Trace fossils from Late Carboniferous storm deposits, Upper Silesia Coal Basin, Poland

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Eighteen ichnospecies (two new) referred to 17 ichnogenera (one new) as well as formally unclassified equilibrichnia, fugichnia and faecal pellets constitute a diverse and well-preserved invertebrate trace fossil suite present in storm deposits within the Franciszka X marine horizon of the Hrušov Beds (Late Carboniferous Namurian A, Pendleian) as exposed in the Kozłowa Góra quarry, Upper Silesia, Poland. The new forms are *Fimbritubichnus biserialis* igen. et isp. n., which is interpreted as the work of a deposit-feeding bellerophont gastropod, and *Cylindrichnus candelabrus* isp. n. An emended diagnosis of the ichnospecies *Parahaentzschelinia ardelia* is given. Presence of the trace fossils marks a marine influence, so that they can be utilized to discern marine versus nonmarine deposition within the Paralic Series of the Upper Silesia Coal Basin in which other paleontological evidence is scanty or lacking.

Key words: Invertebrate trace fossils, storm deposits, Namurian A, Upper Silesia Coal Basin.

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Introduction

Traces of animal activity in sediment provide an effective *in situ* record of either environment or environmental change (Bromley 1996). Reflecting ecological limiting factors that control benthic life, trace fossils record the history of local sedimentation. Hence, ichnological data have been used widely in studies of sedimentary environments and basin evolution (e.g., Mortimore & Pomerol 1991; Savrda 1993; Greb & Chesnut 1996).

Relatively little is known about trace fossils in coal-bearing strata of the Upper Silesia Coal Basin. Głuszek (1995a) described trace fossils from the continental segment of the coal-bearing succession and discussed their potential in sedimentary environment analysis of the continental deposits that are comparatively well worked
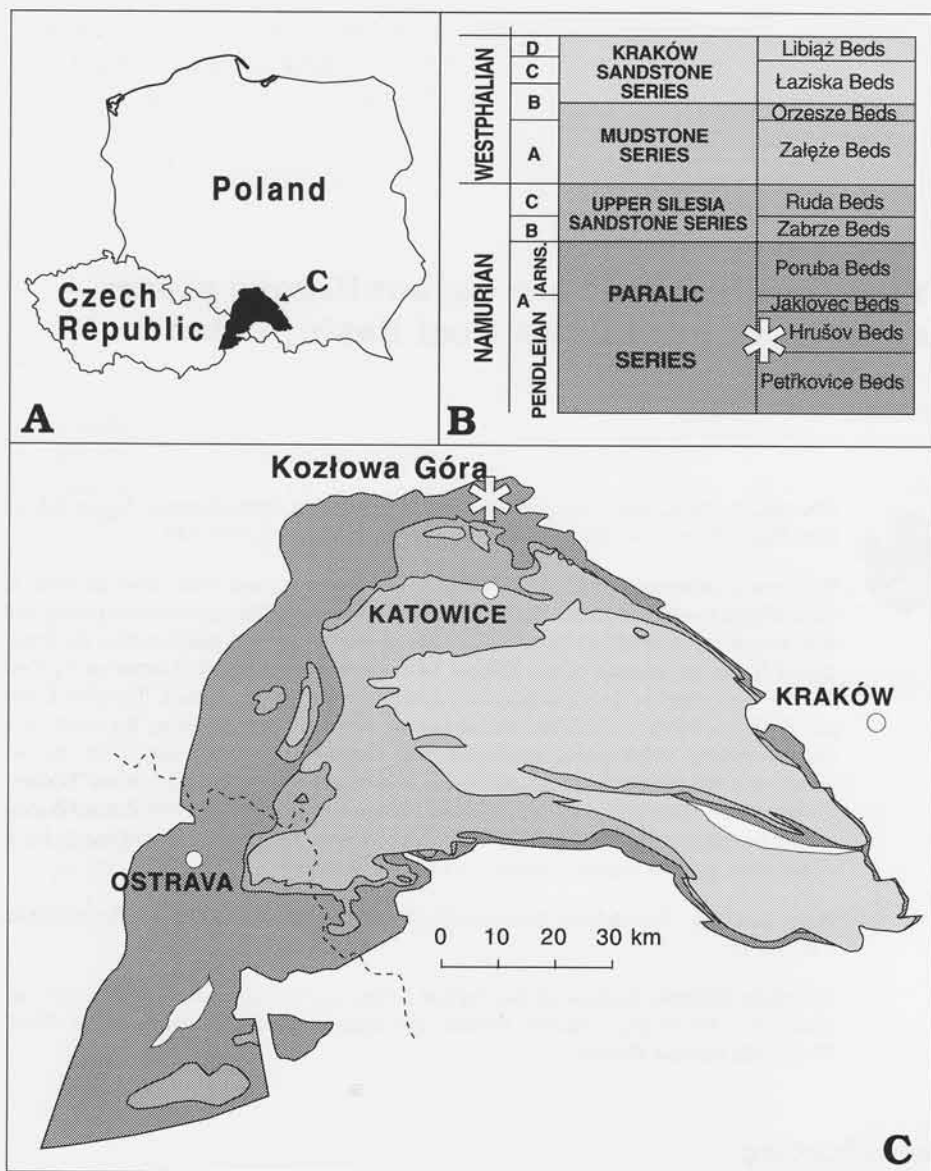
Fig. 1. Graphic and geologic setting of the Kozłowa Góra quarry. **A**. Location map; the Upper Silesia Coal Basin is indicated in black. **B**. Stratigraphy of the Upper Silesia Coal Basin (based on Dembowski 1972); the Kozłowa Góra Section asterisked. **C**. The geologic map of the Upper Silesia Coal Basin with the Kozłowa Góra locality asterisked.

out (Doktor & Gradziński 1985; Gradziński *et al.* 1995). On the other hand, the paralic segment of the succession has not been studied extensively due to its poor exposure. One of the rare surface exposures, the quarry in Kozłowa Góra, has been studied recently revealing the presence of storm deposits and well-preserved trace fossils (Głuszek 1994).

