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Lower Cambrian trace fossils from the Holy Cross Mountains, Poland

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Additional data on the Lower Cambrian ichnotaxa from the Holy Cross Mountains are presented. Nine ichnotaxa are described for the first time from the area, additional descriptions of three known ichnotaxa are supplied, and two ichnotaxa are shown to have extended stratigraphic ranges. Most Lower Cambrian trace fossils belong to the *Cruziana* ichnofacies. The high taxonomic diversity of the Early Cambrian trace fossil assemblages from the Holy Cross Mountains in comparison to the trace fossil assemblages of the Mid- and Late Cambrian of the area is confirmed.

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Key words: Holy Cross Mountains, Lower Cambrian, trace fossils.

INTRODUCTION

Trace fossils were first recognised in the Cambrian rocks of the Holy Cross Mountains over eighty years ago (Czarnocki, 1919). Descriptions of particular ichnotaxa appeared successively since the early 1960s (for details concerning bibliography see Orłowski and Żylińska, 1996).

Throughout the years the collection of Cambrian trace fossils, particularly from Lower Cambrian strata, has considerably increased. In comparison with the specimens presented previously from the Lower Cambrian strata of the area (Orłowski, 1989, 1992), the ichnotaxa described in this paper are represented by few, in many cases only single specimens.

This paper describes ichnotaxa not known previously from the Cambrian rocks of the Holy Cross Mountains, gives additional descriptions of known ichnotaxa, and details their extended stratigraphic ranges (Figs. 1 and 2). Particular attention is given to trace fossils commonly known from younger deep-water environments, those presented in this paper as well as those described earlier by Orłowski (1989) and others (Kowalski, 1978, 1987; Pacześna, 1985).

In relation to ichnotaxonomy we follow here the approach outlined in the International Code of Zoological Nomenclature (*International Commission …*, 1999). Particular ichnotaxa are applied to traces of animal behaviour preserved within strata of different age. Such traces reflect various types of animal behaviour within the sediment, and therefore their morphology often strongly depends on taphonomic processes (Uchman, 1998). As animals belonging to different biotaxa can produce quite similar traces (Seilacher, 1953; Bromley, 1990), ichnotaxa do not reflect phylogenetic relationships between the particular trace makers.

The specimens studied are housed in the Institute of Geology of the University of Warsaw (abbreviated as IGPUW).

LOCALITIES INVESTIGATED

Ociesęki Formation. Localities with the greatest number of trace fossils include the Sterczyna, Jaźwina and Igrzyczna hills, forming the Ociesęki Range, as well as the Leśniakowa Dębina Hill and other outcrops occurring in the vicinity of Ociesęki in the central part of the Klimontów Anticlinorium. At present, the largest accessible outcrop in the area is a small quarry on the northern side of Sterczyna Hill; other outcrops of this formation are temporary ones, though these typically show a rich trace fossil content. Fine-grained, yellow sandstones of the Ociesęki Formation with many bioturbated horizons yield trilobites indicating the Early Cambrian Holmia-Schmidtiellus Zone (Orłowski, 1985*a*, *c*). The trace fossil assemblage is equally rich both in non-arthropod and arthropod trace fossils (Orłowski, 1989, 1992), among them *Phycodes palmatum*,

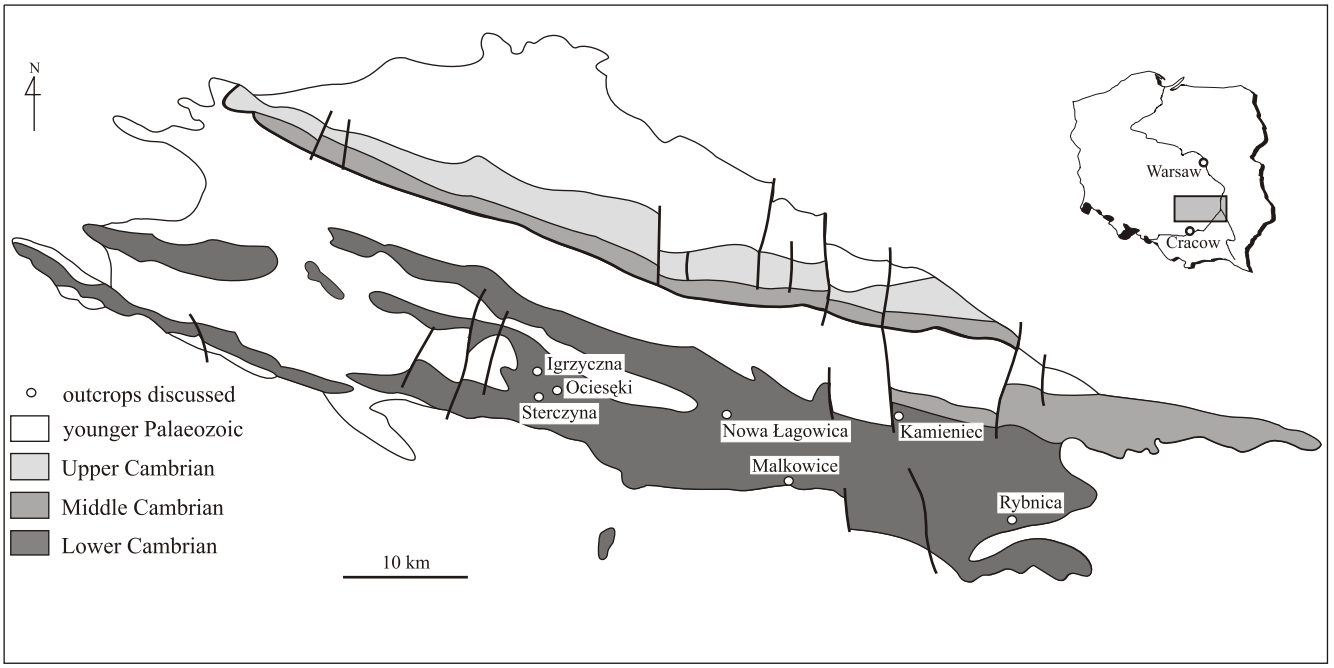

Fig. 1. Geological sketch-map of the Holy Cross Mountains (modified after Orłowski, 1992) with localities of the described trace fossils

Rhizocorallium jenense, *Teichichnus rectus*, *Bergaueria perata*, *Cruziana rusoformis* and *Rusophycus crebrus*. Another outcrop of the same formation, Malkowska Hill near Malkowice, occurs in the eastern part of the Klimontów Anticlinorium, about 8 km south-westwards from Iwaniska in the Wygiełzów Range. Fine-grained sandstones yield few fossils, such as *Schmidtiellus nodosus* and *Holmia* sp., indicating the Holmia-Schmidtiellus Zone, as well as fragments of *Velumbrella czarnockii* and *Rotadiscus* sp. (Orłowski, 1985*a*; Masiak and Żylińska, 1994). Trace fossils include *Halopoa imbricata*. A few specimens of *Diplichnites* isp. were also collected in this part of the Klimontów Anticlinorium near Rybnica in the Koprzywianka River valley, about 2 km south of Nawodzice.

