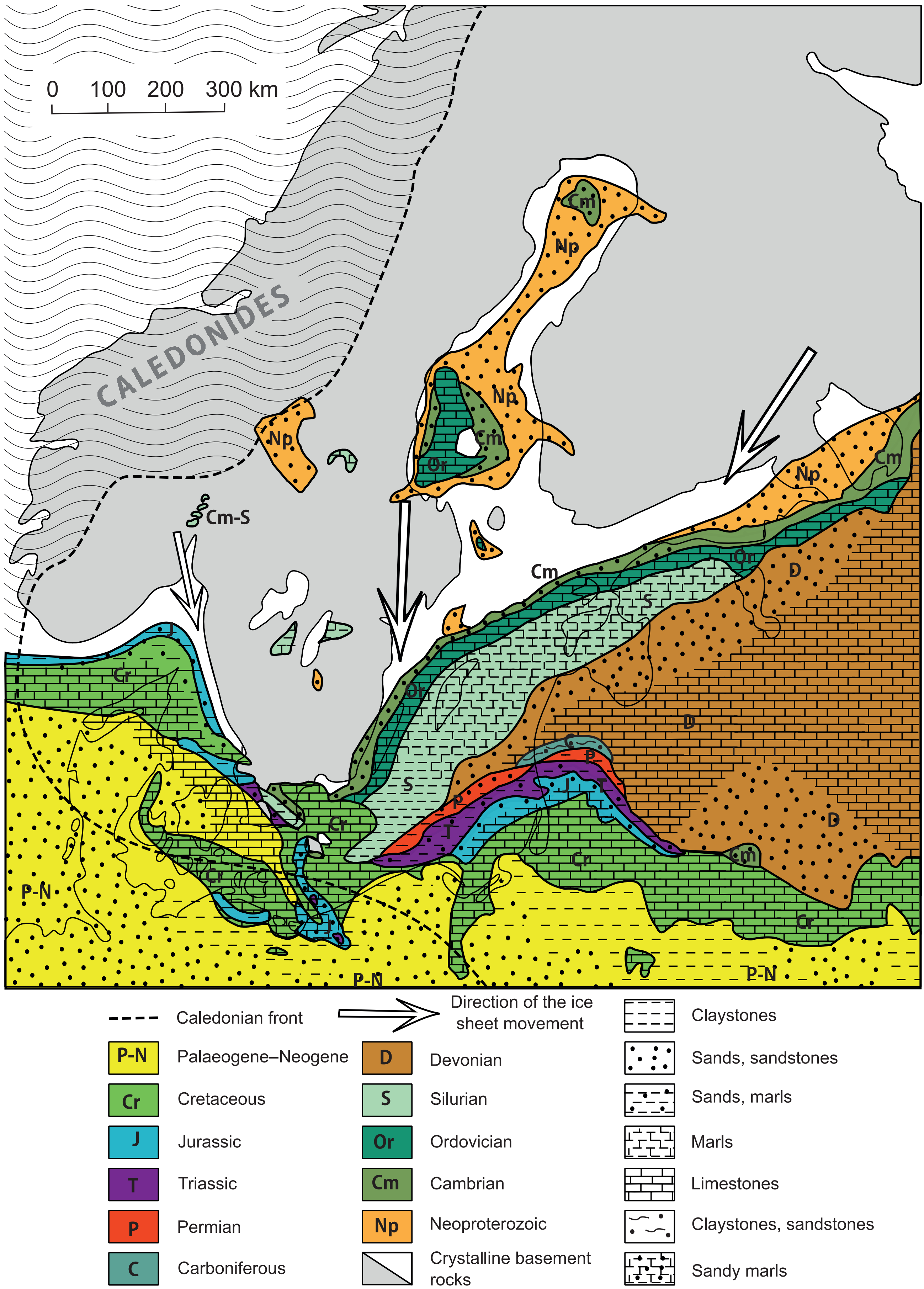



**Fig. 11.** Geological map of Baltoscandia with possible directions of movement of source material (ice-sheet movement), after Schulz (2003), modified by the authors.

recognized on a cephalopod (Fig. 3A) and on hyolithids (Fig. 3B) in the Mokrzeszów Quarry. Hyolithids are also abundant in the *A. raniceps* Zone (Kunda Regional Stage; Lindskog *et al*., 2015; Tab. 1). Limestones of the glacial erratic boulders studied, grey in colour, which contain *Arachnostega* on a cephalopod and especially on hyolithids, come from Russia and less probably from Estonia (middle Darriwilian, ?Kunda Regional Stage).