The Kozłowa Góra trace fossils constitute the richest and most diverse assemblage present in marine horizons of the Upper Silesia Coal Basin (Głuszek 1995b). This paper describes and discusses 18 ichnotaxa, with references to other Carboniferous, especially coal-bearing strata, and is thought to constitute the ichnotaxonomical background for further ichnofabric studies in cores.

Geological setting

The Upper Silesia Coal Basin (Fig. 1A–C) represents a Variscan fore-deep basin. The coal-bearing succession is the product of the Namurian A – Westphalian clastic and coal deposition and is up to 8500 m in thickness (Kotas 1994). The succession has informally been subdivided into four main lithostratigraphic units, traditionally named 'series', and further subdivided into 'beds' (Dembowski 1972). The lowest unit, the Paralic Series, contains intercalations of marine deposits. They are mainly recognized in boreholes and coal mines. The surface exposures are rare brick-yard quarries including that of Kozłowa Góra.

The Kozłowa Góra quarry is located in the northern part of the coal basin (Fig. 1C). The marine deposits from former outcrops near the quarry have been reported for a long time owing to a rich marine fauna containing crinoids, brachiopods, bivalves, gastropods of the families Bellerophontidae and Euphemitidae, cephalopods, and trilobites of the genus *Paladin*. The fauna has been collected from the part of the succession that was described recently as storm deposits (Głuszek 1994). The studies of the macrofauna (Roemer 1870; Cramer 1910 *vide* Alexandrowicz 1959; Kuchcińska in Alexandrowicz 1959), forams (Alexandrowicz 1959) and spores (Jachowicz 1959) have shown that the deposits belong to the Franciszka X marine horizon of the Hrušov Beds. According to Kotas (1994), the horizon can be located in the higher part of the Pendleian Stage, Lower Namurian (Fig. 1B).

The storm sequence

The measured section (Fig. 2) consists of marine mudstones, siltstones and sandstones, a paleosol, a coal bed and heterolites. The storm sequence is situated within marine mudstone above a paleosol and a thin coal bed. The first horizon of microhummocky cross-laminated lenses marks the bottom of the sequence. Very fine sandy lenses are up to 15 cm in width and up to 2.5 cm in height. They form individual units within wavy-laminated silty mudstone. Larger lenses occur 60 cm above the bottom of the sequence. They consist of fine to medium sandstone containing shell lags, mud chips and coal clasts. The basal surface of the lenses is apparently erosive and is covered by coarser material, whilst the upper part of the lenses is flat-laminated. Hummocky-cross stratified (*HCS*) sandstone beds form the upper part of the sequence. The tops of these beds are covered with dark mudstone. The total thickness of the storm sequence is 1.5 m.
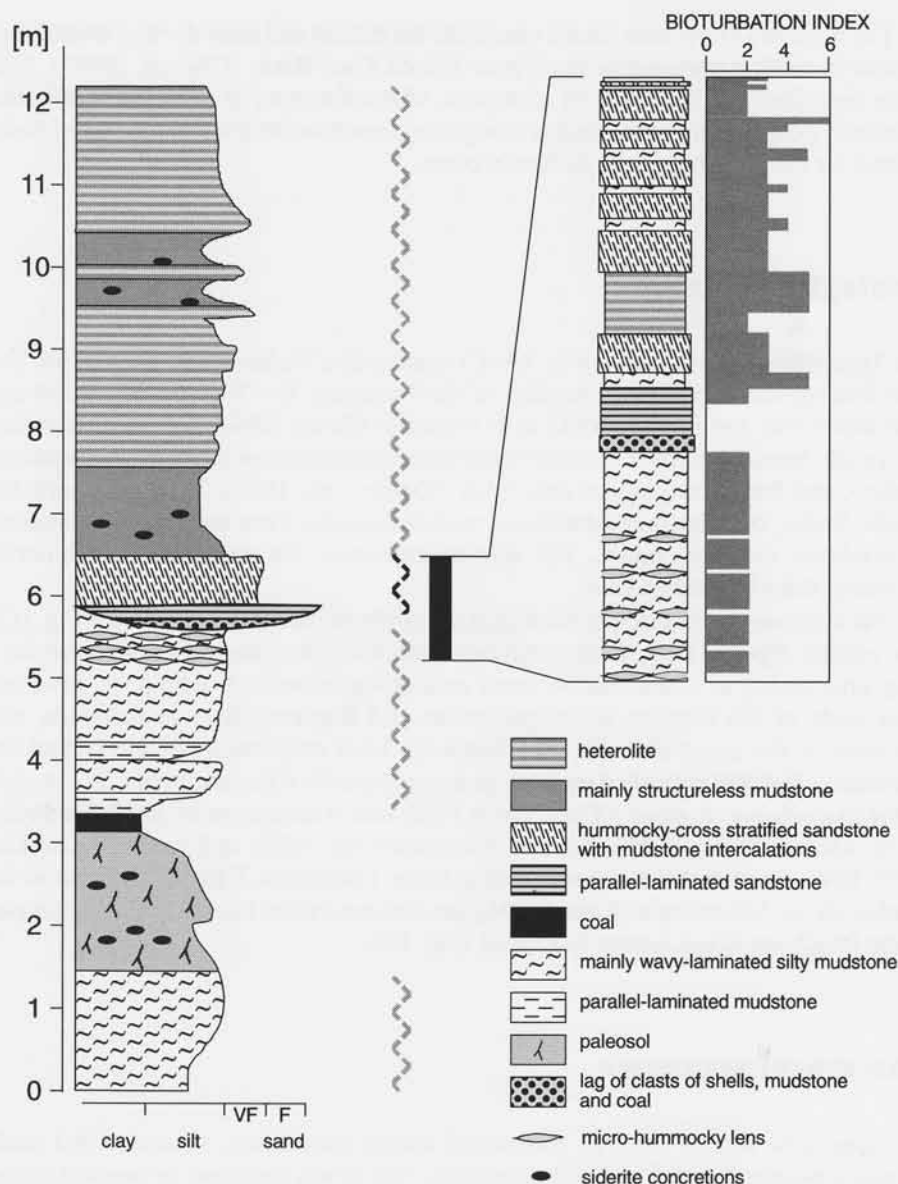
Fig. 2. Kozłowa Góra section. The storm sequence is indicated by the thick black vertical line. The sequence is enlarged to show the variation in intensity of bioturbation using the bioturbation index of Taylor & Goldring (1993). The vertical gray wavy line shows the extent of the *Phycosiphon incertum* dominated assemblage. The black wavy line indicates the level of maximum diversity and density of trace fossils.