Kamieniec Formation. Trace fossils within this formation are generally rare and represented mainly by *Bergaueria*-type traces. These were collected at Nowa Łagowica, south-east of Łagów and at Kamieniec, north of Konary, both in the eastern part of the Klimontów Anticlinorium, in strata representing the Protolenus-Strenuaeva Zone (Orłowski, 1985*a*). Outcrops in Kamieniec were already known to Jan Samsonowicz in the early 1930s. They occur near the dam on the Koprzywianka River.

OUTLINE OF STRATIGRAPHY

Trace fossils have been collected from various levels of the Lower Cambrian strata of the Holy Cross Mountains, Poland (Fig. 2). Most of the trace fossils presented in this paper occur in the Lower Cambrian part of the Ociesęki Formation. The formation consists of fine-grained, thin- to medium-bedded hard sandstones, with siltstones and rare shale intercalations. Its thickness reaches the greatest values in the central part of the area (up to 1200 m), where it ranges up to the lowermost Middle Cambrian (Orłowski, 1985*b*, 1988). The age of the strata is determined on the basis of trilobites. The lower part of the formation includes *Holmia marginata*, *Kjerulfia orcina*, *Schmidtiellus panovi* and *Strenuella polonica*, indicating the Holmia-Schmidtiellus Zone, while the upper part yields *Ellipsocephalus sanctacrucensis* and *Strenuaeva orlowinensis*, indicating the Protolenus-Strenuaeva Zone (Orłowski, 1985*a*).

Trace fossils are much less frequent in the Lower Cambrian Kamieniec Formation. This formation is limited to the eastern part of the Holy Cross Mountains area and is represented by clayey and silty shales with fine-grained sandstone intercalations. Its thickness reaches about 600 m. Biostratigraphically the strata comprise the upper part of the Holmia-Schmidtiellus as well as the Protolenus-Strenuaeva zones, yielding such trilobites as *Holmia marginata*, *Kjerulfia orcina*, *Micmacca klimontowi* as well as *Protolenus* (*Protolenus*) *expectans*, *P.* (*Latoucheia*) *glabellosus*, *Strenuaeva trifida* and *Serrodiscus primarius* (Bednarczyk *et al.*, 1965; Orłowski, 1985*a*).

SYSTEMATIC DESCRIPTIONS

CIRCULAR STRUCTURES

Bergaueria Prantl, 1945

R e m a r k s . — Cubichnial or domichnial trace fossil, produced probably by suspension-feeders (Fürsich, 1975). *Bergaueria* Prantl is commonly referred to sea-anemones or

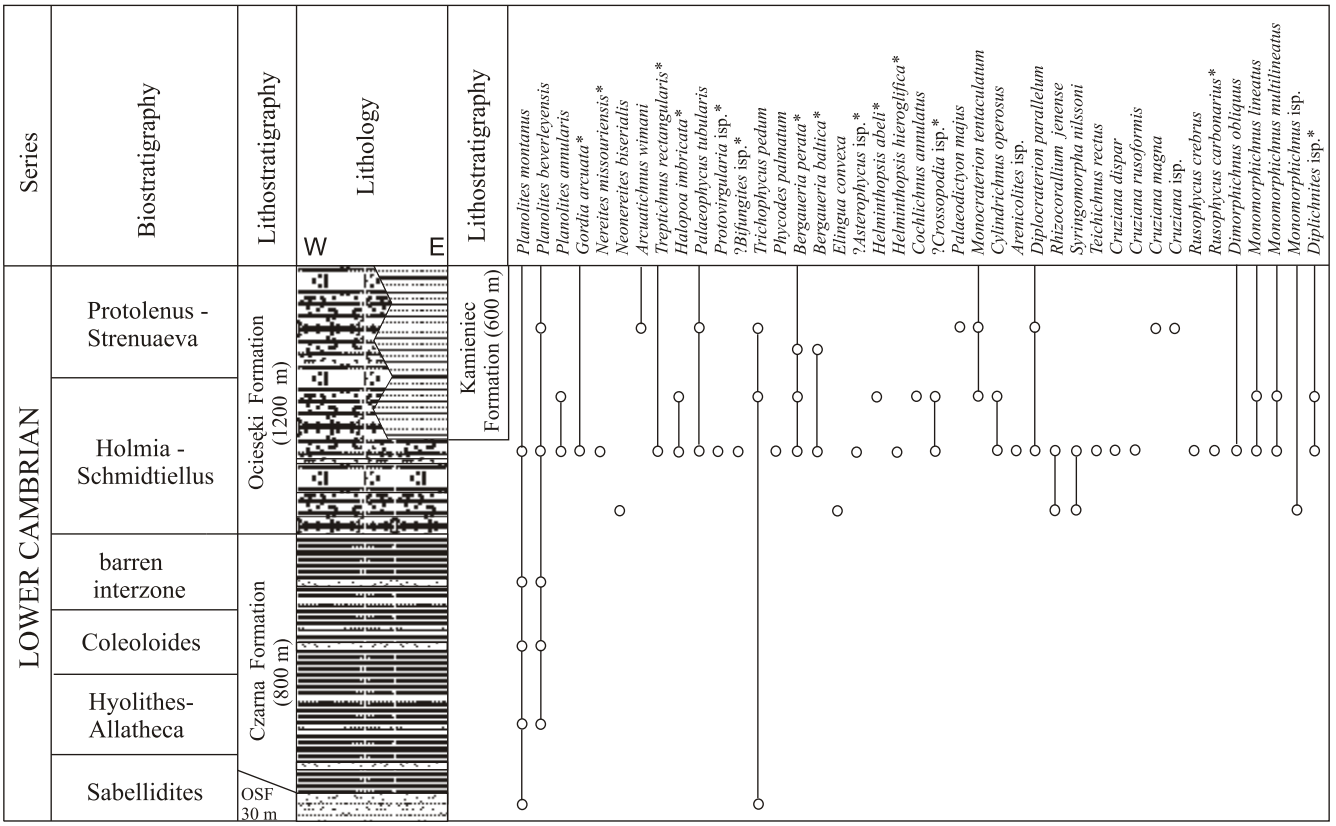

Fig. 2. Stratigraphic ranges of the trace fossils in the Lower Cambrian strata of the Holy Cross Mountains, after Kowalski (1978, 1987), Orłowski (1985*b*, 1989, 1992) and Pacześna (1985)

Trace fossils discussed in this paper are marked with an asterisk; OSF — Osiek Sandstone Formation

sea-pens (Prantl, 1945; Alpert, 1973; Pemberton *et al*., 1988; Seilacher-Drexler and Seilacher, 1999).

