

# Coniacian sandstones from the North Sudetic Synclinorium revisited: palaeoenvironmental and palaeogeographical reconstructions based on trace fossil analysis and associated body fossils

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## Abstract

The Coniacian quartz sandstones (Żerkowice Member, Rakowice Wielkie Formation) that crop out at quarries near Czaple-Nowa Wieś Grodziska (North Sudetic Synclinorium) contain a low-diversity assemblage of trace fossils: *Gyrochorte* isp., *Ophiomorpha nodosa* Lundgren, 1891, *Ophiomorpha* isp., *Phycodes* cf. *curvopalmatum* (Pollard, 1981), *Phycodes* isp., *Planolites* cf. *beverleyensis* (Billings, 1862), *Thalassinoides paradoxicus* Woodward, 1830 and *Thalassinoides* isp. Moreover, interesting compound burrow systems, here referred to as *Thalassinoides-Phycodes* cf. *palmatus* and *Thalassinoides-Phycodes*, were recognised at the Czaple Quarry. Additionally, *Gyrochorte* isp., *Phycodes* cf. *flabellum* (Miller and Dyer, 1878) and *Treptichnus* isp. were encountered at correlative levels in the Rakowice Małe Quarry. Some of these ichnotaxa have not been recorded previously from Coniacian sandstones of the Żerkowice Member. Additionally, in slabs of these sandstones, the gastropod *Nerinea bicincta* Bronn, 1836 and the bivalve *Lima haidingeri* Zittel, 1866 were found. These interesting finds, in particular the gastropods, were already noted from the study area in the first half of the twentieth century by Scupin (1912–1913). Ethologically, the trace fossil assemblage is represented by domichnia or domichnia/fodinichnia (*Ophiomorpha*, *Thalassinoides*), fodinichnia (*Phycodes*) and pascichnia (*Gyrochorte*, *Planolites*). The compound burrow systems (*Thalassinoides-Phycodes*) are interpreted as dwelling/feeding structures. The possible tracemakers are crustaceans (*Ophiomorpha*, *Thalassinoides*) or worm-like animals (annelids and other) (*Planolites*, *Phycodes*, *Gyrochorte* and *Treptichnus*). The assemblage of trace fossils is characteristic of the *Skolithos* ichnofacies and *Cruziana* ichnofacies, typical of shallow-marine settings. Ichnological studies, as well as the presence of accompanying fossils (bivalves, gastropods), confirm the palaeoenvironmental reconstruction of the Żerkowice Member sandstones by Leszczyński (2010). That author interpreted the Coniacian sandstones as bar and storm deposits laid down in a shallow epicontinental sea (mainly the foreshore-upper shoreface; up to the middle shoreface) under normal oxygenation and salinity, in soft substrate, above fair-weather wave base. The deposition of the Żerkowice Member sandstones is linked to a regression that started after uplift of the southeastern part of the North Sudetic Synclinorium.

**Key words:** ichnology, Upper Cretaceous, Sudetes Mountains, Żerkowice Member, foreshore, shoreface

## 1. Introduction

Quartz sandstones are well exposed in the North Sudetic Synclinorium (Fig. 1); they have been referred to as Upper Quadersandstein (Oberquader;

see Scupin, 1912–1913) and belong to the Żerkowice Member of the Rakowice Wielkie Formation (Milewicz, 1985, 1997). Outcrops of these sandstones are situated in the eastern and central part of the North Sudetic Synclinorium (e.g., Rakowice Małe,

Żerkowice, Żeliszów, Czaple, Nowa Wieś Grodziska; see Milewicz, 1997 and Figure 1 here). The present study was conducted at four quarries near the villages of Czaple and Nowa Wieś Grodziska (Figs 2–4). A low-diversity assemblage of trace fossils has been recognised: five ichnogenera, eight ichnospecies and two compound burrow systems. Additionally, three other ichnotaxa, previously unknown from Coniacian sandstones of the Żerkowice Member, were found in coeval levels at the Rakowice Małe Quarry (Figs 5D, 7H–I, 10C). The gastropod *Nerinea bicincta* Bronn, 1836 and the bivalve *Lima haidingeri* Zittel, 1866 were also encountered in the sandstone blocks (Fig. 10D–F). The blocks with gastropods probably were transported from an adjacent quarry of Coniacian sandstones (Żeliszów Quarry; Fig. 1), where these fossils occur in quarry faces (pers. comm., A.M. Sroka, 2016). Additionally, earlier reports of such specimens by Scupin (1912–1913) support this view. He recorded *Lima haidingeri* (pl. 14/1; text-figs. 42, 43) and *Nerinea bicincta* (pl. 4/1; 5/17) from the Coniacian at Żeliszów Quarry (former Giersdorf). Additionally, *Lima haidingeri* was described by this author from the Rakowice Małe Quarry (former Wenig-Rackwitz; pl. 12/9). In the collections of the Geological Museum of Wrocław University there are also gastropods *Nerinea buchi* Zekeli, 1852 (formerly *Cerithium buchii* Keferstein, 1828), now *Nerinea bicincta* Bronn, 1836 (see synonym list of Scupin, 1912–1913; compare also Tiedt, 1958) found by Drescher in 1867 (MGUWr-1592s) in the same outcrop (Żeliszów Quarry, “Giersdorf”; Fig. 10G). According to Kollmann (2014, references therein), *Nerinea (Parasimploptyxis) bicincta* is synonymous with *Nerinea (Parasimploptyxis) buchi*.

Recently, a new ichnogenus and ichnospecies, *Rosarichnoides sudeticus*, were proposed for a well-preserved crustacean burrow collected at Czaple Quarry (Chrząstek et al., 2018). Those authors also described inoceramids (*Inoceramus kleini* Müller, 1888, *Inoceramus* sp.) and starfish (*Astropecten scupini* Andert, 1934), which had been earlier reported by Scupin (1912–1913) from this site. The Coniacian sandstones of the Żerkowice Member that crop out at the Rakowice Małe Quarry, were also studied by Leszczyński (2010), who described *Thalassinoides* isp. and *Ophiomorpha* isp. from these deposits, as well as a richer assemblage of ichnogenera from the Santonian (Rakowice Małe Quarry). On the basis of trace fossils recovered and sedimentary structures, Leszczyński (2010) suggested that these deposits were laid down in the foreshore-upper shoreface. He also reported that the trace fossil assemblage at Żerkowice Quarry represented a wider spectrum of ethological categories and ichnodiversity than

the one at Rakowice Małe Quarry (i.e., more horizontal burrows of *Ophiomorpha* and *Thalassinoides*). Leszczyński (2010, p. 6) proposed the middle shoreface (distal expression of the *Skolithos* ichnofacies) as possible palaeoenvironment for these deposits.

In comparison to Leszczyński’s study (2010), the current note demonstrates that in the Coniacian sandstones (Żerkowice Member) at the Czaple-Nowa Wieś Grodziska quarries, a more diverse ichnoassemblage occurs (*Gyrochorte*, *Ophiomorpha nodosa*, *Ophiomorpha* isp., *Phycodes* cf. *curvipalmatum*, ?*Phycodes* isp., *Planolites* cf. *beverleyensis*, *Thalassinoides paradoxicus*, ?*Thalassinoides* isp., compound burrow systems *Thalassinoides-Phycodes* cf. *palmatus*, ?*Thalassinoides-Phycodes*) than at Rakowice Małe, from where only *Ophiomorpha* and *Thalassinoides* were described (Leszczyński, 2010). On the other hand, ?*Gyrochorte* isp., *Phycodes* cf. *flabellum* and ?*Treptichnus* isp. are here recorded for the first time from the Rakowice Małe Quarry.

The trace fossil assemblage described was visible mainly in the field on the surfaces of sandstone blocks. Some specimens were collected; these are housed in the collections of the Geological Museum of the University of Wrocław (MGUWr-6623s to 6631s).

The aim of the present paper is to document and describe all trace fossils (in some cases unknown earlier from the strata studied) found in the sandstones of the Żerkowice Member at Czaple and Nowa Wieś Grodziska quarries, as well as in the Rakowice Małe Quarry. Additionally, some body fossils (*Nerinea bicincta*, *Lima haidingeri*), found in the Czaple-Nowa Wieś Grodziska quarries (origin probably from the Żeliszów Quarry) and from the collections of the Geological Museum of the University of Wrocław (*Nerinea buchi* Zekeli, 1852 and *Cyrena cretacea* Drescher, 1863; MGUWr-1592s, 1542s; Fig. 10G–H), were also studied. The present study matches the sedimentological analysis of the Żerkowice Member by Leszczyński (2010). Here some data on the newly collected trace and body fossils (in particular those unknown previously from the Żerkowice Member) are added to the palaeoenvironmental and palaeogeographical interpretations.

## 2. Geological setting

The Czaple-Nowa Wieś Grodziska quarries are situated in the southern part of the North Sudetic Synclinorium (Sudetes Mountains, southwest Poland) in the Leszczyna-Jerzmanice halfgraben (Fig. 1). Boundaries of this geological unit include the Karkonosze-Izera Pluton, the Kaczawa Massif

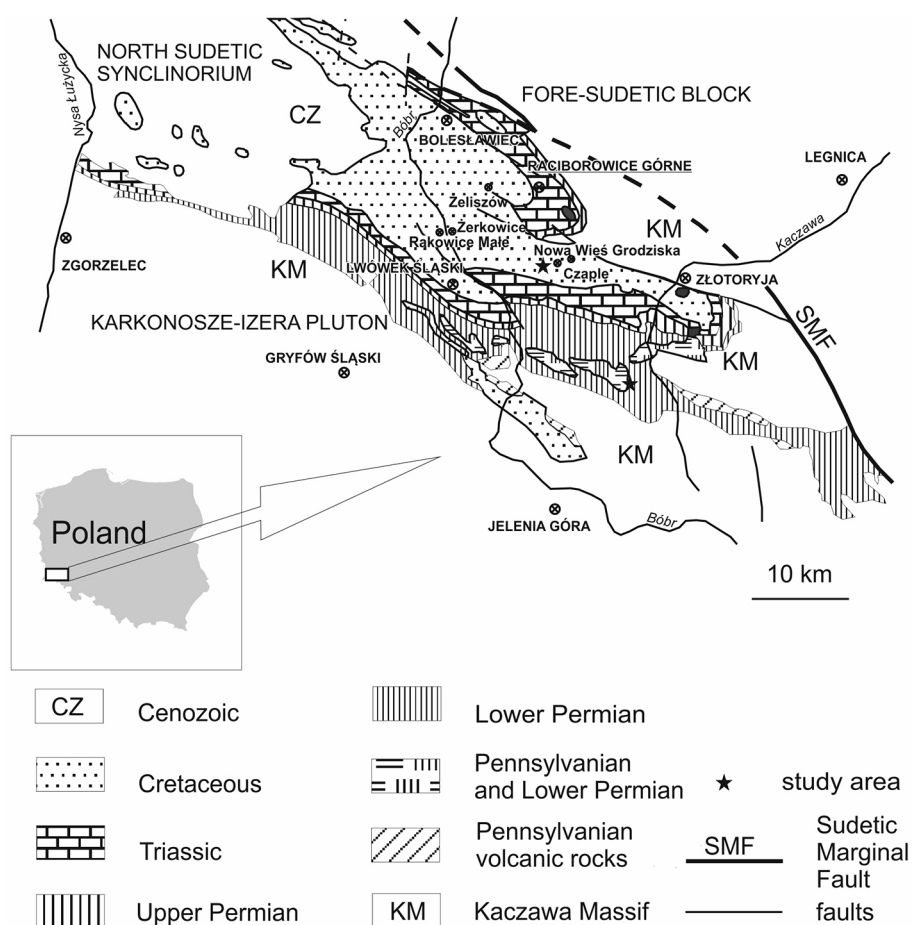


Fig. 1. Geological map of the North Sudetic Synclinorium.