Vertical distribution of trace fossils

Trace fossils are variously distributed within the section (Fig. 2). *Phycosiphon incertum,* associated occasionally with *Nereites missouriensis* and *Chondrites intricatus*, are

randomly distributed within mudstone below the paleosol, between the coal bed and the storm sequence, and above the storm sequence. These ichnotaxa appear more commonly in the lowermost part of the storm sequence that contains the micro-hummocky lenses. Additionally, escape and rare equilibrium traces have been recorded there. The greatest diversity of trace fossils is found in the upper part of the storm sequence. All 18 ichnotaxa present in the sequence were found within the 80 cm interval comprising the *HCS* sandstone beds.

The variation in the distribution of trace fossils throughout the storm sequence is reflected by either diversity of ichnotaxa or intensity of bioturbation (Fig. 2). Both diversity and intensity increase towards the top of individual *HCS* sandstone beds, reaching their maxima within the overlying mudstone. This mudstone may be totally bioturbated. The lowermost parts of the *HCS* sandstone beds and the micro-hummocky lenses show zero bioturbation.

The Kozłowa Góra trace fossils were collected in 1991–1994 and are housed in the Museum of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków (abbreviated ZNGPAN, collection A-I-110).

Systematic ichnology

Ichnogenus *Arthrophycus* Hall, 1852
Arthrophycus isp.

Fig. 3A, B.

Material. — Six specimens.

Description. — Single, straight to slightly curved, horizontally or subhorizontally oriented unbranched burrows, preserved either as full relief, concave epirelief or convex hyporelief. The burrow surface is covered with transverse ridges that are commonly rounded but in cross-section show pointed terminations (Fig. 3B). The burrow length is up to 140 mm and its width varies from 10 to 15 mm. The ridge width is 1.5–2 mm; the spacing of the ridges is commonly 3–7 mm. The maximum height of the surface relief reaches 2 mm. The burrow fill does not exhibit any internal structure.

Ichnogenus *Asterichnus* Bandel, 1967
Asterichnus lawrencensis Bandel, 1967

Fig. 3C.

Material. — Six specimens.

Description. — Irregular rosette structure preserved in full relief on bedding planes within sandstone. The structure is composed of rays that are straight to slightly curved, shallow grooves 4 mm in mean width and up to 90 mm long. The grooves are filled with fine mudstone and are enclosed by sandy marginal ridges. Branching is extremely rare but can appear in distal parts of the grooves. The central part of the entire structure is formed by an irregular perforated depression filled with sandstone and mudstone. This is apparently the outlet of the oblique shaft that tapers down its distal part, running at approximately 30 degrees downward in the opposite direction to that of the rays. In cross-section, the oblique shafts are mostly 3 cm long and display a cone-in-cone internal structure. The width of the rosette does not exceed 14 cm. The diameter of the central depression is up to 2 cm. The total number of rays of a single structure varies between 3 and 30.

Remarks. — Bandel (1967) stated that the rays do not branch. He described, however, overlapping of neighbouring structures which may mimic branching (Bandel 1967: p. 3). *Asterichnus* has been recorded only from Carboniferous deposits (Bandel 1967; Chamberlain 1971; Eagar *et al.* 1985;

Seilacher 1990b). Some of the described rosettes are close to *'Zonarites' reticularis* von Sternberg, 1833 from the Ordovician and Devonian of Nevada (Chamberlain 1979) in terms of overall morphology. Bandel (1967) regarded *Asterichnus* as combined feeding and dwelling traces created within sediment along bedding planes by a relatively large organism of unknown systematic position.

Ichnogenus *Asterosoma* Otto, 1854
Asterosoma radiciforme Otto, 1854

Fig. 3D, E.

Material. — A dozen or so incomplete specimens.