Bergaueria perata Prantl, 1945
(Fig. 3a, b)

M a t e r i a l : Five specimens (IGPUW Tf/1/213, 240–243).

D e s c r i p t i o n . — Cylindrical convex hyporeliefs with rounded base bearing a shallow central depression. Single specimens, diameter from 15 to 45 mm. Walls occasionally with rings parallel to bedding planes.

R e m a r k s . — The specimens described occur in strata older than those described previously from the area (Orłowski, 1989), thus extending the stratigraphic range of the taxon in the Holy Cross Mts. The parallel rings present on sides of specimens may result from compaction of sediment.

S t r a t i g r a p h i c d i s t r i b u t i o n . — From the late Precambrian (Crimes, 1987) to the Miocene (Uchman, 1995).

O c c u r r e n c e i n t h e H o l y C r o s s M o u n t a i n s . — Lower Cambrian of the Kamieniec Formation at Nowa Łagowica and Kamieniec (Orłowski, 1989); Lower Cambrian part of the Ociesęki Formation at Sterczyna Hill and Ociesęki; Middle Cambrian Góry Pieprzowe Formation at Kobyla Hill (Orłowski and Żylińska, 1996); Upper Cambrian Wiśniówka and Klonówka formations at the Wiśniówka Duża and Wiśniówka Mała quarries and Krzemionka Hill (Orłowski and Żylińska, 1996).

Bergaueria baltica Pacześna, 1996
(Fig. 3c, f)

M a t e r i a l : Three specimens (IGPUW Tf/1/244, 245, 275).

D e s c r i p t i o n . — Cylindrical convex hyporeliefs with convex lower termination and with regular, broad, slightly convex, well marked margin. The burrows are 10 to 20 mm long and their diameter varies from 20 to 30 mm. The “lobes” on specimen IGPUW Tf/1/275 (Fig. 3c) are apparent.

R e m a r k s . — This ichnospecies differs from *B. perata* in possessing a broad, well visible margin around the central convex part. In this respect the trace is identical to *Bergaueria baltica* Pacześna from northern Poland and the Lublin region (Pacześna, 1996, pl. 1, figs. 2–4). The trace resembles specimens of *B. hemispherica* figured by Crimes *et al.* (1977), which are, however, generally without any ornamentation. Although *Bergaueria*-type trace fossils are typically considered as of sea-anemone origin, those without a central depression (*B. hemispherica* or *B. baltica*) might possibly be of other origin.

S t r a t i g r a p h i c d i s t r i b u t i o n . — Early and Middle Cambrian (Pacześna, 1996).

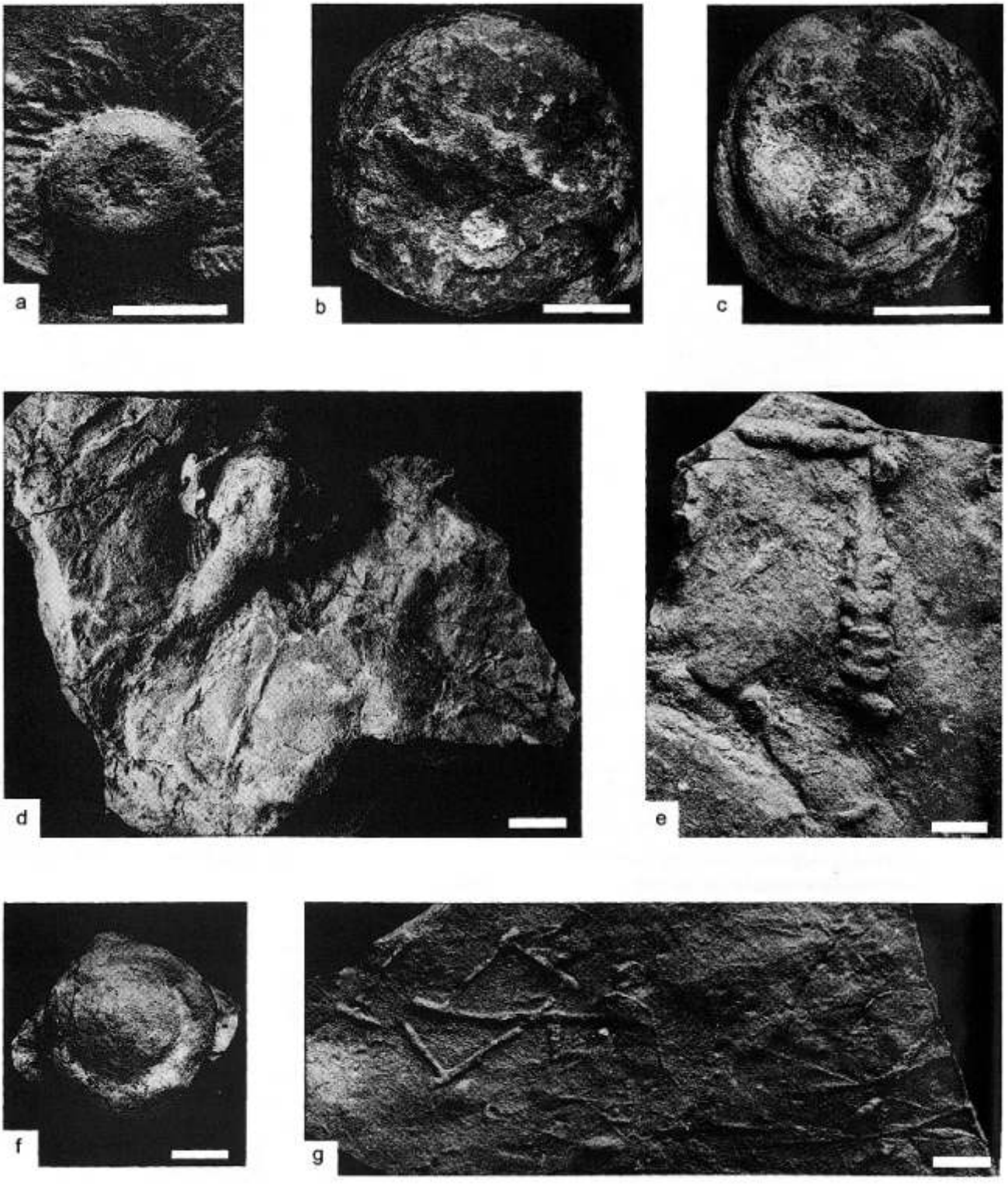

Fig. 3. **a, b —** *Bergaueria perata* Prantl, Lower Cambrian Kamieniec Formation: **a** — IGPUW Tf/1/213, Kamieniec, the radial structures around the trace fossil are preparation marks; **b** — IGPUW Tf/1/240, Nowa Łagowica. **c, f —** *Bergaueria baltica* Pacześna: **c** — IGPUW Tf/1/275, Lower Cambrian part of the Ociesęki Formation, Sterczyna Hill; **f** — IGPUW Tf/1/244, Lower Cambrian Kamieniec Formation, Nowa Łagowica. **d —** ?*Bifungites* isp., IGPUW Tf/1/259, Lower Cambrian part of the Ociesęki Formation, Sterczyna Hill. **e** — *Protovirgularia* isp., IGPUW Tf/1/257, Lower Cambrian part of the Ociesęki Formation, Igrzyczna Hill. **g —** *Treptichnus rectangularis* Orłowski and Żylińska, IGPUW Tf/1/255, Lower Cambrian part of the Ociesęki Formation, Sterczyna Hill. Scale bar 1 cm