(or Kaczawa Greenstone-and-Slate Fold Belt, see Żelaźniewicz et al., 2011) and the Fore-Sudetic Block.

Outcrops of the Upper Cretaceous rocks are found mostly in the central part of the North Sudetic Synclinorium, where the greatest thickness of these deposits was recorded, with Permian and Triassic strata along its northern and southern margins (Fig. 1). The North Sudetic Synclinorium is composed of two structural stages: the lower or basement, consisting of metamorphic rocks of the Kaczawa Massif, of ?Ediacaran to Mississippian age, and the upper or platform deposits (Late Palaeozoic-Mesozoic cover) ranging in age from Pennsylvanian to Late Cretaceous and Cenozoic (Baranowski et al., 1990; Kryza et al., 2007). The platform sediments (of Pennsylvanian, Permian, Triassic, Late Cretaceous and Cenozoic age) were folded and faulted during the Palaeogene (Żelaźniewicz & Aleksandrowski, 2008). Upper Middle and Upper Triassic rocks are known only from boreholes (Milewicz, 1985; Chrzastek, 2002, 2013a; references therein). The entire Cretaceous sequence, from the middle Cenomanian to the middle Santonian, is 600–1,300 m thick (Baranowski et al., 1990; Milewicz, 1991; Walaszczyk, 2008; Greguš et

al., 2013). The thickness of the Coniacian deposits, which consist mainly of marls and sandstones, is about 300 m (Milewicz, 1973).

The Upper Cretaceous sequence overlies Triassic deposits, i.e., lower and middle Buntsandstein in the south and Röt and Muschelkalk in the north. In some cases, especially in the Wleń Graben, it lies transgressively on older rocks, either Rotliegendes or Lower Palaeozoic strata (Gorczyca-Skała, 1977; Milewicz, 1997).

The Upper Cretaceous of the North Sudetic Synclinorium is subdivided into three formations: the Rakowice Wielkie Formation (Cenomanian-Coniacian), the Czerna Formation and the Węgliniec Formation (Santonian) (Milewicz, 1985, 1997). The Coniacian quartz sandstones that crop out at the Czaple-Nowa Wieś Grodziska quarries belong to the Żerkowice Member of the Rakowice Wielkie Formation (Milewicz, 1997; Śliwiński et al., 2003; Chrzastek et al., 2004).

The sandstones studied are fine to medium-grained, in some cases coarse-grained arenites. The thickness of individual beds, which dip towards the south and southeast (compare Leszczyński,

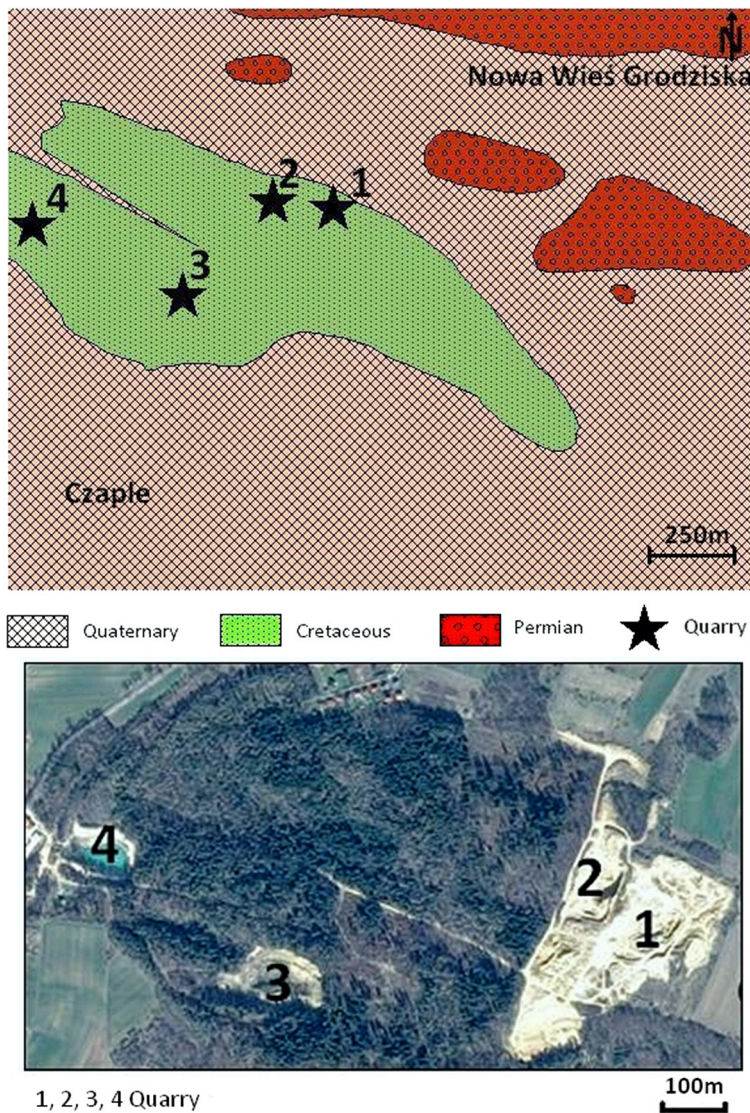


Fig. 2. Geological sketch of the vicinity of the villages of Czaple and Nowa Wieś Grodziska.

2010), attains up to a few metres (usually about 3 m; Fig. 4A). The thickness of these deposits is up to 100 m (Milewicz, 1979). The sedimentary structures are poorly preserved in comparison to those in correlative deposits at the Rakowice Małe Quarry (see Fig. 4B), where trough cross-stratification, tabular cross-stratification and parallel stratification are visible (see also Leszczyński, 2010, fig. 5). These sandstones are mainly structureless or in some cases parallel lamination is marked (Fig. 4C) or poorly visible large-scale cross-stratification and ripple marks (Fig. 4C-E), especially in the upper part of the sections at the Nowa Wieś Grodziska (Fig. 3; quarry 1) and Czaple quarries (Fig. 3; quarry 4). They are well sorted, the best among the Upper Cretaceous sandstones from the North Sudetic Synclinorium, but their grains are poorly rounded (Milewicz, 1997; Leszczyński, 2010). In some cases, in the upper part of the section, these sandstones

are covered with a ferric crust, particularly visible at the Nowa Wieś Grodziska Quarry (see also Leszczyński, 2010; Fig. 4A here). The quartz sandstones are interpreted as bar and storm deposits, which were mainly deposited in the foreshore/upper shoreface (Leszczyński, 2010). The stratigraphy of the Upper Cretaceous deposits is based predominantly on inoceramid bivalves (Walaszczyk, 1992, 2008; Chrzęstek, 2008; Walaszczyk & Wood, in press), but also on other biota (e.g., foraminifera, cephalopods and echinoids; see Walaszczyk et al., 2016). According to Milewicz (1979, 1985, 1997), these sandstones are of early Coniacian age, a hiatus comprising the middle Coniacian. According to Walaszczyk (2008), the hiatus between Rakowice Wielkie Formation and overlying Czerna and Węgliniec formations comprised only a part of the middle Coniacian and the boundary between the former and the latter is placed in the middle/upper

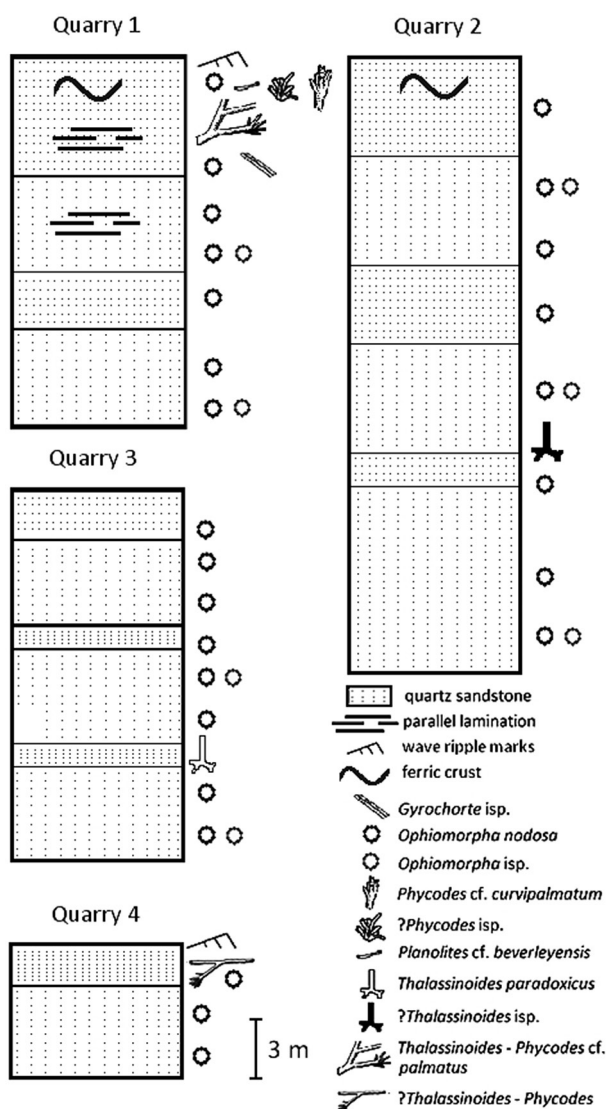


Fig. 3. Coniacian sections at Czaple-Nowa Wieś Grodziska quarries; 1-2: Nowa Wieś Grodziska; 3-4: Czaple.

Coniacian. Consequently, the boundary between the Coniacian and Santonian has been located in the middle part of the Czerna and Węgliniec formations (see discussion in Leszczyński, 2010).

Santonian deposits include mudstones, siltstones, sands and sandstones with plant roots, pieces of wood and amber, as well as intercalations of coal and kaoline (Alexandrowicz & Kwiecińska, 1977; Leszczyński, 2010). These deposits are indicative of lacustrine, lagoonal, coastal and paludal environments and brackish bays, separated from the open sea by a sand barrier (see Leszczyński, 2010). In the collections of the Geological Museum of the University of Wrocław there are specimens of *Cyrena cretacea* found by Drescher in 1867 (MGUWr-1542s; Fig. 10H) in the Upper Cretaceous of the Rakowice Małe Quarry (former Wenig-Rackwitz). These bivalves,

typical of mesohaline conditions, were also recorded by Alexandrowicz (1976) and Milewicz (1988) from the Santonian of the North Sudetic Synclinorium. Earlier, Scupin (1912–1913, p. 166, text-fig. 23) had illustrated this bivalve species, encountered in the Rakowice Małe Quarry (Wenig-Rackwitz). Drescher (1863) also found *Cyrena cretacea* in the Upper Cretaceous of the North Sudetic Synclinorium (Lwówek Śląski, “Löwenberg”). Additionally, Scupin (1912–1913) documented in plates bivalves belonging to the genus *Cyrena* from the Żerkowice Quarry (former Sirgwitz; pl. 7/4, 6, 10).