Description. — Complex fan-like burrow system preserved in full relief in sandstone bed, rarely in concave epirelief. They consist of tunnels fanning or radiating from a common point. Individual branches exhibit shape of swollen cigars or twisted clubs, commonly with blunt ends. The full relief forms are strongly flattened and resemble sand-stuffed sacks, the thin walls of which are made of dark mudstone. The internal sandy cores are enclosed in barely visible, eccentric sandy laminae. The fill consists of material similar to the surrounding sediment or of slightly darker tone. External wall surface is covered with longitudinal delicate striae. The semirelief forms are composed of a vertical, upwards-expanding, concentrically filled shaft passing into steeply oblique, extended oval grooves fanning upwards. The fan-like structures are up to 10 cm wide. The width of the individual tunnel does not exceed 15 mm, and its maximum length is 50 mm. The average diameter and height of the vertical shaft are 9 and 20 mm respectively.

Discussion. — Externally, *Asterosoma* resembles *Gyrophyllites* Glocker, 1841 which also has stellate burrows with central, vertical shaft, but in the latter ichnogenus these are arranged in more than one level. Thus, *Asterosoma* might be a peculiar, one-level *Gyrophyllites*. Some authors (Eagar *et al.* 1985) have synonymised them, ascribing poorly preserved, one-level stellate burrows from the Namurian to *Gyrophyllites*. The three-dimensional orientation of the whole burrow system seems to be crucial in understanding the ethology of *Asterosoma* producers. Judging from descriptions, it is clear that some authors have regarded *Asterosoma* as a burrow system constructed downwards or, in other words, ramifying from the base of the shaft (e.g., Chamberlain 1971; Häntzschel 1975; Lees 1991). In contrast, Percival (1981), Gregory (1985) and Miller & Knox (1985) have suggested the near-surface formation of the trace with upward expansion. The latter interpretation is supported here. Moreover, the Upper Silesian specimens conform to Gregory's interpretation (Gregory 1985) that *Asterosoma* reflects selective and progressive mining forays from a central dwelling shaft into and through the shallow superficial organic rich layer of muddy sediment. Additionally, Gregory (1985: p. 63) indicated that the central shaft flattens out at depths of 30 cm or so to lie more or less horizontal. Gregory (1985) compared his Tertiary *Asterosoma* with the structure produced by modern crabs. Percival (1981) recovered a tellinid bivalve from one of the units containing *Asterosoma* in the Lower Namurian of northern England. He considered the bivalve to be a producer of *Asterosoma* and referred to the living bivalve *Tellina squalida* as a modern analogue. *Tellina squalida* is a deposit feeder that dwells in a deep vertical burrow, below a siphonal activity zone (compare Bromley 1996: p. 67–68).

A. *radiciforme* has been widely reported from Carboniferous deposits (e.g., Chamberlain 1971; Seilacher 1990b), particularly from the coal-bearing strata (Chamberlain 1971, 1978; Bandel 1967; Miller & Knox 1985; Bjerstedt 1988; Rindsberg 1991; Lees 1991; Greb & Chesnut 1994). It has frequently been described under the name *Asterophycus*.

Ichnogenus *Chondrites* Sternberg, 1833

Remarks: *Chondrites* is one of the commonest ichnotaxa throughout the fossil record. In spite of its long history, the first modern revision was published by Fu (1991). Taking branching pattern into consideration, Fu (1991) reduced over 170 existing ichnospecies to four valid ones: *C. targionii* (Brongniart, 1828), *C. intricatus* (Brongniart, 1828), *C. patulus* Fischer-Ooster, 1858 and *C. recurvus* (Brongniart, 1828). She mentioned, however, that there exist some intermediate forms. The Fu's (1991) revision of *Chondrites* is accepted herein, although ethology of *Chondrites* is as yet far from
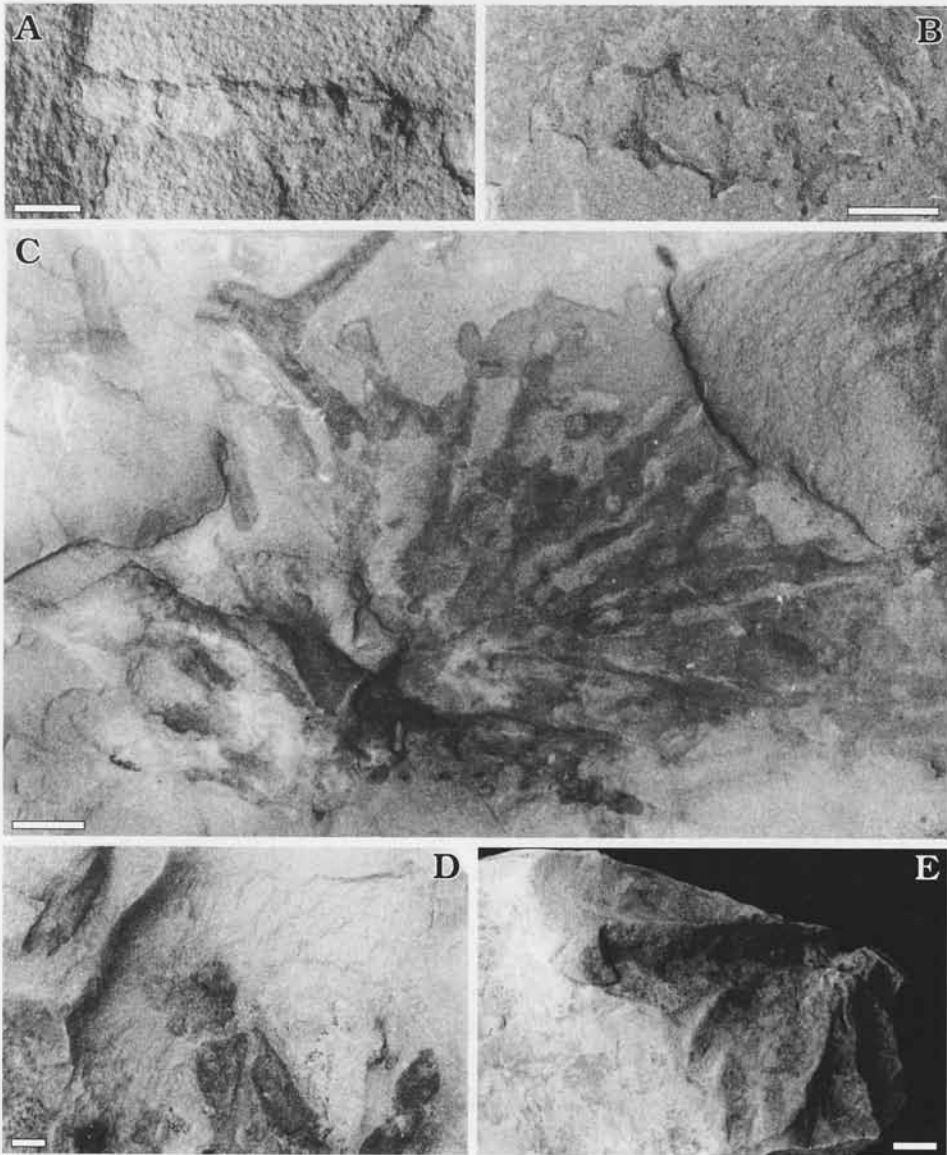
Fig. 3. **A, B.** *Arthrophycus* isp. on bedding plane. **A.** Short horizontal burrow seen in hypichnial view (ZNGPAN A-I-110/069). **B.** Endichnial horizontal burrow with pointed terminations of transverse ridges (ZNGPAN A-I-110/163). **C.** *Asterichnus lawrencensis* (ZNGPAN A-I-110/002) on upper bedding surface, full relief. **D-E.** Top view of *Asterosoma radiciforme*. **D.** Complex fan-like burrow system in bedding plane view (ZNGPAN A-I-110/127), full relief. **E.** A semirelief form with oblique oval grooves fanning upwards from vertical shaft (ZNGPAN A-I-110/098). Scale bars 1 cm.