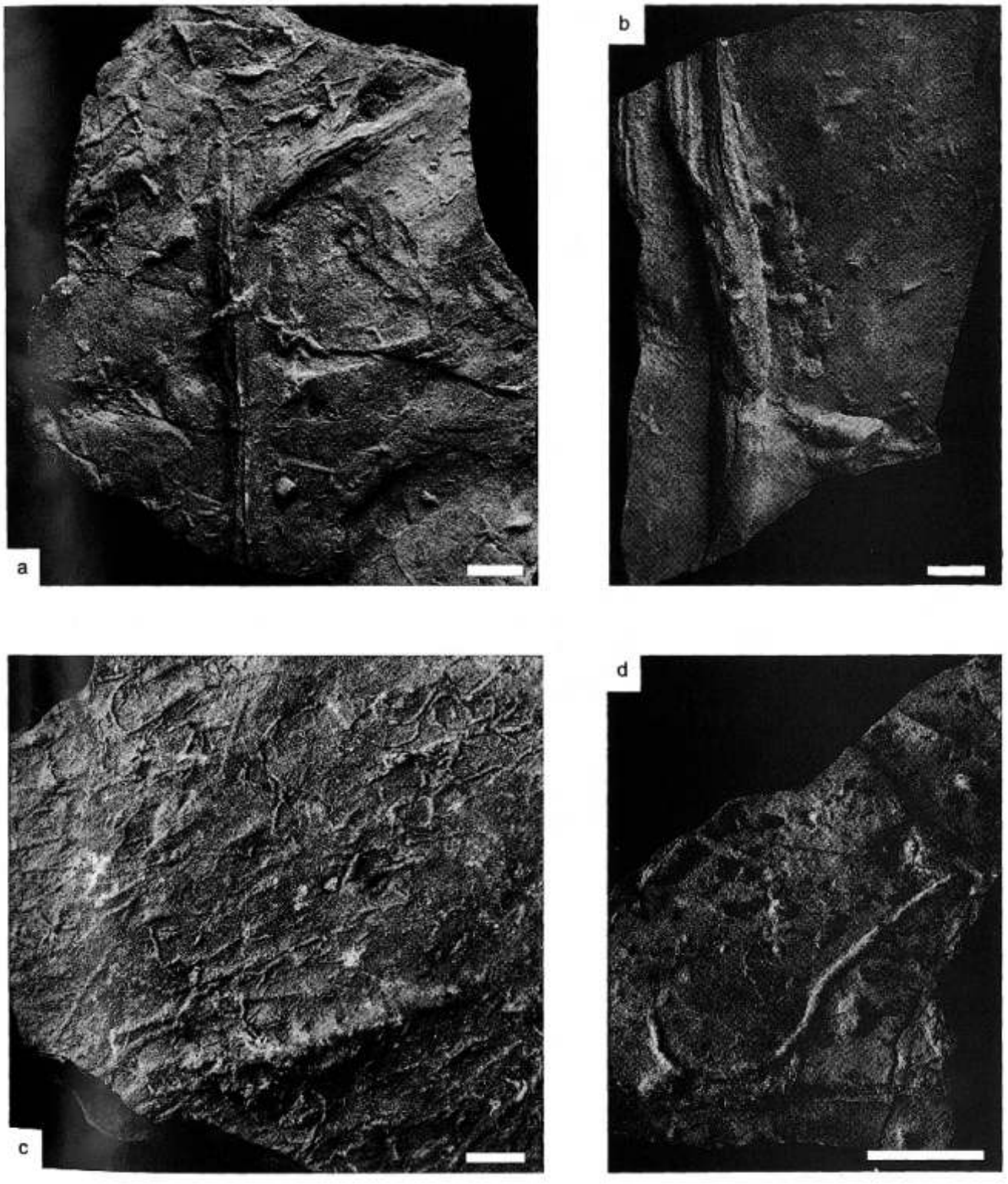

Fig. 4. **a, b —** *Halopoa imbricata* Torell, Lower Cambrian part of the Ociesęki Formation: **a** — IGPUW Tf/1/269, Igrzyczna Hill; **b** — IGPUW Tf/1/271, Ociesęki. **c, d** — *Gordia arcuata* Książkiewicz, Lower Cambrian part of the Ociesęki Formation: **c** — IGPUW Tf/1/262, Igrzyczna Hill; **d** — IGPUW Tf/1/261, Sterczyna Hill. Scale bar 1 cm