*Arachnostega* was described from Baltoscandia only from the Middle and Upper Ordovician. This trace fossil was most abundant in the Darriwilian, less common in the Sandbian and rare in the Katian (Vinn *et al*., 2014b). The authors cited suggested that the *Arachnostega* trace-maker preferred colder (temperate) rather than tropical climates. They connected the common appearance of this ichnogenus in the Darriwilian with the Ordovician drift of Baltica to the north towards the lower latitudes/palaeoequator (Cocks and Torsvik, 2005). These authors also reported that *Arachnostega* preferentially occurs on bivalves compared to gastropods and for unknown reasons it does not appear on echinoderms and trilobites in Estonia. The occurrences of *Arachnostega* on the pygidia of the trilobites ?*Megistaspis* and *Asaphus* (from Sweden?) in the glacial erratic boulders in SW Poland, at the Mokrzeszów Quarry, and on the cystoids in Estonia (Chrząstek and Pluta, 2017) show that this ichnotaxon also might occur on other groups of invertebrates in Baltoscandia, not only on molluscs.

### *Balanoglossites*

*Balanoglossites* occurs in the reddish Orthoceratite Limestone in the erratic blocks, which derive from Sweden. It is common in the Mokrzeszów Quarry. This trace fossil was described by Knaust and Dronov (2013) from the Orthoceratite Limestone in Russia (St. Petersburg region). According to these authors, *Balanoglossites* is very abundant in the Ordovician. So abundant occurrence of *Balanoglossites* in Baltoscandia in the Ordovician Orthoceratite Limestone might be connected with the abundance of the scolecodont-bearing polychaetes at that time (Knaust and Dronov, 2013), the possible producers of this trace fossil (see Knaust, 2008). During the Middle Ordovician, the majority of polychaete taxa appeared for the first time and started to diversify very fast (Hints, 2000; Eriksson *et al*., 2013). A rapid increase in the number of genera was recorded in the Middle Ordovician (Darriwilian) and early Late Ordovician. Scolecodont-bearing polychaetes were very abundant from the Middle Ordovician (Darriwilian) in Estonia, Sweden, northwestern Russia (Hints, 2000; Hints and Eriksson, 2007, 2010; Eriksson *et al*., 2016) and in Poland, in glacial erratic boulders (Kielan-Jaworowska, 1962, 1964). The source areas for glacial erratic boulders with *Balanoglossites* (Fig. 3C–F) were probably in Sweden, as suggested by the red colour of the limestones. Additionally, *Balanoglossites* co-occurs with *Anthoceras vaginatum*, which is most common in Sweden (Öland) in the Kunda Regional Stage (near the base of the *A*. *raniceps* Zone, middle Darriwilian, Tab. 1).

### *Osprioneides kampto*, ?*Palaeosabella*, *Trypanites*

Another interesting and rare trace fossil is *Osprioneides kampto*, recognized in the ?Ordovician bryozoan and the Silurian stromatoporoid in the erratic blocks of the Mokrzeszów Quarry. The most famous Palaeozoic stromatoporoid outcrops are known from Saaremaa, Estonia, and Gotland, Sweden (Sandström and Kershaw, 2002, 2008). The only report concerning *Osprioneides* in bryozoans comes from the Upper Ordovician of Estonia (Vinn *et al*., 2014 b). Earlier, it was regarded as a Silurian trace fossil (Beuck *et al*., 2008; Vinn and Wilson, 2010a). According to Brood (1981), in the Late Ordovician in Baltoscandia (Sweden, Estonia, Norway) bryozoans were especially common and rich in species by comparison with the Early Silurian. The reefs with bryozoans were abundant and commonly bored at that time (Kröger *et al*., 2014).

In the Mokrzeszów Quarry, *Trypanites* and *Palaeosabella* were also encountered in the Silurian stromatoporoids. ?*Palaeosabella* was reported from the Scandinavia and Baltic region, from the Silurian corals and stromatoporoids (Gotland in Sweden, Saaremaa in Estonia) by Beuck *et al*. (2008) and Vinn and Wilson (2010a). *Trypanites*, the most common Palaeozoic boring, was described from the Ordovician-Silurian hardgrounds, tabulate corals, stromatoporoids, bryozoans from Estonia, Sweden and Russia by Dronov *et al*. (2002), Beuck *et al*. (2008), Mikuláš and Dronov (2010), and Vinn and Wilson (2010a).

### Other common trace fossils and associated fossil associations

Other trace fossils studied (e.g., *Chondrites*, *Phycodes*, *Skolithos*, *Diplocraterion*, *Thalassinoides*) have a wide distribution and are common as well as in Palaeozoic and Mesozoic rocks. Though they occur in Baltoscandia (Russia, Denmark, Sweden, Estonia and Norway), especially in the Lower Palaeozoic, it is very difficult to speculate about source areas of the rocks bearing them (see Synopsis of trace fossils). Jurassic corals (?*Thamnasteria*; Fig. 8E) with *Trypanites* might have their origin in the south-western Baltic coast, which are the source areas for erratics containing this trace fossil, described by Roniewicz (1984). It is difficult to speculate about source areas of the Jurassic and Cretaceous shells with the borings ?*Gastrochaenolites*, *Maeandropolydora*, *Talpina* or the bone of ?*Platecarpus* with *Trypanites*. The outcrops of these deposits are located from Denmark, through the southern Baltic Sea area to Lithuania (Fig. 11). Vertebrate remains of Mesosauridae (*Platecarpus*) were described from Sweden by Lindgren (1998). The source areas for Cenozoic (Miocene) gastropods with *Oichnus* might be located in northern Denmark and Germany (see Rohde, 2008).