clear. Four models for the formation of this trace have been proposed so far, namely by Tauber (1949 cited in Häntzschel 1975); by Simpson (1956; modified by Ferguson 1965); by Seilacher (1990a) and by Kotake (1991). Producers of *Chondrites* have been sought among annelids (Tauber 1949 see
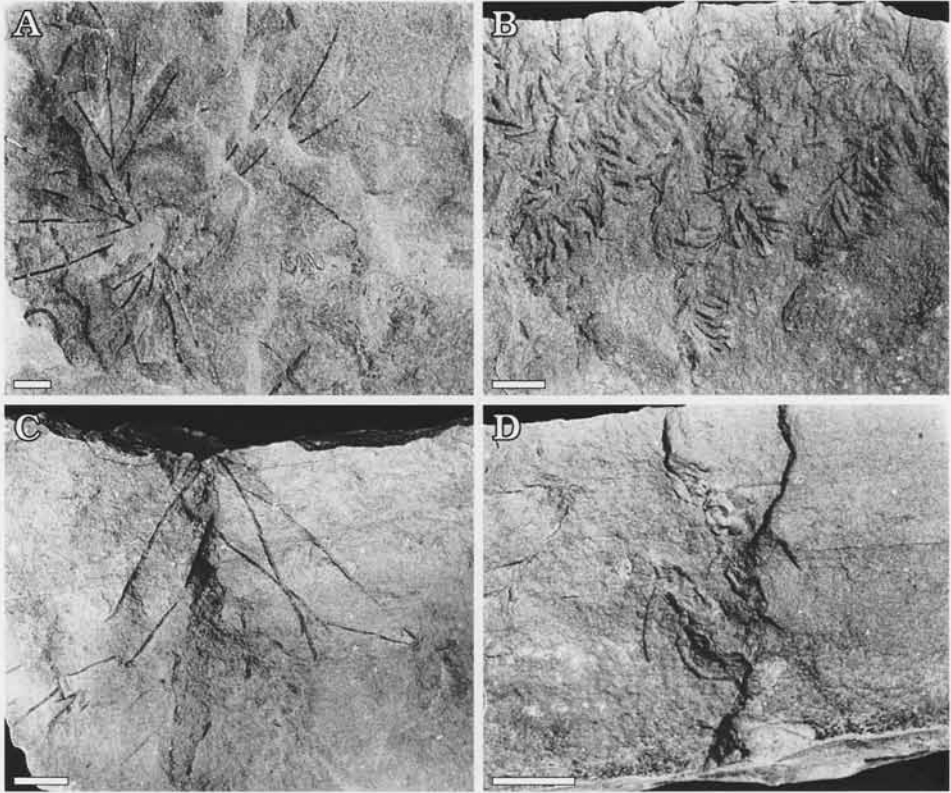
Fig. 4. **A**. *Chondrites intricatus* in bedding plane view (ZNGPAN A-I-110/110), full relief. **B**. *C. recurvus* in bedding plane view (ZNGPAN A-I-110/086), full relief. **C**. Full relief endichnial expression of *C. intricatus* (ZNGPAN A-I-110/110), vertical surface. **D**. Full relief endichnial expression of *C. recurvus* (ZNGPAN A-I-110/098), vertical surface. Scale bras 1 cm.