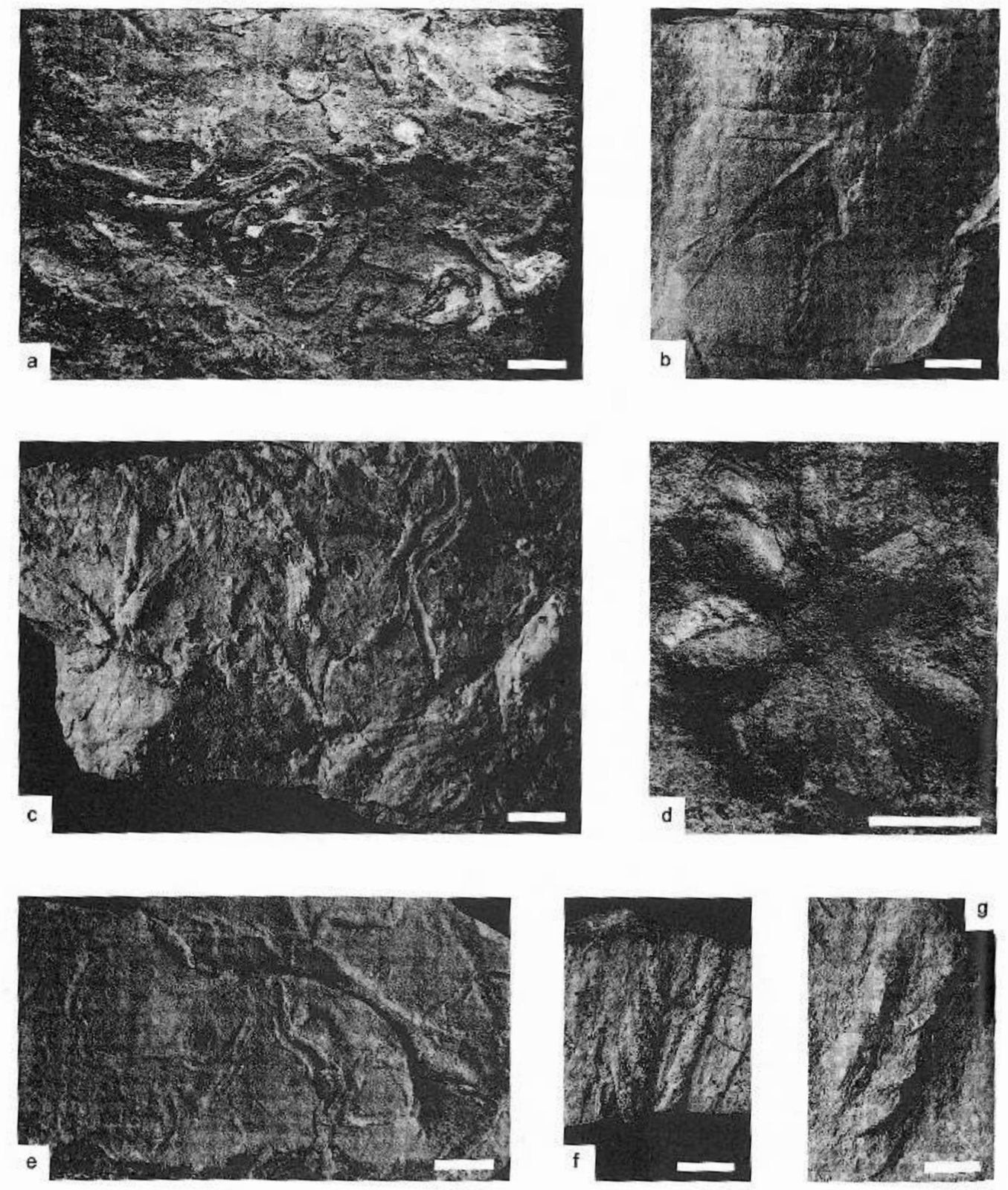

Fig. 5. **a** — *Helminthopsis abeli* Książkiewicz, IGPUW Tf/1/77, Lower Cambrian part of the Ociesęki Formation, Leśniakowa Dębina Hill. **b** — *Nereites missouriensis* (Weller), IGPUW Tf/1/256, Lower Cambrian part of the Ociesęki Formation, Igrzyczna Hill. **c, e —** *Helminthopsis hieroglyphica* Wetzel and Bromley, Lower Cambrian part of the Ociesęki Formation, Sterczyna Hill: **c** — IGPUW Tf/1/248; **e** — IGPUW Tf/1/267. **d —** ?*Asterophycus* isp., IGPUW Tf/1/258, Lower Cambrian part of the Ociesęki Formation, Sterczyna Hill. **f, g —** ?*Crossopodia* isp., Lower Cambrian part of the Ociesęki For-

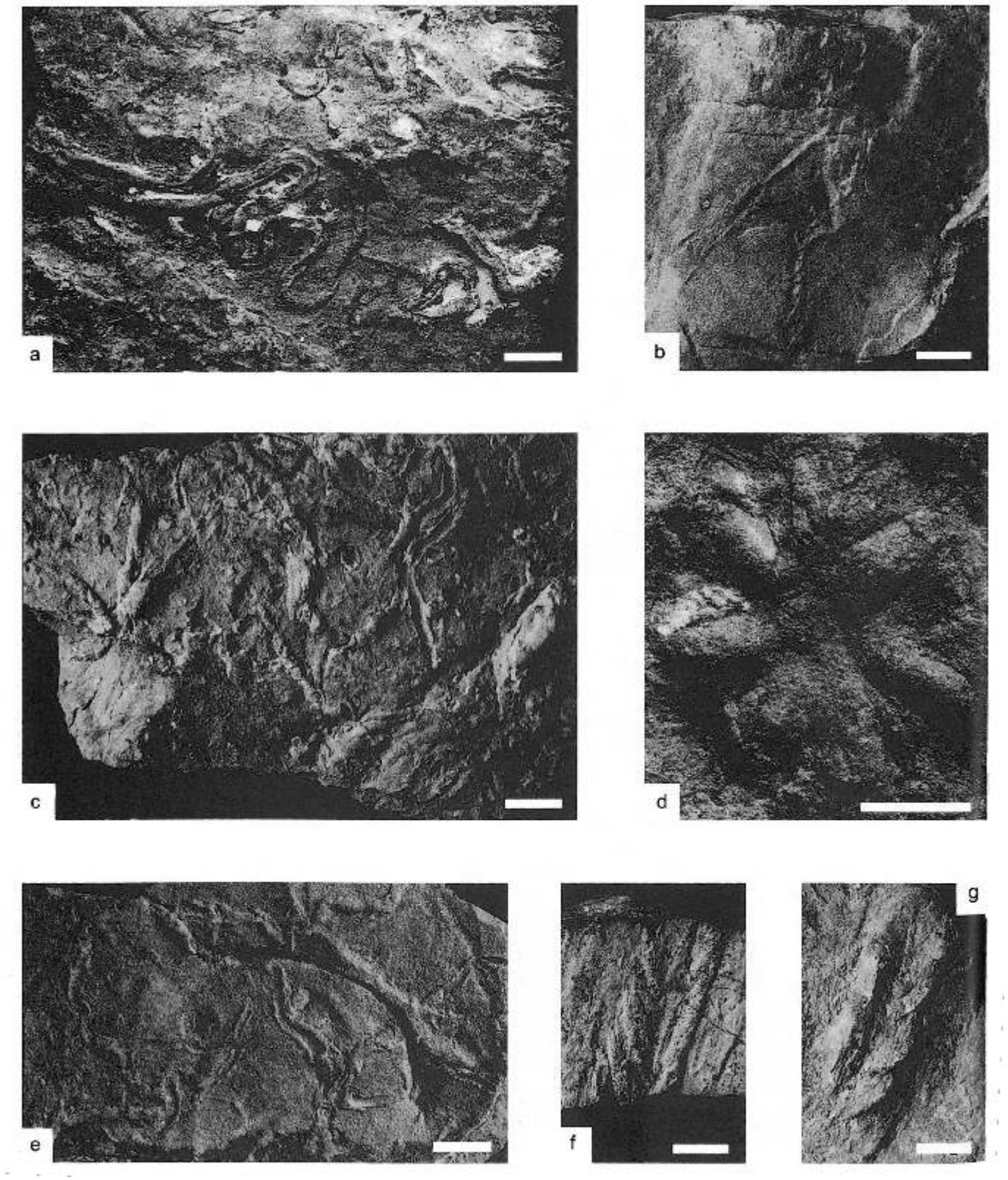

Fig. 6. **a —** *Rusophycus carbonarius* (Dawson), IGPUW Tf/1/250 with five individuals (arrowed) and *Gordia arcuata* Książkiewicz, Lower Cambrian part of the Ociesęki Formation, Sterczyna Hill. **b–d —** *Diplichnites* isp., Lower Cambrian part of the Ociesęki Formation: **b** — IGPUW Tf/1/252, Sterczyna Hill; **c** — IGPUW Tf//253, Rybnica Quarry; **d** — IGPUW/Tf/1/254, Rybnica Quarry. Scale bar 1 cm

Occurrence in the Holy Cross Mountains. — Lower Cambrian part of the Ociesęki Formation at Sterczyna Hill; Lower Cambrian of the Kamieniec Formation at Nowa Łagowica.