The accompanying skeletal fossils, such as coral/coral (*Halysites*/*Heliolites*, *Aulopora*/*Heliolites*; Figs 8H, 9A) or coral/stromatoporoid (*Favosites*/stromatoporoid, *Halysites*/stromatoporoid; Fig. 9B–D) intergrowths or stromatoporoid/Rugosa coral symbioses (Fig. 9E), which were encountered in the Mokrzeszów Quarry and the Świebodzice outcrop, were probably derived from Silurian stromatoporoids. The excellent, very well preserved stromatoporoid outcrops are situated in Sweden (Gotland) and Saaremaa (Estonia). Isolated fossils of corals (bored with *Trypanites* and encrusted by microconchid) and bryozoans, which were also found in the study area (Fig. 8A–D), might have encrusted both the Baltoscandian Ordovician-Silurian stromatoporoids and hardgrounds (Kershaw, 1987, 1990; Lebold, 2000). Lower Palaeozoic hardgrounds were encrusted mainly by rugose and tabulate corals, bryozoans, crinoids and microconchids (Vinn and Wilson, 2012a, b; Taylor and Wilson, 2003; Vinn *et al*., 2015a). Different fossil associations were reported from outcrops in Baltoscandia and the Baltic region by several authors (see Vinn and Wilson, 2016 and references therein), as well as coral/stromatoporoid symbiosis (e.g., Vinn and Mõtus, 2014). Just recently, Zatoń *et al*. (2016) described the first microconchid-encrusted corals from Estonia (Saaremaa).

Besides rare fossil associations (coral/microconchid) and Rugosa/stromatoporoid coral symbiosis, new fossil associations, such as bryozoan/brachiopod (Fig. 9G), coral/brachiopod (Fig. 9H) and crinoid/stromatoporoid (Fig. 9F), unknown in Baltoscandia, also were observed. The sources of the different fossil associations described are probably Upper Ordovician-Silurian stromatoporoids or hardgrounds in Sweden and Estonia (Webby *et al*., 2012).

## CONCLUSIONS

In the glacial erratic boulders (rocks, bones, shells, wood), Cambrian–Miocene in age, found in the Mokrzeszów Quarry and the Świebodzice outcrop (Fore-Sudetic Block) seventeen ichnogenera were found. One unidentified polychaete boring in coral and root traces also were collected.

Some coral/coral, coral/stromatoporoid intergrowths, as well as fossil associations that are new (brachiopod/bryozoan, brachiopod/coral, crinoid/stromatoporoid) and rare in Baltoscandia (coral/microconchid; stromatoporoid/Rugosa coral symbiosis) also were noted (some specimens with *Trypanites* borings).

The majority of the trace fossils were derived from the Ordovician Orthoceratite Limestone (*Arachnostega*, *Balanoglossites*, *Planolites*), outcrops of which are located in Sweden (e.g., Öland), Estonia and Russia (St. Petersburg region).

This is the first report of *Arachnostega* on trilobites (?*Megistaspis* sp.) from Sweden. *Arachnostega* on *Asaphus* sp. and cephalopods probably are from Russia or Estonia. This burrow also was found on hyoliths (previously unknown), probably from Russia (St. Petersburg region). They are probably Middle Ordovician (Darriwilian, Kunda Regional Stage, *A. raniceps* trilobite Zone) in age. The occurrence of *Arachnostega* on trilobites from Baltoscandia (e.g., Sweden, ?Estonia), demonstrates that this ichnotaxon also occurs on other groups of fauna, not only on molluscs.

The rare boring *Osprioneides kampto* from the Mokrzeszów Quarry is the second report of this ichnotaxon in a bryozoan (?Ordovician). It occurs also in Silurian stromatoporoids, together with ?*Palaeosabella* isp. and *Trypanites* isp., possibly from Sweden (Gotland) and Estonia (Saaremaa) or adjacent areas where stromatoporoid biostromes are well developed.

The Lower Palaeozoic erratic boulders with common trace fossils (e.g., *Chondrites*, *Diplocraterion*, *Phycodes*, *Rosselia*, *Skolithos*, *Thalassinoides*) probably came from Sweden, Denmark (Bornholm), Russia, Norway, where they previously were described.

Mesozoic and Cenozoic shells and wood with the borings *Maeandropolydora*, *Oichnus*, *Talpina*, *Teredolites*, *Trypanites* might have their origin in the south-east Baltic region (from Denmark, S Sweden to Lithuania), where relevant outcrops occur.

The glacial erratic boulders probably were transported mainly from the north and north-east (Scandinavia: Sweden, Öland, Gotland and the Baltic area, i.e., Saaremaa, Estonia, and the St. Petersburg region, Russia) and less commonly from the north-west, especially in the case of younger Mesozoic/Cenozoic blocks (see Fig. 11).

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