Häntzschel 1975), sipunculoid worms (Simpson 1956), chemosymbiotic bivalves (Seilacher 1990a), nematodes (Swinbanks & Shirayama 1984), crustaceans (e.g., Ekdale 1992) and sea pens (Bradley 1981).

Chondrites intricatus (Brongniart, 1828)

Fig. 4A, C.

Material. — Several tens of specimens.

Description. — Full-relief, three-dimensional and multi-level root-like burrow structure composed of vertical, oblique and horizontal cylindrical burrows. The vertical elements are composed of bundles of several shafts, each of them branching monopodially at an angle of approximately 45 degrees. The second-order branches, in turn, give rise to initially oblique and then horizontal branches of the third order. The terminations of some of the latter are turned slightly upwards. The horizontal elements radiate around dendritically in some horizons with predominant tendency of clockwise turning. These galleries branch monopodially at a maximum angle of 45 degrees. The branching within the entire burrow system is most commonly of first- or second-order, and sporadically up to fourth-order. All the outgrowths run straight or show a tendency to curve. The maximum observed height of a shaft is 8 cm. The length of either the oblique or the horizontal unbranched part of the gallery is up to 5 cm. The overall diameter of the burrow structure does not exceed 15 cm. The

individual burrow has a constant diameter of 1 mm. The burrows are filled with darker and finer sediment than that of the host rock. There are poorly preserved and sparse menisci hardly visible in the fill structure.

Remarks. — *Chondrites intricatus* from Upper Silesia is distinguished by its larger dimensions and less frequent branching than those defined by Fu (1991). Its multistorey development shows the closest similarities to the model drawn by Bromley (1990: p. 133).

Chondrites recurvus (Brongniart, 1828)

Figs 4B, D, 5 and 11B.

Material. — Twelve specimens.

Description. — Full-relief, multi-storey burrow system consisting of vertical and horizontal segments. Bow-like burrows branch bilaterally into similarly curved outgrowths. Such burrow architecture is present throughout the whole system. The vertical segments curve distally giving access to the extensively developed horizontal segments. The first-order branching is commonly observed; the second-order one is exceptional. The burrows branch monopodially in a very characteristic way. On one side of a gallery or shaft there is a dense concentration of branches which are identically curved running out off the parent stem, whereas those on the other side are sparser and run at more acute angles to and towards the main burrow mimicking the course of their counterparts from the opposite side of the parent burrow (Fig. 5). Cross-sections of the burrows are elliptical and compressed. Long axes of the ellipses change their orientation in relation to bedding. They are vertical in main galleries, then rapidly bend in proximal, short parts of branches to lie almost horizontally. As a result of such organization, parting surfaces mostly show curved branches. The burrows are filled with darker and finer sediment than that of the host rock. The fill structure reveals presence of a dark dust film and hardly visible segmentation. The height of the preserved vertical segment is 4 cm. The length of
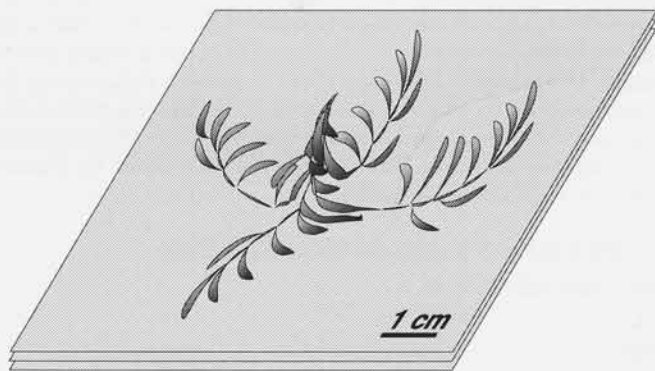

Fig. 5. Idealised spatial development of *Chondrites recurvus*.

horizontal branched gallery and individual branch is up to 3 cm and up to 1 cm, respectively. The entire structure is up to 12 cm wide. The width of single burrow is constant and is 1 mm as measured along the long axis of the cross-section.

Remarks. — Unlike other ichnospecies of *Chondrites*, *C. recurvus* was apparently created by non-cylindrical organism. The state of preservation of *C. recurvus* permits the reconstruction of its spatial appearance (Fig. 5). This ichnospecies commonly co-occurs with *C. intricatus*.

Ichnogenus *Cladichnus* D'Alessandro & Bromley, 1987
Cladichnus isp.

Fig. 6.

Material. — Nine specimens.

Fig. 6. *Cladichnus* isp. cut by *Micatuba* isp. (ZNGPAN A-I-110/144), full relief. Scale bar 1 cm.

Description. — Horizontal, branched, dendritic burrow system preserved in full relief. The burrows show meniscate fill and a very thin, dark wall. The infill material is similar to the host sediment in terms of lithology. Branching is primarily successive. The width of the burrows is from 3 to 5 mm. The length of the branches is up to 35 mm. The total width of the burrow system is up to 10 cm.

Remarks. — A similar dendritic burrow was described by Pedersen & Surlyk (1983) as *Taenidium* ichnosp. Subsequently, D'Alessandro & Bromley (1987) regarded a Pedersen and Surlyk's form as *Cladichnus* with suggestion that it could represent a distinct ichnospecies of *Cladichnus* owing to its root-like branching pattern (D'Alessandro & Bromley 1987: pp. 759–760). Carboniferous *Cladichnus* in coal-bearing deposits were described from the Yoredale facies by Chisholm (1970) (as 'burrowed ironstone nodules') and by Lees (1991).