SIMPLE AND BRANCHED STRUCTURES

Protovirgularia McCoy, 1850

Remarks. — The trace fossil is regarded as of molluscan origin, and neoichnological experiments have shown that it results from the action of the cleft-foot of protobranchs and scaphopods (Seilacher and Seilacher-Drexler, 1994).

Protovirgularia isp.
(Fig. 3e)

Material: One specimen (IGPUW Tf/1/257).

Description. — Straight cylindrical convex hyporelief, narrowing slightly at one end, with diagonal chevron ribs. The specimen is 20 mm long, 3 mm wide and about 1.5 mm high.

Remarks. — The trace fossil is rather small and incompletely preserved, however, it resembles *Protovirgularia*-type trace fossils with wide chevron marks. It might therefore indicate the early adaptation of molluscs to cleft-foot sediment penetration. Trace fossils representing this taxon display strong morphological variation (Uchman, 1998).

Stratigraphic distribution. — From the Early Ordovician (Fillion and Pickerill, 1990) to the Miocene (D'Alessandro, 1982).

Occurrence in the Holy Cross Mountains. — Lower Cambrian part of the Ociesęki Formation at Igrzyczna Hill.

Bifungites Desio, 1940
?*Bifungites* isp.
(Fig. 3d)

Material: One specimen (IGPUW Tf/1/259).

Description. — Dumbbell-shaped convex hyporelief in the form of a straight oval tube with a rounded and convex structure at its end. The structure seems to extend into the sediment. Specimen partly destroyed, about 40 mm long.

Remarks. — According to Häntzschel (1975), the trace fossil can be interpreted as a cast of a protrusive, U-shaped, spreite-bearing burrow. However, closer examinations have shown that *Bifungites* lacks spreite structures (Gutschick and Lamborn, 1975; Miller, 1979). The complete structure has a shape of an inverted pi (π), which is also partly shown by this specimen. Its incompleteness does not, however, allow a definite assignment.

Stratigraphic distribution. — From the Early Cambrian (Häntzschel, 1975) to the Early Carboniferous (Gutschick and Lamborn, 1975).

Occurrence in the Holy Cross Mountains. — Lower Cambrian part of the Ociesęki Formation at Sterczyna Hill.

Treptichnus Miller, 1889

Remarks. — The trace represents a 3-D burrow system composed of simple or zigzag, straight or curved segments associated with vertical or oblique tubes (Buatois and Mángano, 1993). It ranges from the Early Cambrian (Pacześna, 1989; this paper) to the Eocene (Crimes *et al.*, 1981).

Treptichnus rectangularis Orłowski and Żylińska, 1996
(Fig. 3g)

Material: Two specimens (IGPUW Tf/1/255, 256).

Description. — Horizontal systems of cylindrical elongated units, oval in cross-section, preserved as convex hyporeliefs. Minor units formed as a rule on one side of system. Angle of branching variable, close, however, to right angles. One of the systems contains six units. Distal ends of units slightly thicker and directed toward the sediment surface.

Remarks. — In comparison with the rich and well preserved forms of this ichnospecies from the Upper Cambrian of the Holy Cross Mountains (Orłowski and Żylińska, 1996), the cylindrical units described herein are longer and of smaller diameter. No longitudinal ridges or traces of faecal pellets are present. Priapulid worms, common Cambrian infauna, were possibly responsible for the production of these traces (Orłowski and Żylińska, 1996; Sören Jensen, pers. comm., 1999).

Stratigraphic range. — Early to Late Cambrian (Orłowski and Żylińska, 1996; this paper).

Occurrence in the Holy Cross Mountains. — Lower Cambrian part of the Ociesęki Formation at Sterczyna Hill; Middle Cambrian Słowiec Formation at Konary (Orłowski and Żylińska, 1996); Upper Cambrian Wiśniówka and Klonówka formations at the Wiśniówka Duża, Wiśniówka Mała and Wąworków quarries and at Chabowe Doły (Orłowski and Żylińska, 1996).

Halopoa Torell, 1870

Remarks. — Uchman (1998) showed that the trace is formed as a *Teichichnus*-type pattern, however the particular probes were not exactly vertical and the spreite structure is thus not that regularly developed as in *Teichichnus*.

Halopoa imbricata Torell, 1870
(Fig. 4a, b)

Material: Six specimens (IGPUW Tf/1/267–272).

Description. — Cylindrical, full relief convex hyporeliefs, straight, unbranched, covered by irregular, short wrinkles or longer striae forming a plait structure. Largest specimen is 80 mm long and 10 mm wide.

Remarks. — According to Martinsson (1965), the trace makers of this ichnospecies were mainly epipsammonts digging long trails along a silt surface. However, the trace fossils were rather produced by deposit-feeding organisms, by probing the sediment and pushing out the formerly reworked sediment in older probes (Uchman, 1998), as is testified by deformation of laminae above the trace fossils in cross-section

views. The specimens presented here are rather regular, with a distinct plait structure.

Stratigraphic distribution. — From the Early Cambrian (Jensen, 1997) to the Miocene (Crimes and McCall, 1995).

Occurrence in the Holy Cross Mountains. — Lower Cambrian part of the Ociesęki Formation at the Sterczyna, Igrzyczna and Malkowska hills, and at Ociesęki.

WINDING AND MEANDERING STRUCTURES

Nereites MacLeay, 1839

Remarks. — According to Rindsberg (1994) and Uchman (1995), *Neonereites* Seilacher, along with *Scalarituba* Weller, *Palaeohelminthoida* Ruchholz, and *Helminthoida* Schafhäutl are considered as synonyms of *Nereites* MacLeay.

Nereites missouriensis (Weller, 1899) (Fig. 5b)

Material: One specimen (IGPUW Tf/1/256).

Description. — Irregular, slightly curved chain of oval concave marks, about 40 mm long and 3 mm wide. Concave epirelief.

Remarks. — This ichnospecies is interpreted as a postdepositional, internal burrow developed in the course of grazing within the sediment. *Neonereites* isp. from the Lower Cambrian part of the Ociesęki Sandstone Formation near Chęciny (Kowalski, 1987) is most probably synonymous.