In the collections of the Geological Museum of the University of Wrocław are also tree fern remains (genus *Protopteris*), probably from Turonian-Coniacian deposits of the North Sudetic Synclinorium (Żeliszów Quarry [“Giersdorf”] and Lwówek Śląski [“Löwenberg”]), which have recently been described by Greguś et al. (2013), who suggested that tree fern taxa were good indicators of climate and usually appeared in tropical forests.

The majority of trace fossils were observed in the field, on exposed rock surfaces. Some of them, e.g., ?*Thalassinoides* isp. and *Ophiomorpha nodosa*, plus the body fossils *Lima haidingeri* and *Nerinea bicincta*, were prepared from the rock and are now housed in the collections of the Geological Museum of the University of Wrocław (MGUWr-6623s-6631s).

### 3. Systematic description of trace fossils

#### *Gyrochorte* Heer, 1865

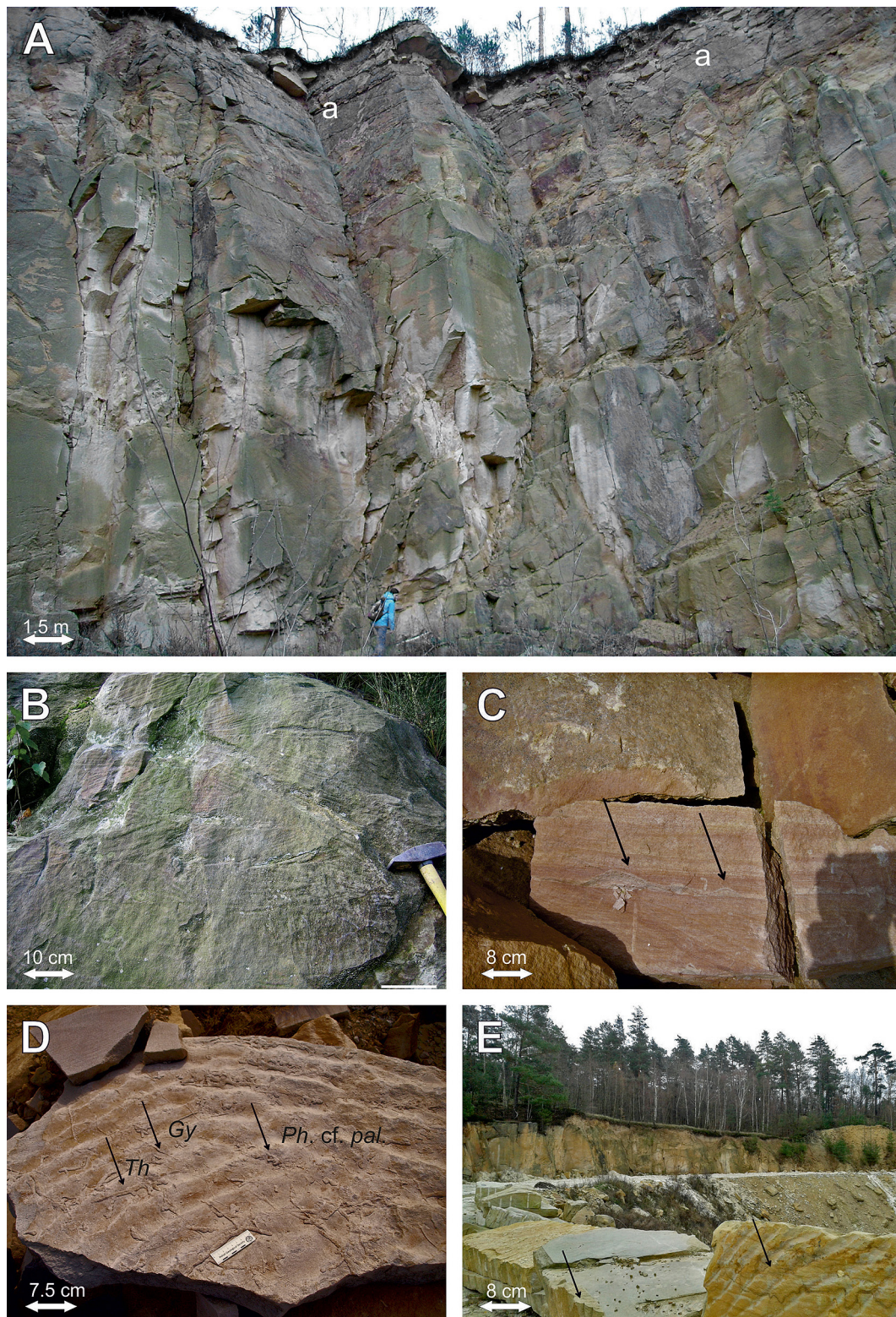
##### *Gyrochorte* isp.

Figs 4D, 5A–D

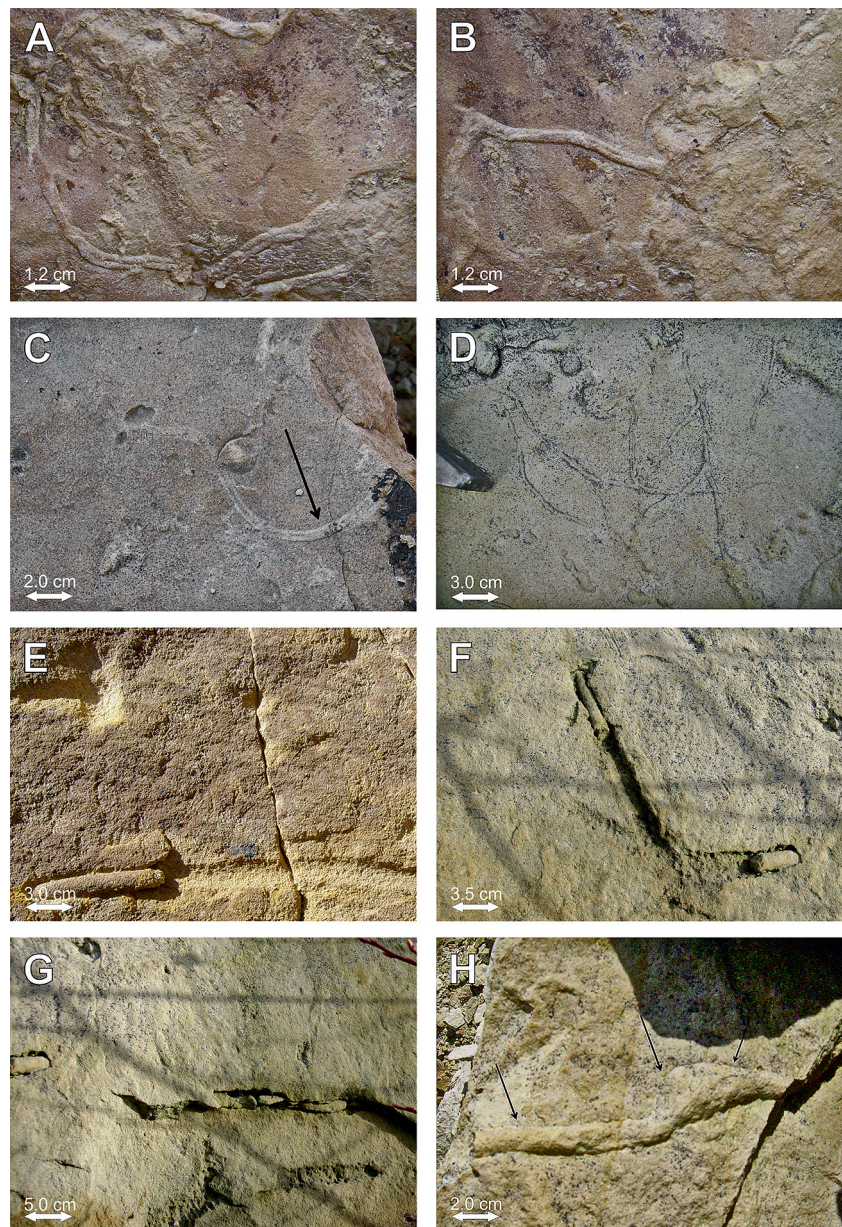
**Material:** Several specimens observed in the field on exposed surfaces of sandstone blocks at Czaple (Fig. 4D), Nowa Wieś Grodziska (Fig. 5A–C) and Rakowice Małe quarries (Fig. 5D).

**Descriptor:** Straight or gently curved bilobate burrow, consisting of two convex lobes with a median furrow (positive relief; Fig. 5A, B) or two grooves with a median ridge (negative hyporelief; Fig. 5C). Specimens studied are 4.0–5.0 mm wide and 12–20 cm long; burrows often cross cut and the median furrow is poorly visible (see Fig. 5D); for this reason, the latter specimens are assigned to *Gyrochorte* isp. with a query (as ?*Gyrochorte* isp.).

**Remarks:** These burrows show some similarities to material described by Gibert & Benner (2002, figs 2–4) and Uchman & Tchoumatchenco (2003, p. 29, fig. 3C). Heinberg & Birkelund (1984) interpreted *Gyrochorte* as a combination of sediment-feeding



**Fig. 4.** Sedimentary structures. **A** - photograph of quartz sandstone at Czaple Quarry; **a** - ferric crust; **B** - trough cross-stratification, Rakowice Male Quarry; **C** - planar cross-stratification and wave ripple marks, Czaple Quarry; arrows indicate ripple marks; **D** - ripple marks, *Thalassinoides-Phycodes* cf. *palmatus*; *Thalassinoides* (*Th*), *Phycodes* cf. *palmatus* (*Ph. cf. pal.*), *Gyrochorte* (*Gy*); specimens found by A. Kowalski (photograph by A. Kowalski) at Czaple Quarry; **E** - ripple marks, Czaple Quarry; arrows point to ripple marks.



**Fig. 5.** *Gyrochorte* and *Ophiomorpha*. **A-C** - *Gyrochorte* isp., Nowa Wieś Grodziska; **D** - ?*Gyrochorte* isp., Rakowice Małe Quarry; **E-F** - *Ophiomorpha nodosa*, Nowa Wieś Grodziska Quarry, MGU-WR-6623s-MGUWR-6624s; **G** - *Ophiomorpha nodosa*, Nowa Wieś Grodziska Quarry; **H** - *Ophiomorpha nodosa*, swollen chamber, Nowa Wieś Grodziska Quarry. Arrows indicate trace fossils and swollen chamber of *Ophiomorpha nodosa*.

and locomotion (pascichnion). On the other hand, Mieras et al. (1993), Buatois & Mángano (2011) and Minter et al. (2016) described this ichnotaxon as a locomotion trace (repichnion).

Tracemakers were deposit- or detritus-feeders, probably worm-like organisms (annelids) (Heinberg & Birkelund, 1984; Gibert & Benner, 2002; Gibert & Ekdale, 2002; Fürsich et al., 2006). Gastropods or crustaceans have also been suggested as potential producers of *Gyrochorte* (Chen et al., 2011; Pazos et al., 2012; Bayet-Goll & Neto de Carvalho, 2016; references therein). Schlirf (2000) regarded *Gyrochorte* as an arthropod trace (see also Uchman & Tchoumatchenco, 2003).