Ichnogenus *Cylindrichnus* Toots (in Howard), 1966
Cylindrichnus candelabrus isp. n.

Figs 7A–C and 9A.

Holotype: ZNGPAN A-I-110/126 (Fig. 7A) .

Type locality: Kozłowa Góra quarry, Upper Silesia Coal Basin, Poland.

Type horizon: Hrušov Beds, Upper Pendleyian Stage, Lower Namurian, Upper Carboniferous.

Derivation of the name: Latin *candelabrum* – candelabrum, a decorative holder for several candles, as a reference to three-dimensional shape of the burrow.

Material. — Besides the holotype there are two paratypes: ZNGPAN A-I-110/077 and A-I-110/126; and eight additional specimens.

Diagnosis. — U-shaped, upward-branching, cylindrical burrows with central or eccentrically located core surrounded by irregular but concentric layers.

Description. — U-shaped, branching, wide and asymmetric penetrations that are oriented perpendicularly to the bedding plane and preserved as full relief in hummocky cross-stratified, very fine sandstone. The branching arm is directed more obliquely to the bedding surface. The burrow does not deform adjacent sedimentary lamination and is filled with dark mudstone that differs lithologically from the sediment of the host rock. In fact, wall-lining constitutes most of the infill. Pale stripes of coarser grained sediment are visible within the lining. The tiny, inner core of about 0.5 mm in diameter is indistinct and consists of pale silt or sand, but in some cases seems to be a sandy cylinder
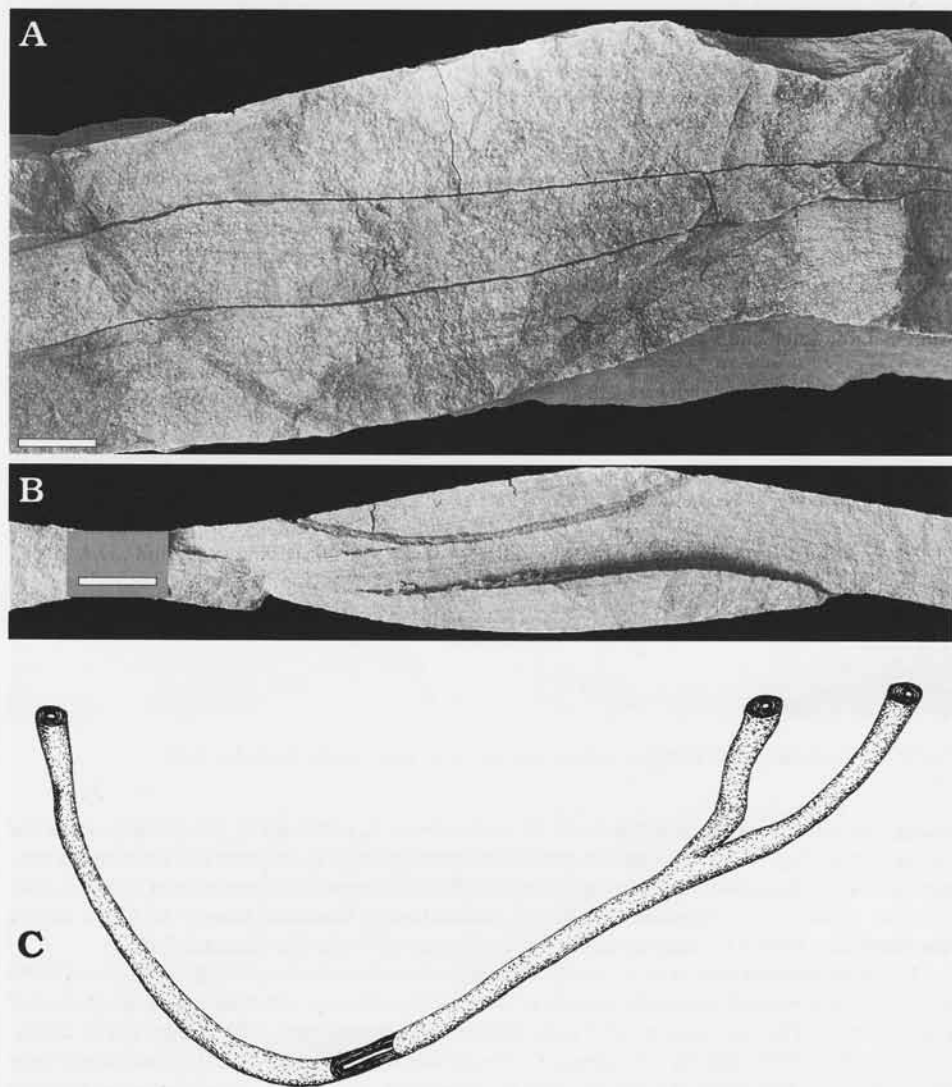
Fig. 7. **A–C.** *Cylindrichnus candelabrus* isp. n. **A.** Full relief endichnial expression of the type specimen (ZNGPAN A-I-110/126). **B.** Full relief endichnial expression of lowermost part of the burrow (ZNGPAN A-I-110/126). **C.** Drawing of *Cylindrichnus candelabrus* isp. n. to illustrate its three-dimensional appearance and internal structure. Scale bars 1 cm.

filled with dark mudstone. In the lower part of some burrows, there are distinct, though incomplete, spreiten lying somewhat obliquely to the burrow margin. The burrows have a circular to oval outline in horizontal cross-sections. Burrow apertures are not preserved and the traces appear to be only the lower part of a structure. The total width of the structure does not exceed 160 mm and its depth reaches 55 mm. The diameter of the lowermost, horizontal part of the burrow varies from 1 to 5 mm and occasionally decreases along the vertical arms.