Stratigraphic distribution. — From the late Precambrian (Crimes, 1987) to the Miocene (Uchman, 1995).

Occurrence in the Holy Cross Mountains. — Lower Cambrian part of the Ociesęki Formation at Igrzyczna Hill.

Gordia Emmons, 1844

Remarks. — Fillion and Pickerill (1990) and Pickerill and Peel (1991) have recently discussed the ichnotaxonomy of *Gordia* Emmons. The trace fossil is typically unbranched, winding or irregularly meandering, horizontal.

Gordia arcuata Książkiewicz, 1977 (Figs. 4c, d, 6a)

Material: Four specimens (IGPUW Tf/1/250, 261–263).

Description. — Slender, smooth, of even diameter, curved, thread-like trace fossils, less than 1 mm thick and up to 50 mm long. Single or covering surface with irregular meanders. Convex hyporeliefs.

Stratigraphic distribution. — From the latest Proterozoic to the Oligocene (Walter *et al*., 1989).

Occurrence in the Holy Cross Mountains. — Lower Cambrian part of the Ociesęki Formation of the Sterczyna and Igrzyczna hills; as *Gordia* isp. in the Upper Cambrian Wiśniówka and Klonówka formations at the Wiśniówka Duża and Wiśniówka Mała quarries and at Chabowe Doły (Orłowski and Żylińska, 1996).

Helminthopsis Heer, 1887

Remarks. — The ichnogenus *Helminthopsis* Heer was critically examined by Han and Pickerill (1995), who used the statistical method of "Fourier Transfer Analysis" to distinguish the various ichnospecies. An independent evaluation of the ichnogenus based on Heer's type material (Wetzel and Bromley, 1996) revealed the validity of three ichnospecies out of the earlier described ones. Results obtained from FT Analysis (Han and Pickerill, 1995) were criticised as being based on wrongly produced functions by Wetzel and Bromley (1996, p. 18), who pointed out that Heer's material can be included in *Spirocosmoraphe* Seilacher and *Taphrhelminthopsis* Sacco [= *Scolicia strozzii* (Savi and Meneghini) — see Uchman, 1995, 1998]. However, in order to retain *Helminthopsis* as an ichnogenus, they selected an unillustrated specimen from Heer's collection, determined by him as *Helminthopsis hieroglyphica*, as the holotype of the type species. *Helminthopsis* is a facies-crossing trace fossil, quite common in flysch deposits. It can be preserved in different modes, as a convex hyporelief, semirelief or concave epirelief (Wetzel and Bromley, 1996). Polychaete annelids were probably responsible for the production of such trace fossils, however, priapulids are more likely to have been producers in Cambrian sediments (Książkiewicz, 1977).

Stratigraphic distribution. — Cambrian (Crimes, 1987) to Recent (Wetzel, 1983).

Helminthopsis abeli Książkiewicz, 1977 (Fig. 5a)

Material: Three specimens (IGPUW Tf/1/77, 246, 249).

Description. — Trace fossils in the form of cylindrical, partly empty hypichnial semireliefs, with some parts collapsed, with smooth walls, with meanders irregular and variable in shape, typically with horseshoe-like turns, occasionally with some parts of the trace fossil straight within the wide open meanders. The diameter of the trace fossil is 2 to 3 mm, length exceeds 100 mm. In collapsed segments a tube wall, about 0.2 mm thick, is visible.

Remarks. — Wetzel and Bromley (1996) have shown the validity of this ichnotaxon. The tube wall is most probably the outer zone of a two-zoned burrow fill, and can be considered as a mantle (*sensu* Bromley, 1990, and Keighley and Pickerill, 1994), thus not a true burrow wall. It was probably made by a deposit-feeding organism during its passage through the substrate.

Occurrence in the Holy Cross Mountains. — Lower Cambrian part of the Ociesęki Formation at Leśniakowa Dębina Hill and at Ociesęki.

Helminthopsis hieroglyphica Wetzel and Bromley, 1996 (Fig. 5c, e)

Material: Three rock slabs with about twenty specimens (IGPUW Tf/1/248, 249, 267).

Description. — Simple, elongate, non-branched semireliefs with irregular low-amplitude windings, of small diameter. Windings are composed of low-angle kinks and

straight sections giving the trace an appearance of a box-shaped fold. Trace fossils 2–3 mm in diameter and up to 30 mm long.

Occurrence in the Holy Cross Mountains. — Lower Cambrian part of the Ociesęki Formation at Sterczyna Hill.

BILOBATE TRACES

Crossopodia M'Coy, 1851
?*Crossopodia* isp.
(Fig. 5f, g)

Material: Two specimens (IGPUW Tf/1/265, 266).

Description. — Straight convex endoreliefs consisting of two rows of branches of dense ribs, directed diagonally to a broad median furrow separating the rows. The specimens are about 40 mm long and 15 mm broad.

Remarks. — The ichnotaxonomic relationship of this trace fossil is rather unclear (Maples and Suttner, 1990), however, the most characteristic feature, which differs this material from other ichnogenera, are the ribs separated from each other by a broad median furrow. The ribs originated probably as a result of backfill activities, thus resembling *Psammichnites* Torell.

Stratigraphic distribution. — Early Cambrian (Crimes, 1992) to Carboniferous (Häntzschel, 1975; Maples and Suttner, 1990).

Occurrence in the Holy Cross Mountains. — Lower Cambrian part of the Ociesęki Formation of the Sterczyna and Leśniakowa Dębina hills.

RADIAL STRUCTURES

Asterophycus Lesqueraux, 1876
?*Asterophycus* isp.
(Fig. 5d)

Material: One specimen (IGPUW Tf/1/258).

Description. — Radial convex epirelief, about 30 mm in diameter, oval, consisting of seven ribs radiating regularly from central area, being the termination of a vertical shaft. Each rib is from 10 to 15 mm long, about 4 mm broad, regular, semioval in cross-section, outer terminations plunged into the sediment.

Remarks. — The systematic position of this trace fossil is not clear. Ichnogenera interpreted as ribs radiating around a vertical shaft include *Asterichnus* Bandel, *Asterophycus* Lesqueraux, *Asterosoma* von Otto, *Stelloglyphus* Vialov and *Volkichnium* Pfeiffer (Häntzschel, 1975). *Asterichnus* sp. and *Volkichnium volki* Pfeiffer were described from the Upper Cambrian of the area (Orłowski and Żylińska, 1996). In comparison to the analysed specimen the central area in those taxa is less pronounced and the ribs radiate in a more random pattern. *Stelloglyphus* Vialov is characterised by densely spaced and overlapping ribs, petaloid in outline (Häntzschel, 1975). The analysed specimen comprises seven regular, evenly broad smooth ribs radiating from a vertical shaft, terminating in the central area. It is thus closest to *Asterophycus* Lesqueraux, the number of ribs, however, followed by the lack of longitudinal wrinkles within them and the rather small diameter of ribs in cross-section, distinguish the specimen studied from the known specimens of *Asterophycus*, e.g. *A. coxii* (Häntzschel, 1975) or *Asterophycus* sp. (Bandel, 1967). *Asterophycus* was probably made by worm-like animals or crustaceans (Bandel, 1967).