This ichnotaxon is typical of the *Cruziana* ichnofacies (Fillion & Pickerill, 1990). *Gyrochorte* usually

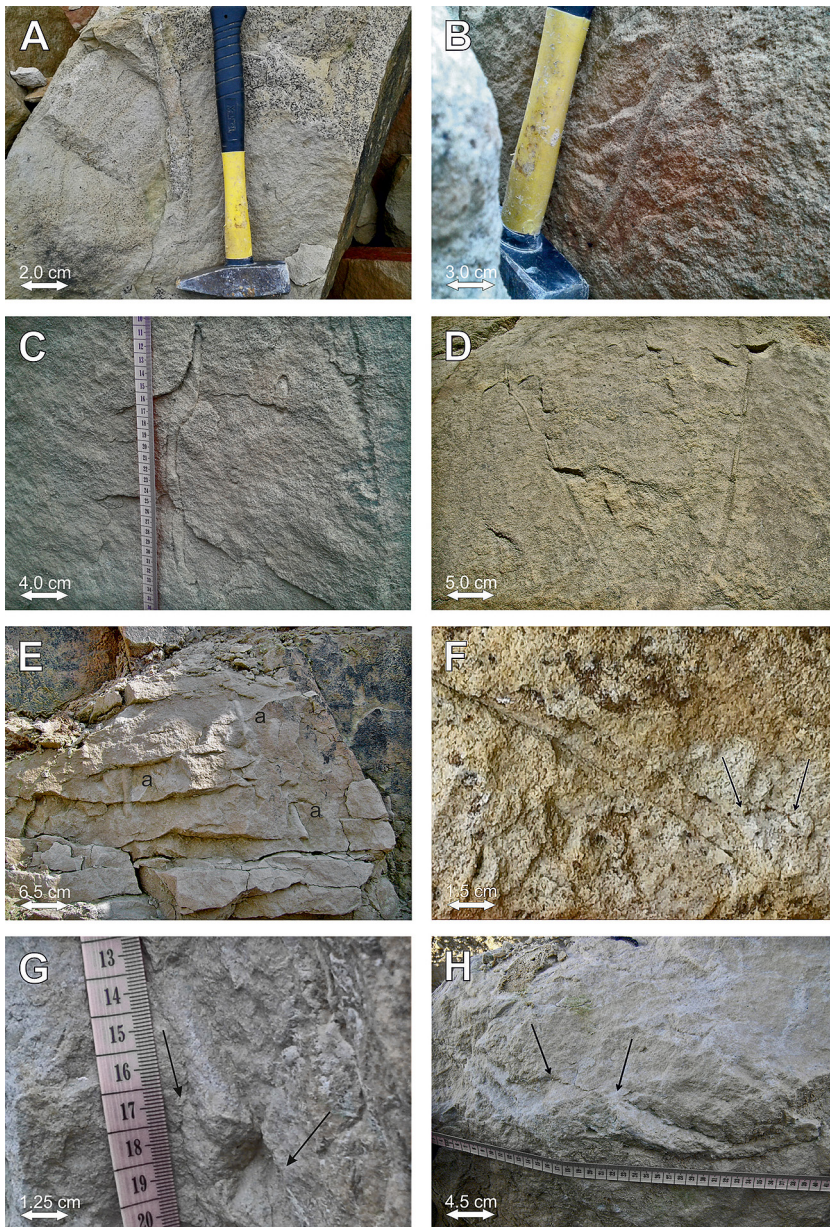
occurs in shallow- and marginal, low- to moderate-energy marine settings (Gibert & Benner, 2002). This ichnotaxon is common in foreshore/upper shoreface to lower shoreface settings (Mieras et al., 1993; Pemberton et al., 2001; Pearson et al., 2013) and its stratigraphical range is Ordovician to Pliocene (Gibert & Benner, 2002).

### *Ophiomorpha* Lundgren, 1891

#### *Ophiomorpha nodosa* Lundgren, 1891

Figs. 5E-H, 6A-H, 7A-F

**Material:** Forty specimens on quarry faces at Czaple-Nowa Wieś Grodziska, the majority of them on sandstone slabs. Some of them were collected



**Fig. 6.** *Ophiomorpha*. **A, B** - *Ophiomorpha nodosa* Lundgren, 1891, both Nowa Wieś Grodziska Quarry; **C-E** - *Ophiomorpha* isp., (C, D - Czaple Quarry; E - Nowa Wieś Grodziska Quarry); **F-H** - *Ophiomorpha nodosa* Lundgren, 1891, swollen chambers, Nowa Wieś Grodziska Quarry. Arrows indicate swollen chambers of *Ophiomorpha*.

and are now housed in collections of the Geological Museum of the University of Wrocław (MGUWr-6623s-6624s).

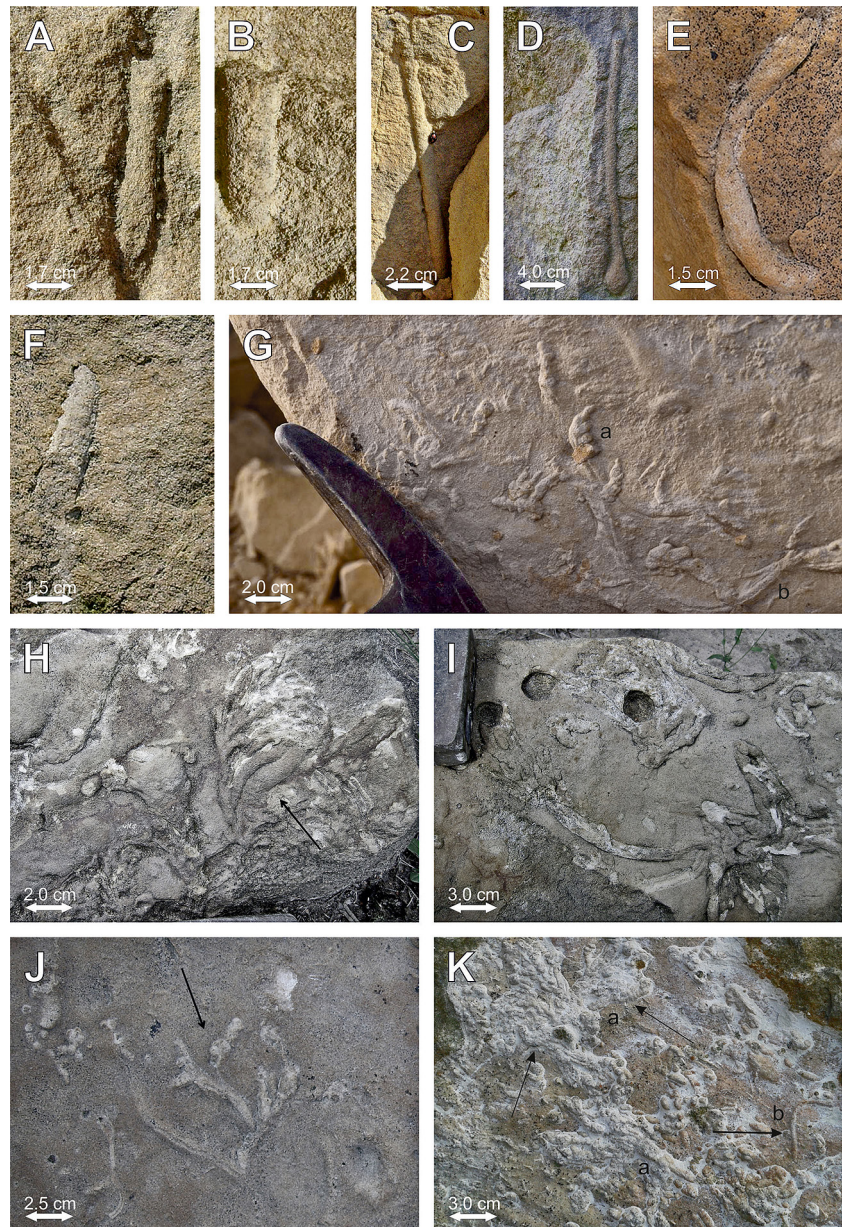
**Diagnosis:** *Ophiomorpha* occurs as vertical, horizontal or inclined tunnels (isolated or creating boxwork). Burrow wall consisting predominantly of dense, irregular pellets, regularly distributed, very characteristic and diagnostic of this ichnogenus (after Frey et al., 1978).

**Description:** Specimens of *Ophiomorpha nodosa* studied appear mainly as single isolated shafts, vertical or subvertical or inclined, rarely horizontal with characteristic pelleted walls. In some cases an *Ophiomorpha* boxwork or Y-shaped branching pattern has been observed. The visible length of the burrows preserved on slab surfaces ranges from 4.0

to 40 cm, while the diameter consistently is 0.3–1.5 cm, usually about 1.0 cm. Burrow fill is structureless and the same as the host rock. *Ophiomorpha* is mostly elliptical, rarely circular in cross section. Some *Ophiomorpha* have swelling chambers (turnarounds), usually 2.0–3.0 cm (maximum 6.0 cm) in width and up to 6.0 cm in length (Figs 5H, 6F–H). One specimen shows a swelling at the end of the burrow (Figs 7D, 8). In some cases, burrow walls are poorly preserved, probably due to erosion, lacking well-developed pelleted lining. For this reason some specimens are indicated only at ichnogenus level (*Ophiomorpha* isp.) rather than *O. nodosa* (Fig. 6C–E).

**Remarks:** *Ophiomorpha* is interpreted as a domichnion or domichnion/fodinichnion, even agrichnion





**Fig. 7.** *Ophiomorpha*, *Phycodes* and *Planolites*. **A-F** - *Ophiomorpha nodosa* Lundgren, 1891, (A-D - Czaple Quarry; E, F - Nowa Wieś Grodziska Quarry); **G** - *Phycodes* cf. *curvipalmatum*, Nowa Wieś Grodziska Quarry; a - arcuate ridge, b - branches; specimen found by A. Kowalski (photograph by A. Kowalski); **H-I** - *Phycodes* cf. *flabellum* (Miller and Dyer, 1878), Rakowice Małe Quarry; **J** - ?*Phycodes* isp., Nowa Wieś Grodziska Quarry; **K** - ?*Phycodes* isp. (a), Nowa Wieś Grodziska Quarry and *Planolites* cf. *beverleyensis* (Billings, 1862) (b). Arrows indicate trace fossils.

(Frey et al., 1978; Bromley, 1996; see also Uchman & Gaździcki, 2006). The *Ophiomorpha* tracemakers 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 have also been considered as potential producers (Frey et al., 1978; Gibert et al., 2006). Modern analogues of possible tracemakers are *Callinectes major* (formerly *Callianassa major*), *Protocallianassa*, *Axius* and *Neotrypaea* (Frey et al., 1978; Curran, 1984; Curran & White, 1991; Svrda et al., 2010).

*Ophiomorpha* is most typical of the *Skolithos* and *Cruziana* ichnofacies (Frey & Seilacher, 1980; MacEachern et al., 2007, 2012), being commonest under shallow-marine and marginal marine condi-

tions (Frey et al., 1978; Curran, 1985, 2007; Pollard et al., 1993; Goldring & Pollard, 1995), although also occurring in offshore (Frey, 1990; Frey & Howard, 1990), deep-sea (Uchman, 1991, 1992) and non-marine settings (Merill, 1984). It is most typical of the upper shoreface to upper offshore, although does appear in abundance in the upper-middle shoreface (Pemberton et al., 2001, 2012; Buatois & Mángano, 2011). It is worth noting that *Ophiomorpha nodosa* prevails in shallow-marine settings (littoral and sublittoral; see Leaman et al., 2015, p. 39, fig. 2), whereas other ichnospecies such as *O. rudis* Książkiewicz, 1977 and *O. annulata* Książkiewicz, 1977 usually occur in deeper-water settings of the *Nereites* ichnofacies (see Tchoumatchenco & Uchman, 2001; Uchman, 2009).