Stratigraphic distribution. — ?Early Cambrian (this paper) and Early Carboniferous (Häntzschel, 1975).

Occurrence in the Holy Cross Mountains. — Lower Cambrian part of the Ociesęki Formation at Sterczyna Hill.

TRACES OF ARTHROPOD ORIGIN

Rusophycus Hall, 1852

Remarks. — This bilobed trace is typically interpreted as a resting trace of trilobites and related arthropods.

Rusophycus carbonarius (Dawson, 1864)
(Fig. 6a)

Material: One slab with five individuals (IGPUW Tf/1/250).

Description. — Small, oval coffee-bean-shaped convex hyporeliefs, consisting of two slightly convex lobes, separated by a straight, narrow furrow visible on the whole length of the trace. Very fine striations, not extending beyond lobes, are visible only on one specimen. Length of traces 3 to 5 mm, width 2 to 3 mm.

Remarks. — Small coffee-bean-shaped trace fossils, of arthropod origin, are widely known from Cambrian and younger strata. According to Keighley and Pickerill (1996), coffee-bean-shaped trace fossils without transverse striations can be considered as taphonomic variants of striate specimens (typically *R. carbonarius*) and are here referred to as such.

Stratigraphic distribution. — From the Early Cambrian to the Triassic (Keighley and Pickerill, 1996).

Occurrence in the Holy Cross Mountains. — Lower Cambrian part of the Ociesęki Formation at Sterczyna Hill.

Diplichnites Dawson, 1873
Diplichnites isp.
(Fig. 6b–d)

Material: Three specimens (IGPUW Tf/1/252–254).

Description. — Concave epireliefs, about 100 mm long, consisting of two parallel rows of narrow depressions slightly curved in the same direction. Each row generally contains 10 depressions, about 10 mm long. In one case (IGPUW Tf/1/254, Fig. 6d) the depressions are filled with finer sediment. The distance between the two rows is about 15 mm.

Remarks. — The trace fossils are interpreted as marks of arthropod limbs cutting through the substrate along with its deformations caused by the animal. The most characteristic feature of the trace fossils is a short distance between the rows. This suggests that the depressions could be produced by the basal parts of limbs of a trilobite or another arthropod. Similar

trace fossils were recently described from the Yu'anshan Formation in Chengjiang, China (Zhu, 1997).

Stratigraphic distribution. — Common in Palaeozoic strata, but in a broad concept of the ichnogenus recognised also in the Triassic (Machalski and Machalska, 1994 and references therein).

Occurrence in the Holy Cross Mountains. — Lower Cambrian part of the Ociesęki Formation at Sterczyna Hill and Rybnica Quarry; Upper Cambrian Wiśniówka Formation at the Wiśniówka Duża Quarry (Orłowski, 1992).

DISCUSSION

Early Cambrian trace fossil assemblages from the Holy Cross Mountains show a considerably high taxonomic diversity (Kowalski, 1978, 1987; Pacześna, 1985; Orłowski, 1989, 1992) in comparison to those characterising the Mid- and Upper Cambrian of the area (Orłowski, 1992; Orłowski and Żylińska, 1996). They include simple trace fossils, e.g. simple and branched structures (*Planolites*, *Gordia*, *Treptichnus*) and cylindrical structures (*Bergaueria*), as well as much complex forms, e.g. meandering traces (*Helminthopsis*, *Cochlichnus*), vertical spreite forms (*Syringomorpha*), radial structures (*Asterophycus*) and networks (*Paleodictyon*), revealing diverse sediment penetration patterns (Kowalski, 1978, 1987; Pacześna, 1985; Orłowski, 1989, 1992). Most of the traces represent the *Cruziana* ichnofacies (Seilacher, 1967; Frey and Seilacher, 1980), however there are also individual representatives of the *Nereites* ichnofacies, e.g. *Helminthopsis* or *Paleodictyon*. *Protovirgularia* occurs both in the *Cruziana* and *Nereites* ichnofacies. The Ociesęki Formation, which yields numerous representatives of the two ichnofacies, comprises fine-grained, strongly bioturbated inner shelf sandstones. The *Nereites* ichnofacies in turn is characteristic of environments with sedimentation mostly from suspension (Seilacher, 1967) on an outer shelf and slope. The co-occurrence of trace fossils of these two ichnofacies within deposits of the inner-shelf confirms that post-Cambrian deeper water sediment penetration patterns appeared in shallow marine environments of the Early Cambrian (Hofmann and Patel, 1989).

Representatives of the genera *Helminthopsis*, *Paleodictyon*, *Gordia* and *Protovirgularia* have also been recognised in the Tertiary Carpathian flysch (Książkiewicz, 1977; Uchman, 1998). Obviously, the producers of Cambrian and Tertiary traces did not represent the same genus or species, but also most probably might have belonged to different orders. However, they had similar behavioural patterns, which developed in Early Cambrian or even Precambrian shallow-water environments (Crimes and Anderson, 1985; Hofmann and Patel, 1989; Crimes and Fedonkin, 1994; Orłowski and Żylińska, 1996). The appearance of such patterns is expressed by a high taxonomic diversity of trace fossils, to be followed by its decrease at the beginning of the Middle Cambrian (Crimes, 1992). The colonisation of deep-sea environments by trace-making organisms was delayed until the Early Ordovician (Crimes *et al.*, 1992; Crimes and Fedonkin, 1994), resulting likewise as an increase in ichnogeneric diversity.

The extremely low taxonomic diversity and content of trace fossils within the Czarna Shale Formation (Orłowski, 1989, fig. 2) might either be a result of sedimentation in oxygen-depleted environments or a consequence of poor fossilisation potential of trace fossils in shaly facies.

CONCLUSIONS

1. Nine ichnotaxa supplement the list of Lower Cambrian trace fossils from the Holy Cross Mountains. These include representatives of the genera ?*Asterophycus*, *Bergaueria*, ?*Bifungites*, ?*Crossopodia*, *Halopoa*, *Helminthopsis*, *Protovirgularia* and *Rusophycus*.

2. Most Lower Cambrian trace fossils from the Holy Cross Mountains represent the *Cruziana* ichnofacies; they are, however, accompanied by singular specimens of ichnotaxa from the *Nereites* ichnofacies.

3. In comparison with the Mid- and Late Cambrian trace fossil assemblages from the Holy Cross Mountains, those from the Lower Cambrian of the area are characterised by a higher ichnotaxonomic diversity.

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