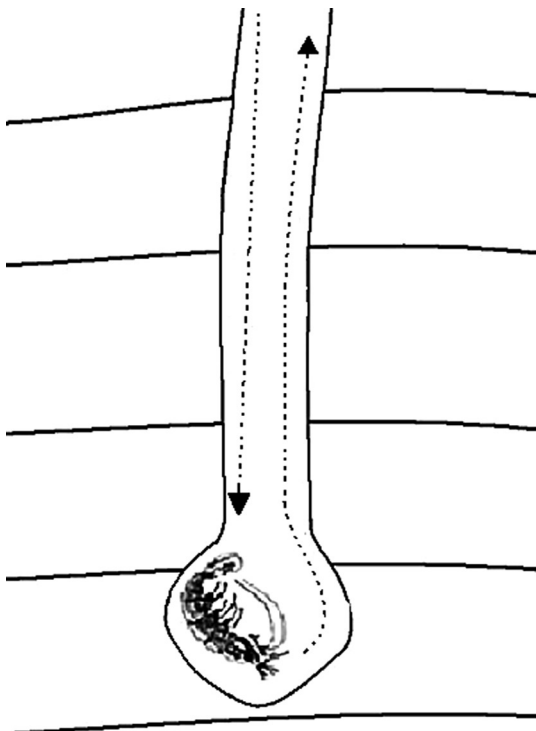


Fig. 8. Drawing of crustacean burrow with swollen chamber occurring at the end of the burrow (Fig. 7D).

This ichnogenus ranges from the Pennsylvanian (Anderson & Droser, 1998) or Permian to Holocene (Frey et al., 1978; Buatois et al., 2016). Baucon et al. (2014) noted that *Ophiomorpha* in nearshore environments first appeared during the Permian.

#### *Phycodes* cf. *curvivalmatum* (Pollard, 1981)

Fig. 7G

**Material:** A few specimens preserved on sandstone slabs at the Nowa Wieś Grodziska Quarry.

**Diagnosis:** "Closely packed burrows, parallel at proximal end, then gently diverging to give a fasciculate appearance, or with oblique, closely spaced short branches; number of branches low, about 5" (after Jensen, 1997).

**Description:** Parallel, short, closely packed curved branches (3–4), 5–10 mm long, 3.5–4 mm wide. Burrows are horizontal, bending sharply upwards in distal portion. Some branches are strongly recurved. Burrow surface smooth or slightly wrinkled. A few, fragmentarily preserved arcuate ridges (up to several centimetres in length and 2–4 mm wide) with individual branches are visible.

**Remarks:** The specimens studied show similarities to *Phycodes curvivalmatum* described by Jensen (1997, fig. 51A, B), Desai et al. (2010) and Han & Pickerill (1994, fig. 5/5) in having short, densely packed interwoven branches, which slightly curve upwards. According to Jensen (1997), *Phycodes curvivalmatum*

differs from *P. palmatus* Hall, 1852 in having shorter, more curved branches.

Ethologically it is a fodinichnion produced by worm-like organisms (annelids) or pennatulacean and anthoptiloid sea pens (Häntzschel, 1975; Fillion & Pickerill, 1990; Han & Pickerill, 1994; Singh et al., 2008; references therein).

*Phycodes* is recorded mainly from shallow-marine environments characteristic of the *Cruziana* ichnofacies (Bromley, 1996; MacEachern et al., 2007). This ichnogenus usually occurs in lower shoreface/upper offshore settings (Buatois & Mángano, 2011), but may appear in shallower settings, e.g., upper to middle shoreface (Bjerstedt, 1987) and, less commonly, in deep-marine or even non-marine and brackish settings (Han & Pickerill, 1994; Abbassi, 2007; Hubbard et al., 2012).

Its stratigraphical range is lower Cambrian to Palaeogene (Osgood, 1970; Chlupáč, 1997; Jensen & Grant, 1998; Miller, 2001; Mángano & Buatois, 2016; Shahkarami et al., 2017). Recently, Belaústegui & Muñiz (2016) extended the range by describing *Phycodes* from Pliocene deposits in southwest Spain.

#### *Phycodes* cf. *flabellum* (Miller & Dyer, 1978)

Fig. 7H, I

**Material:** Several specimens, preserved as horizontal broom-like or flabellate bundles (convex hyporelief) found on sandstone slabs at the Rakowice Małe Quarry.

**Diagnosis:** "*Phycodes flabellum* has horizontally protrusive spreite fans, which are only on one side of a main shaft along which they may alternate between right and left" (after Osgood, 1970; see also Seilacher, 2000, p. 254, fig. 14).

**Description:** *Phycodes* cf. *flabellum* appears as a multibranch cylindrical or subcylindrical, horizontal burrow with thick rounded branches (creating a broom-like structure), originating from nearly the same point of a thick tunnel. Individual broom-like or flabellate sets comprise 5–7 burrows, which are straight or gently curved, semi-circular in cross section and distributed on one side of the main, straight ridge. In the studied specimens, branches are 0.5–0.7–1.0 cm wide and up to 6 cm long. The surface of the ridges is rather smooth. In some cases, burrow diameter in individual sets slightly increases distally. The diameter of the set usually is about 5.0 cm and a length of 8.5 cm. On the surface of the sandstone at Rakowice Małe Quarry, typically unconnected sets occur (Fig. 7I). The burrow fill is similar in lithology to the host rock.

**Remarks:** Specimens studied (Fig. 7H, I) show some similarities to *Phycodes flabellum* as described by Seilacher (2000, p. 254, fig. 14) and to *Phycodes*

cf. *flabellum* recorded by Stachacz (2016, p. 307, fig. 14C), especially in having branching ridges situated along the main stick, on one side (right) only. Material studied also resembles *Phycodes flabellum* as recorded by Bjerstedt & Erickson (1989, pp. 221–223, fig. 14D–F), especially the specimen illustrated in their fig. 14E (branches are distributed on right side of the main channel and are slightly winding). Some similarities also exist to *Phycodes flabellum* of Aceñolaza et al. (2010, pp. 166–167, fig. 3), but the surface of the studied burrow is not so distinctly ornamented. Another difference is the lack in our material of any alternation of ridges between right and left, along one side of main tunnel. The specimen illustrated in fig. 9A in Rindsberg & Martin (2003) is closely similar to material from the Czaple Quarry, but another one (their fig. 9B) possesses longer and ornamented branches. In comparison to *Phycodes palmatus* Hall, 1852, as described by Han & Pickerill (1994, p. 43, fig. 5/12), Chlupáč (1997, fig. 5/6), Jensen & Grant (1998, fig. 6/a), Singh et al. (2008, fig. 4/b, c) and Stachacz (2016, p. 307, fig. 14D), our material does not show branches diverging from the same point, creating a palmate structure. They differ also from *Phycodes* cf. *palmatus* as recorded by El-Hedeny et al. (2012, p. 727, fig. 5C, D) by having more branches in individual broom-like sets and are quite different from *Phycodes templus* Han and Pickerill, 1994 (p. 3, fig. 2), due to a lack of a pagoda-like structure, which consists of several interconnected broom-like bundles.

### *Phycodes* Richter, 1850

#### ?*Phycodes* isp.

Fig. 7J, K

**Material:** A single specimen preserved in full relief on a sandstone block (Fig. 7J) at the Nowa Wieś Grodziska Quarry. Numerous specimens visible on surfaces of sandstone, co-occurring with *Planolites* cf. *beverleyensis* Billings, 1862 (Fig. 7K) at the same quarry.

**Description:** *Phycodes* appears as a broom-like burrow, occurring as a bundle of tubes originating likely from the same point of a single stem. Horizontal tubes usually consist of few branches (usually 5–6). The diameter and length of the whole structure is 9.0 and 7.0 cm, respectively, whereas individual burrows in the set are 0.5–0.7 cm wide (Fig. 7J). The specimens that co-occur with *Planolites* cf. *beverleyensis* (Fig. 7K) are 5 cm wide and 6 cm long and consist of 5–6 branches in individual sets.

**Remarks:** These structures do not differ from other specimens assigned to the ichnogenus *Phycodes* (for

a discussion of the ichnogenus see Osgood, 1970, Fillion & Pickerill, 1990; Han & Pickerill, 1994). The state of preservation is not good and does not allow ichnospecific identification. The studied specimen (Fig. 7J) shows some similarities to *Phycodes* isp. described by Zhang & Zhao (2015, p. 335, fig. 6a) in having arc-shaped branches diverging nearly from the same point. However, it differs in having another structural pattern (not flabellate) and a smaller number of branches. It also differs from *Phycodes palmatus* Hall, 1852 in the lack of a palmate structure (compare Han & Pickerill, 1994, p. 43, fig. 5.12). The present specimen does not show branches situated on one side of the main stick, as in *Phycodes flabellum* (see Stachacz, 2016, p. 254, fig. 14C). It differs also from *P. circinatus* Richter, 1853 in having a smaller number of larger ridges (smaller and closely spaced, parallel to one another, see Stachacz, 2016, pp. 305–307, fig. 14A, B). Numerous specimens on sandstone slabs (Fig. 7K) resemble mainly *Phycodes* isp. as recorded by Zhang & Zhao (2015, fig. 6a) in having straight or slightly winding 5–6 branches in broom-like sets that are not arranged on one side of main stick (i.e., not as in *Phycodes flabellum*).

### *Planolites* Nicholson, 1873

#### *Planolites* cf. *beverleyensis* Billings, 1862

Fig. 7K

**Material:** A single specimen preserved on the surface of a sandstone block at Nowa Wieś Grodziska Quarry.

**Diagnosis:** Straight or slightly curved, horizontal semi-circular or semi-elliptical cylindrical ridges with smooth surface (without lining), which are infilled by material that differs slightly in colour from the host rock (after Stachacz, 2012, 2016; see also Pemberton & Frey, 1982).

**Description:** *Planolites* occurs as slightly curved, horizontal, unbranched meandering burrows (unornamented, unlined, cylindrical), elliptical in cross section, with a visible length of up to 6.0 cm and a diameter of 0.3 cm, on the bedding plane.

**Remarks:** This specimen does not differ from *Planolites beverleyensis* as described by Shi et al. (2015, figs. 3J, 4E), Stachacz (2016, p. 302, fig. 12C) and Rodríguez-Tovar et al. (2014, p. 550, fig. 7E). In comparison to *Planolites montanus* Richter, 1937, the present specimen does not plunge into the bed, which is characteristic of this ichnospecies (compare Rodríguez-Tovar et al., 2014, fig. 7G) and Stachacz (2012, p. 111, fig. 6A; 2016, p. 302, fig. 12D).

It is interpreted as a pascichnion of deposit feeders, mostly polychaetes (Pemberton & Frey, 1982;

Keighley & Pickerill, 1995), but may also have been produced by bivalves (see Knaust, 2007) or insect larvae in non-marine settings (Gradziński & Uchman, 1994; Kim et al., 2002).

It is a facies-crossing, eurybathic form, but most commonly has been recorded from shallow-marine environments of the *Cruziana* ichnofacies (Buatois & Mángano, 2011; Pemberton et al., 2001, 2012).

This taxon is known from the Proterozoic to Holocene (Häntzschel, 1975; McCann & Pickerill, 1988; Mángano & Buatois, 2016).

### *Thalassinoides* Ehrenberg, 1944

#### *Thalassinoides paradoxicus* Woodward, 1830

Fig. 10A

**Material:** A single specimen preserved on a sandstone quarry face at Czaple.

**Diagnosis:** Irregularly branched, subcylindrical to cylindrical burrows oriented at various angles with respect to bedding; T-shaped branches are commoner than Y-shaped bifurcations (after Howard & Frey, 1984, p. 213).

**Description:** *Thalassinoides paradoxicus* appears as a horizontal or inclined, cylindrical, unlined burrow. At the end of the burrow, T-shaped, rather than Y-shaped, branching is visible (Fig. 10A). The burrow fill is the same as the host rock. The diameter varies from 2.0 to 3.0 cm. The visible length is > 60 cm.

**Remarks:** The variable diameter and irregular pattern of branching suggests assignment to *T. paradoxicus*. The burrow studied does not differ from specimens described by Tiwari et al. (2011, p. 1139, fig. 4e).

*Thalassinoides* is interpreted as domichnia/fodinichnia/agrichnia of deposit feeders (Myrow, 1995; Bromley, 1996; Ekdale & Bromley, 2003). Thalassinoid shrimps (ghost shrimps), lobsters, crayfish and crabs, as well as fish, cerianthid sea anemones and balanoglossan enteropneusts have been suggested as potential tracemakers (Frey et al., 1984; Myrow, 1995; Ekdale & Bromley, 2003; Chen et al., 2011). In non-marine settings, crayfish may be producers of *Thalassinoides* (Kim & Kim, 2002; Yanin & Baraboshkin, 2013). Possible producers (living or extinct crustacean genera; see Stamhuis & Videler, 1998; De Grave et al., 2009) include *Callianassa*, *Mecochirus*, *Meyeria* and *Glypheia* (Neto de Carvalho et al., 2007; Hembree et al., 2011; Neto de Carvalho, 2016).

This eurybathic ichnotaxon occurs in different ichnofacies (MacEachern et al., 2007, 2012), even in deep-sea settings (Uchman, 1991, 1998). It is commonest in shallow-marine settings of the *Cruziana*

ichnofacies (from upper to distal lower shoreface), although its environmental distribution ranges from marginal marine to offshore (Rodríguez-Tovar et al., 2008; Leszczyński, 2010; Pemberton et al., 2012).

This ichnogenus is known from the Cambrian (Fortunian) to Recent (Mikuláš, 2000; Sprechmann et al., 2004; Zhang et al., 2017), being common from Ordovician onwards (Sheehan & Schiefelbein, 1984; Jin et al., 2011; Mángano et al., 2016).

#### ?*Thalassinoides* isp.

Fig. 10B

**Material:** A single isolated specimen, fragmentarily preserved on a sandstone slab at Nowa Wieś Grodziska Quarry, now housed in the collections of the Geological Museum of the University of Wrocław (MGUWr-6625s).

**Description:** ?*Thalassinoides* isp. appears as a cylindrical, unlined, flattened tunnel (probably part of a larger burrow), gently curved, elliptical in cross section, with a diameter from 2.0 to 4.5 cm, usually 2.5 cm and a length of 15 cm.

**Remarks:** This specimen possesses a characteristically flattened shape of *Thalassinoides* and a slightly curved course. This ichnotaxon might probably have exhibited a Y-shaped branching pattern, typical of *Thalassinoides suevicus* Rieth, 1932 (e.g., Uchman & Tchoumatchenco, 2003, p. 31, fig. 8). Due to the lack of branching, it is here listed in open nomenclature.

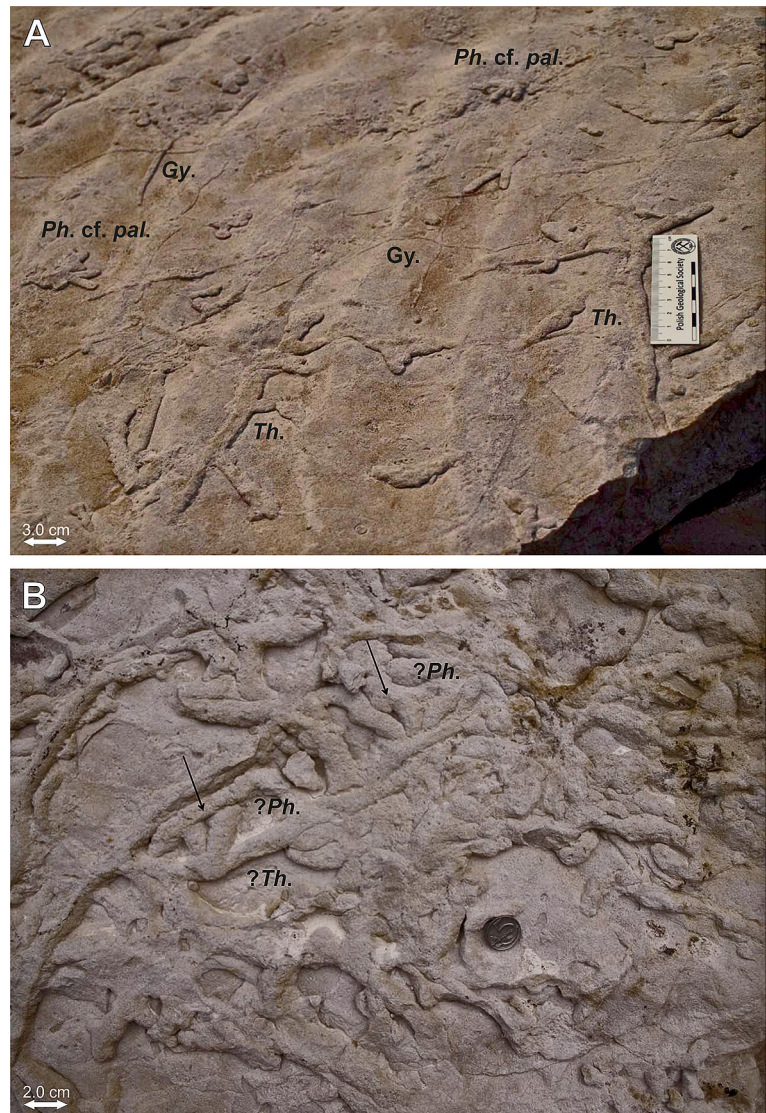
### *Thalassinoides-Phycodes* compound burrow systems

#### *Thalassinoides-Phycodes* cf. *palmatum*

Figs 4D, 9A

**Material:** This composite trace fossil (a compound burrow system of *Thalassinoides-Phycodes* cf. *palmatum* and *Gyrochorte*) occurs on a sandstone surface, covering well-preserved wave ripple marks (Figs 4D, 9A) at Nowa Wieś Grodziska Quarry (Fig. 2; quarry 1).

**Description:** This compound burrow system consists of horizontal, branching tunnels of *Thalassinoides* and *Phycodes* cf. *palmatum*, usually occurring at end end of branches. In some cases, isolated burrows, especially of *Phycodes* cf. *palmatum*, appear on sandstone surfaces (probably reflecting state of preservation). *Thalassinoides*, which forms the core of these compound structures, appears as straight or slightly undulose horizontal tunnels with branches under acute angles; parallel to bedding plane. Vertical tunnels were not noted. Diameter of tunnels

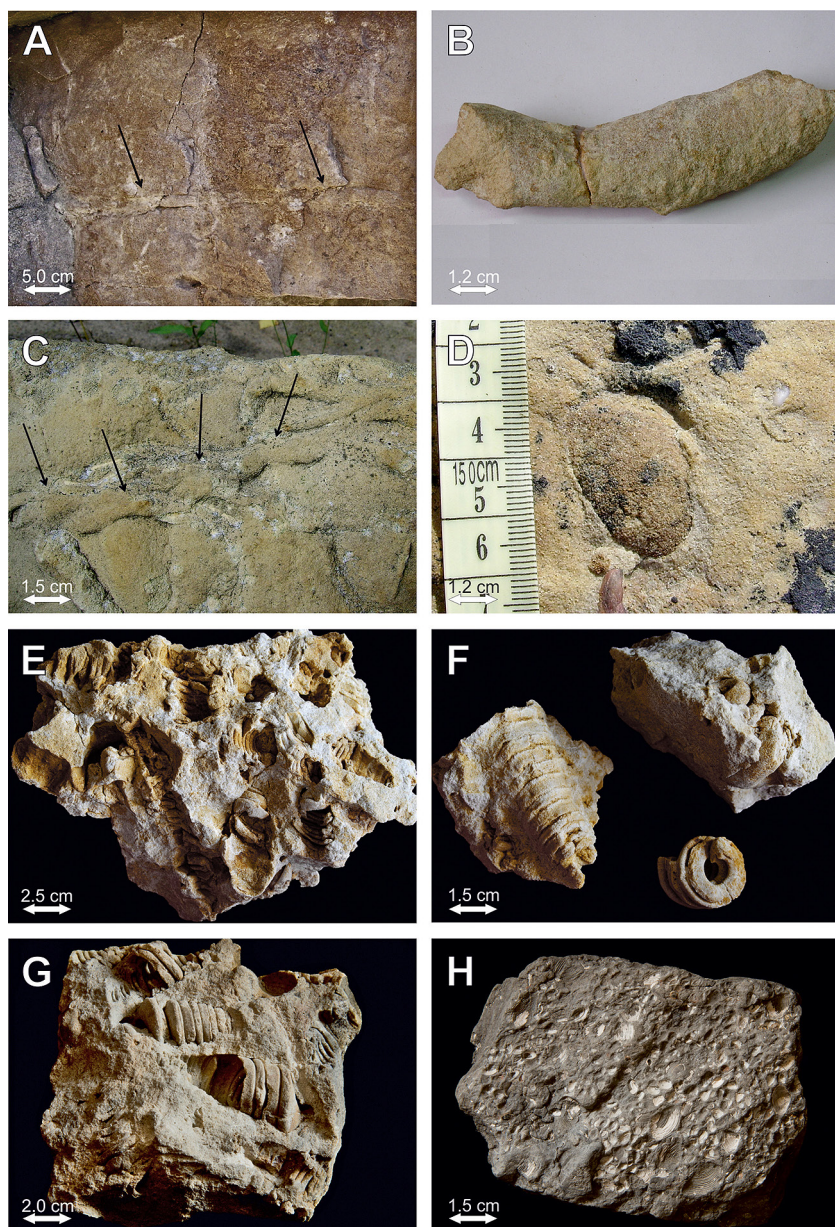


**Fig. 9.** *Thalassinoides-Phycodes* compound burrow systems. **A** - *Thalassinoides-Phycodes* cf. *palmatus*, *Th.* - *Thalassinoides*, *Ph.* cf. *pal.* - *Phycodes* cf. *palmatus*, *Gy.* - *Gyrochorte*; Nowa Wieś Grodziska Quarry; **B** - ?*Thalassinoides-Phycodes*, Czaple Quarry, ?*Th.* - ?*Thalassinoides*, ?*Ph.* - ?*Phycodes*. Both specimens found by A. Kowalski, photographs by A. Kowalski. Arrows indicate ?*Phycodes*.

studied varies from 1.0 to 2.5 cm, the visible length being up to 20 cm. *Phycodes* occurs at distal margins, usually at the end of branches. Up to six individual branches in individual sets are observed (Fig. 9A), which create palmate-like or fan-shaped structures resembling *P. palmatus*. The diameter of these branches is about 0.7 cm, the length of the whole set being 6.0 cm. The *Thalassinoides-Phycodes* compound trace fossil co-occurs with *Gyrochorte*, which probably appeared first (Fig. 9A).

**Remarks:** These specimens resemble the compound burrow system described by Miller (2001, p. 153, fig. 7), in which “one ichnotaxon passes gradually or directly into another” (compare Pickerill, 1994). They usually are interpreted as dwelling-feeding structures produced by crustaceans (see Miller, 2001). Such burrow systems probably were inhabited by tracemakers for a relatively long period and had more than one function (see Miller, 1998, 2001).

In the studied compound burrow systems the tunnels of *Thalassinoides* probably were used as domicinia (runways, protected areas), while *Phycodes* might have been created as food-mining structures (compare Miller, 2001), probably in food-rich zones. Miller (2001) also suggested another possible ethological behaviour for *Thalassinoides-Phycodes* trace-makers, such as e.g., cultivation of bacteria, ventilation of burrow systems and protecting/brooding juveniles. The present specimens (*Phycodes* cf. *palmatus*), which show a characteristic palmate structure, do not differ from specimens described as *Phycodes palmatus* by Chlupáč (1997, pl. 3, figs. 1, 3, 6), Jensen (1997, figs. 50, 51B), Knaust (2004, fig. 7.3), Singh et al. (2008, fig. 4b, c), Desai et al. (2010, fig. 3I) and Stachacz (2016, fig. 14D). It is also most similar to *Phycodes palmatus* as described by Hanken et al. (2016, fig. 10B). These burrows are typical of the *Cruziana* ichnofacies. Compound burrow systems have



**Fig. 10.** *Thalassinoides* and body fossils (bivalves, gastropods). **A** - *Thalassinoides paradoxicus* Woodward, 1830 (Czaple Quarry); **B** - ?*Thalassinoides* isp. (Nowa Wieś Grodziska Quarry; MGUWr-6625s); **C** - ?*Treptichmus* isp. (Rakowice Małe Quarry); **D** - *Lima haidingeri* Zittel, 1866 (Nowa Wieś Grodziska Quarry; MGUWr-6626s); **E, F** - *Nerinea bicincta* Bronn, 1836 (Czaple and Nowa Wieś Grodziska quarries; MGUWR-6627-MGUWr-6631s); **G** - *Nerinea buchi* Zekeli, 1852 (collected by Drescher in 1867), Coniacian at Żeliszów Quarry (formerly Giersdorf; MGUWr-1592s); **H** - *Cyrena cretacea* Drescher, 1863 (collected by Drescher) (MGUWr-1542s), Santonian at Rakowice Małe Quarry (formerly Wenig-Rackwitz).

usually been recorded from deep-sea settings, e.g., the deeper part of the offshore shelf (Miller, 2001; Abbassi et al., 2015). However, the *Phycodes-Rusophycus* association was found by Zhang & Zhao (2015) in the low-energy zone of the upper shoreface.

#### ?*Thalassinoides-Phycodes*

Fig. 9B

**Material:** Numerous specimens preserved on sandstone slabs at Czaple Quarry (Fig. 2; quarry 4).

**Description:** This compound trace fossil (Fig. 9B) occurs as horizontal, straight or more commonly slightly curving tunnels. It seems that the main tunnels (?*Thalassinoides*) have two or three branches, which originated from nearly the same point. These branches are arranged on one side of the main tun-

nels and form “palmate-like” structures, which resemble *Phycodes* (Fig. 9B). The dimension of the main tunnels and branches is similar, between 15 and 20 mm, their visible length being up to several centimetres. Due to the poor state of preservation, the studied specimens are referred to as ?*Thalassinoides-Phycodes*.

#### *Treptichmus* Miller, 1889

##### ?*Treptichmus* isp.

Fig. 10C

**Material:** A single specimen, consisting of six segments and some specimens that comprise of two or three isolated, joined segments, fragmentarily

preserved on a sandstone block at Rakowice Małe Quarry.

**Description:** Six segments, connected at their end (joined to each other), are visible on the sandstone surface, oriented under an oblique angle, to the main axis of the trace. The length of the whole structure is about 12 cm, segments are up to 2 cm long and 0.5–0.7 cm wide, preserved in hyporelief.

**Remarks:** This specimen is similar to *Treptichnus* as described by Singh et al. (2017, fig. 9d) and Jensen (1997, fig. 62B), as “burrows consisting of segments connected at their ends, each to the next one, but not in a zigzag pattern” (compare Singh et al., 2017). It does not differ significantly from specimens recorded by Hofmann et al. (2012, fig. 9/2), Srivastava (2012, fig. 3A, B), Buatois et al. (2013, fig. 1A) and Stachacz (2016, fig. 14E) either. However, due to the poor state of preservation it is difficult to say if individual segments plunged into the bed or not (compare Stachacz, 2016).

*Treptichnus* is interpreted as a fodinichnion or agrichnion produced by vermiform animals (worm-like animals) or insect larvae (Buatois & Mángano, 1993; Schlirf, 2003; Stachacz, 2016; references therein).

Schlirf (2003) recorded *Treptichnus* from the fore-shore-upper shoreface, while Singh et al. (2017) noted examples from the shoreface. Buatois et al. (2013) and Buatois (2018) suggested a broad environmental tolerance of the tracemakers of *Treptichnus*, which can occur both in deep and shallow settings. It is known from the Ediacaran to Recent (Jackson et al., 2016; Mángano & Buatois, 2016).

### 3.1. Associated body fossils

In addition to trace fossils, associated body fossils (bivalves, gastropods) were also collected. The most interesting is the gastropod *Nerinea bicincta* Bronn, 1836 (Fig. 10E, F; MGUWr-6627s-6631s), which was previously recorded from the Coniacian at Żeliszów Quarry (formerly Giersdorf) by Scupin (1912–1913, pp. 118–120, pl. 4, fig. 1; pl. 5, fig. 17). The present specimens are up to 6.0–7.0 cm long and measure 1.0 to 2.8 cm in width. In the collections of the Geological Museum of the University of Wrocław there is a specimen described as *Nerinea buchii* Zekeli, 1852 (now *Nerinea bicincta*, see synonymy in Lommel, 184; Scupin, 1912–1913), which was collected at Żeliszów Quarry (Giersdorf) in 1867 by Drescher (Fig. 10G). Andert (1934) recorded *Nerinea bicincta* (without illustrations) from the Coniacian of Lower Silesia, from Żeliszów Quarry (formerly Giersdorf), Bielawa Dolna Quarry (formerly Niederbielau) and

from Saxony and Austria. *Nerinea bicincta* was also recovered from Upper Cretaceous levels in Austria and Romania by Klinghardt (1944) and Földvay (1988).

The limid bivalve *Lima haidingeri* Zittel, 1866 (Fig. 10D; MGUWr-6626s), which also occurs in these blocks, were previously recorded from the Coniacian of the North Sudetic Synclinorium (Żeliszów Quarry [formerly Giersdorf], Rakowice Małe Quarry [formerly Wenig-Rackwitz] and Żerkowice Quarry [formerly Sirgwitz], see Fig. 1) by Scupin (1912–1913, pp. 231–232, pl. 13, fig. 9; pl. 14, fig. 1; text-figs. 42, 43). Andert (1934) cited *Lima haidingeri* from the same quarries as above, from the Coniacian at Żeliszów Quarry and from the Upper Cretaceous of Rakowice Małe and Żerkowice and Austria. ?*Lima haidingeri* has also been described from the Coniacian at Jerzmanice Zdrój (North Sudetic Synclinorium; Chrzastek, 2008).

Additionally, the bivalve *Cyrena cretacea* Drescher, 1863 is represented in the collections of the Geological Museum of the University of Wrocław (MGUWr-1542s; Fig. 10H). These bivalves, typical of mesohaline conditions, were found by Drescher at Rakowice Małe Quarry (formerly Wenig-Rackwitz) in the Upper Cretaceous. Scupin (1912–1913), Alexandrowicz (1976) and Milewicz (1988) also recorded this species from the Santonian of the North Sudetic Synclinorium.

## 4. Palaeoenvironment of Coniacian sandstones

The low-diversity trace fossil assemblage (six ichnogenera, eleven ichnospecies and two compound burrow systems) allows to add some data towards the palaeoenvironmental interpretation of Coniacian sandstones (Żerkowice Member) by Leszczyński (2010). The trace fossil assemblage at the Czaple-Nowa Wieś Grodziska quarries is typical of shallow-marine settings and characterises the *Skolithos* and *Cruziana* ichnofacies. It is dominated by pascichnia (*Planolites*, *Gyrochorte*), fodinichnia/agrichnia/domichnia (*Thalassinoides*), fodinichnia (*Phycodes*) or domichnia (*Ophiomorpha*) produced by deposit- and suspension-feeders or predators.

Abundant *Gyrochorte* is considered to be indicative of nearshore, shallow-marine settings (Gibert & Benner, 2002). It usually occurs in storm-influenced, lower shoreface/upper offshore settings (Pemberton et al., 2001, 2012; Seidler & Steel, 2001; Buatois & Mángano, 2011, 2013; Bressan et al., 2013) up to the upper to middle shoreface (Mieras et al.,

1993; Pearson et al., 2013; Bayet-Goll et al., 2015). The tracemaker has been suggested to be an opportunistic organism (post-event) that used to colonise the sandy substrate during quiet energy conditions (fair-weather), after high-energy storm events (see Gibert & Benner, 2002; Joseph et al., 2012). *Gyrochorte* usually is associated with other pascichnia or fodinichnia. At the Czaple quarries, this ichnotaxon co-occurs with *Planolites* and *Phycodes*. According to Han & Pickerill (1994) and Neto de Carvalho et al. (2016), *Gyrochorte* often is associated with *Thalassinoides* and *Ophiomorpha* in the post-Middle Jurassic Mesozoic deposits.

*Phycodes* mainly occurs in low-energy, shallow-marine settings (Han & Pickerill, 1994). It is common in storm-dominated shelf deposits (Pickerill et al., 1995) and usually appears from the upper to the lower shoreface (Mayoral et al., 2013). Hanken et al. (2016) recorded *Phycodes* mainly from the upper-middle shoreface. The second ichnotaxon, *Planolites*, is a eurybathic, facies-crossing burrow, but it appears in abundance in shallow-marine settings (Pemberton et al., 2012; Baucon & Neto de Carvalho, 2016). Frey & Dashtgard (2011) reported *Planolites* from the upper/middle shoreface.

*Ophiomorpha* is the most abundant trace fossil at the quarries studied. On account of the common occurrence of *Ophiomorpha* in nearshore settings (high-energy, shallow- and marginal marine) is considered a palaeobathymetric indicator (Frey et al., 1978; Curran & White, 1991; Miller & Curran, 2001; Pemberton et al., 2001). According to Pemberton et al. (2012), *Ophiomorpha nodosa* usually appears from the foreshore to offshore (e.g., Curran, 1985), but is most abundant in the foreshore-upper shoreface-middle shoreface (Pollard et al., 1993; Howell et al., 1996; Malpas et al., 2005), while others such as *Ophiomorpha rudis* or *O. annulata* are typical of deeper settings (see Uchman & Demircan, 1999; Tchoumatchenco & Uchman, 2001; Uchman, 2009; Nagy et al., 2016).

Less common at the Czaple-Nowa Wieś Grodziska quarries are *?Thalassinoides* isp. or *T. paradoxicus*. This ichnogenus, where it appears in abundance, is most typical of the distal lower shoreface (see ichnological-sedimentological models by Pemberton et al., 2001, 2012). Several authors have typified such environments as the most characteristic of *Thalassinoides* (Uchman & Krenmayr, 2004; Pervesler et al., 2011; Chrzastek, 2013b; Mayoral et al., 2013). On the other hand, single occurrence of *Thalassinoides* can be observed also in upper shoreface-middle shoreface settings (Hampson & Storms, 2003; Malpas et al., 2005; Leszczyński, 2010; Buatois & Mángano, 2011; Bayet-Goll et al., 2015). The presence of this

ichnotaxon usually suggests good oxygenation and low-energy conditions (Buatois & Mángano, 2011).

The occurrence of *Thalassinoides-Phycodes* cf. *palmatus* and *?Thalassinoides-Phycodes* compound burrow systems might also suggest the presence of low-energy episodes (see Miller, 2001). Although such burrow systems have usually been noted from open-marine, low-energy, deeper settings, e.g., offshore (Patel et al., 2009; Abbassi et al., 2015), abundant *Phycodes* co-occurring with *Rusophycus* was described from the upper shoreface by Zhang & Zhao (2015). It is worth noting that in the present example, the compound burrow system *Thalassinoides-Phycodes* cf. *palmatus* is preserved on top of wave ripple marks, suggesting deposition of these sandstones above fair-weather wave base. Additionally, the presence of burrows left by deposit feeders, especially *Thalassinoides-Phycodes* compound burrows, might suggest the occasional availability of sufficient organic matter in these deposits (see also Patel et al., 2009). According to Rodríguez-Tovar et al. (2017; references therein), horizontally extended burrow systems (e.g., *Thalassinoides*) without vertical shafts, might indicate favourable environmental conditions (enough food on sea floor and within the uppermost part of the deposit) and exploitation of the sediment by deposit feeders (fodinichnia). On the other hand, those authors recorded that this kind of burrow (horizontal system) might have been produced in order to “maximalize the capture of organic matter, when the substratum has a low nutritional value” (see also Suchanek et al., 1986) or when substrate consistency in the upper part of the deposit is inappropriate (e.g., less cohesive) for tracemakers to produce vertical shafts.

At all quarries, throughout the section, *Ophiomorpha* is present, whereas *Thalassinoides*, *Phycodes*, *Gyrochorte* and *Planolites* appears in the bottom and upper parts (Fig. 3). Vertical, subvertical and inclined burrows of *Ophiomorpha* might suggest higher-energy conditions, whereas the presence of horizontal burrows (*Gyrochorte*, *Ophiomorpha*, *Phycodes*, *Planolites*), as well as compound burrow systems (*Thalassinoides-Phycodes*) suggest lower hydrodynamic conditions (see also Frey et al., 1978; Anderson & Droser, 1998).

The present study is in agreement with sedimentological interpretations of the sandstones of the Żerkowice Member by Leszczyński (2010). That author considered Coniacian sandstones at Rakowice Małe and Żerkowice quarries to be bar and storm deposits, laid down mainly from the foreshore to upper shoreface (up to the middle shoreface). Based on the presence of large-scale cross-stratification (onshore- and offshore-directed), Leszczyński



(2010) suggested that the deposition of these sandstones (Żerkowice Member) occurred in a palaeoenvironment of high hydrodynamics, occasionally during storm events (see Leszczyński, 2010; references therein). The present study seems to support this view. The presence of a trace fossil assemblage typical of shallow-marine settings, trough cross bedding, wave ripples, planar lamination, as well as a lack of hummocky cross-stratification (HCS) suggest deposition above fair-weather wave base, probably from the upper shoreface to middle shoreface (see Dott & Bourgeois, 1982; Duke, 1985; Hampson & Storms, 2003; Leszczyński, 2010; Joseph & Patel, 2015; see Fig. 4).

In comparison with previous work by Leszczyński (2010), the present study shows that Coniacian sandstones at the Czaple-Nowa Wieś Grodziska quarries might have been laid down in an environment similar to that at Żerkowice Quarry (up to the middle shoreface; see Leszczyński, 2010). This is confirmed by the higher ichnotaxonomic diversification in comparison to Rakowice Małe Quarry, from where only *Thalassinoides* and *Ophiomorpha* were recorded, plus the occurrence of numerous horizontal structures (*Phycodes*, *Planolites*, *Thalassinoides*, *Gyrochorte*, *Thalassinoides-Phycodes*).

Callianassid crustaceans – the possible trace-makers of *Ophiomorpha* and *Thalassinoides* – inhabit mainly shallow waters, especially up to 200 m (see Weimer & Hoyt, 1964; Griffis & Suchanek, 1991; Dworschak 2000; Leaman et al., 2015). They prefer waters with normal salinity, although tolerate fluctuations (Frey et al., 1978; Swinbanks & Luterbauer, 1987). The blocks with gastropods (*Nerinea bicincta*) and bivalves (*Lima haidingeri*) also point to a well-oxygenated palaeoenvironment.

According to Sohl & Kollmann (1985), *Nerinea bicincta*, which occurred along the northern margin of Tethys in Poland and the Czech Republic, probably had warm-water affinities. Sanders (1998) recorded that large-sized nerineids usually occurred in shallow subtidal, open lagoonal environments. Wiczorek (1979) and Cataldo (2013; references therein) suggested that nerineoids appeared in abundance in benthic assemblages of Jurassic and Cretaceous carbonate ramps and platform environments, being typical of subtropical to tropical marine conditions of the Tethys Ocean. In summary, nerineids are considered to be indicative of warm, tropical conditions of the Tethyan Realm (see Sohl, 1987; Saul & Squires, 1998). They usually appear in euryhaline and mesohaline waters (Sohl & Kollmann, 1985) in shallow environments with moderate levels of energy.

A similar assemblage of trace fossils, typical of shallow-marine environments (shoreface), were de-

scribed by Singh et al. (2008), Paranjape et al. (2014) and Bayet-Goll et al. (2015).

In summary, both ichnological analysis and the presence of bivalves and gastropods point to a well-oxygenated, shallow-marine environment, probably foreshore-middle shoreface.

## 5. Palaeogeography

During the Late Cretaceous, in the North Sudetic Basin appeared a mixed fauna typical of both warmer and colder seas, e.g., Tethys Ocean and North Sea (see also Chrzastek & Wojewoda, 2011). The occurrence of the gastropod *Nerinea bicincta*, typical of tropical conditions (Sohl, 1987; Saul & Squires, 1998) in Coniacian sandstones (Żeliszów Quarry) supports this view (see also Scupin, 1912–1913). The North Sudetic Basin was a narrow sea-way between the so-called East Sudetic Island during the early Turonian (Biernacka & Józefiak, 2009) and the Karkonosze-Izera and Orlica-Bystrzyca highs (Chrzastek & Wojewoda, 2011; see also Sudetic islands after Voigt et al., 2008; Olde et al., 2016; Košťák et al., in press). The North Sudetic Basin linked the shelf sea of central Europe to that of the Bohemian Cretaceous Basin (Biernacka & Józefiak, 2009). The study of Coniacian flora, originating from the East and West Sudetic islands and studied by Halamski & Kvaček (2015, 2016) and Kvaček et al. (2015), also hinted at a warm, subtropical climate during the Late Cretaceous in the Sudetes. The finds of tree ferns in the vicinity of Żeliszów and Lwówek also supports this view (Greguš et al., 2013).

According to Milewicz (1997, 1998), the wide areal extent of Coniacian sandstones (widest during the early Coniacian) may be connected with a gradual upward movement of the sea floor from the east (probably during the Subhercynian phase of the Alpine orogeny, *sensu* Stille, 1924; see also Voigt et al., 2004). Sandy deposits prevail in the southeast, whereas marls occur on the northwestern margins of the North Sudetic Synclinorium (see Milewicz, 1979).

At the end of the early Santonian, the sea withdrew from northern Bohemia, Saxony and Lower Silesia. Earlier deposition of Santonian sands, sandstones, mudstones and clays, with coal layers and kaoline, occurred in bays separated by barriers from the open sea, due to regression. Mesohaline conditions at the time is confirmed by the presence of *Cyrena cretacea* (MGUWr-1542s; Fig. 10H) in the Santonian at Rakowice Małe Quarry (see also Scupin, 1912–1913; Alexandrowicz, 1976; Milewicz, 1988).

## 6. Summary and conclusions

In Coniacian quartz sandstones (Żerkowice Member, Rakowice Wielkie Formation) at the Czaple-Nowa Wieś Grodziska and Rakowice Małe quarries (North Sudetic Synclinorium, southwest Poland) a low-diversity assemblage of trace fossils, comprising six ichnogenera, eleven ichnospecies and two compound burrow systems, was identified. Some of these, especially *Gyrochorte* isp., ?*Gyrochorte* isp., *Phycodes* cf. *curvoipalmatum*, *Phycodes* cf. *flabellum*, ?*Phycodes*, *Planolites* cf. *beverleyensis*, ?*Treptichnus* and *Thalassinoides-Phycodes* cf. *palmatus* and ?*Thalassinoides-Phycodes* burrow systems have not been recorded previously from these deposits. Some bivalve and gastropod species were also reported.

Ethologically these trace fossils represent domichnia (*Ophiomorpha*), domichnia/fodinichnia/agrichnia (*Thalassinoides*), pascichnia (*Gyrochorte*, *Planolites*) and fodinichnia (*Phycodes*). The compound burrow systems *Thalassinoides-Phycodes* represent combined dwelling-feeding structures.

In the trace fossil assemblage vertical or inclined burrows prevail, which suggests moderate to high energy conditions. However, the presence of horizontal structures (*Phycodes*, *Gyrochorte* and *Planolites*) and compound burrow systems (*Thalassinoides-Phycodes*) suggests episodes of low hydrodynamic conditions and availability of nutrients for tracemakers (deposit feeders) on the sea floor.

The trace fossils studied are characteristic of the *Skolithos* and *Cruziana* ichnofacies that typify the shallow marine (foreshore-middle shoreface). The sedimentation of the Coniacian sandstones may have taken place in an epicontinental sea, above fair-weather wave base, which is confirmed by the presence of sedimentary structures (planar lamination, trough cross-lamination and ripple marks), as well as a lack of hummocky cross-stratification (HCS).

The assemblage of trace fossils and associated body fossils, such as the gastropod *Nerinea bicincta* and the bivalve *Lima haidingeri* (which probably originate from Żeliszów Quarry) suggest that these sandstones were laid down in a soft-bottom environment, under normal oxygenation and salinity. This interpretation is in agreement with views expressed by Milewicz (1997), who reported a shallow epicontinental basin as the environment for Coniacian sandstones (Żerkowice Member, Rakowice Wielkie Formation).

The present ichnological analyses support the sedimentological reconstruction by Leszczyński (2010), who interpreted the Coniacian sandstones at Rakowice Małe Quarry as bar and storm deposits

and suggested mainly the foreshore-upper shoreface as the former environment. The present study demonstrates that the presence of the more diverse trace fossil assemblage in sandstones from the Czaple-Nowa Wieś Grodziska quarries may suggest deposition of these deposits up to the middle shoreface, comparable to the sandstones at Żerkowice Quarry. Deposition of these sandstones was related to the regression that started after the transgressive peak (late Turonian/early Coniacian) in the North Sudetic Synclinorium. The southeastern part of the basin was uplifted (see Milewicz, 1997).

The presence of the gastropod *Nerinea bicincta*, with warm-water affinities, confirms the view that in the Upper Cretaceous basins of the Sudetes mixed assemblages typical of both Tethys Ocean and North Sea occurred, as previously suggested. However, the occurrence of *Cyrena cretacea* in Santonian deposits underscores mesohaline conditions in the Late Cretaceous sea that started to withdraw from the Sudetes.

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