Discussion. — Concentric lamination attributed to passive infill is present among burrows that have been referred to *Cylindrichnus concentricus* (Goldring 1996). The ichnotaxonomical status of the
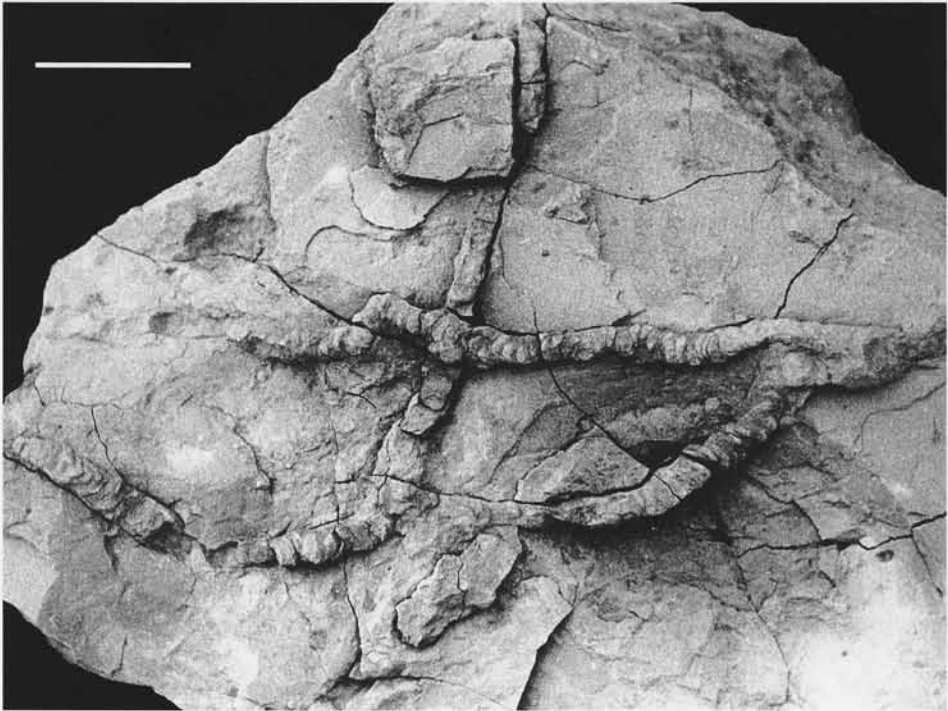
Fig. 8. *'Eione' moniliformis* on upper bedding surface (field photograph). Scale bar 1 cm.

ichnogenus *Cylindrichnus* in general and *C. concentricus* in particular is questionable since the overall morphology is uncertain and the method of construction of *C. concentricus* remains undetermined. A new ichnogenus sould be established to replace this imperfect ichnotaxon or *Cylindrichnus* sould be considered to represent a U-shaped, concentrically laminated burrow of which simple fragments were named *C. concentricus* by Toots (Howard 1966 cited in Häntzschel 1975).

U-shaped burrows similar to *C. candelabrus* have been described by Maples & Suttner (1990) from the Lower Pennsylvanian of Colorado as ?*Teichichnus* ichnosp., whereas those from the Lower Carboniferous of Ireland were referred to as *Arenicolites* ichnosp. type-A (Buckman 1992). Chamberlain (1971) established the ichnogenus *Lanicoidichna* for specimens from Carboniferous strata of the Ouachita Mountains (Oklahoma) that are somewhat similar to *C. candelabrus* in terms of overall morphology but these lack a concentric infill.

C. candelabrus can be interpreted as domichnion of a sessile suspension feeder, a worm feeding on the surrounding detritus, or of an active carnivore waiting in ambush (compare Bromley 1990: p. 171). The development of the composite inner structure points to an analogy with the burrows of the Recent terebellid polychaete *Amphitrite ornata* which feeds on detritus and possibly on bacterial cultures in the burrow wall (Bromley 1990: pp. 54–55).

Ichnogenus *'Eione'* Tate, 1859

Remarks. — According to the rules of the International Zoological Nomenclature (Ride *et al.* 1985), which are accepted in ichnology, biological taxa and ichnotaxa compete for purposes of homonymy (Art. 55a, 56a, 57a). Because the name *Eione* was previously given to a mollusc (*Eione* Rafinesque, 1814), the name of the trace fossil *Eione* Tate, 1859 is a junior homonym and is invalid (Rindsberg 1990b). A new name for the trace fossil together with a thorough descrip-

tion based on neotypical material from the type locality will be published shortly (John Pollard personal communication 1997).

'Eione' moniliformis Tate, 1859

Fig. 8.

Material. — Several tens of specimens.

Description. — Relatively large burrows with intricate internal structure preserved as full relief. Straight to winding, cylindrical to quadrate burrows run parallel or to some extent oblique to bedding which is occasionally undulose. A mutual crossing of burrows lying in the same horizon is common. The longest observed individual burrow does not exceed 31 cm. The width of the burrow is typically 1.0 cm with the maximum of 1.5 cm. The burrows possess a thin muddy lining. The infill consists of a single row of sandy discs that are inclined towards the common direction or lie flat. The discs usually overlap resulting in imbrication and, in consequence, the upper surface of a burrow exhibits the annulation. The sediment of the disc-like lumps is similar to that of the host rock though it is frequently paler. The branching has not been detected.

Remarks. — *'Eione'* is interpreted as the burrow of a worm-like, deposit-feeding, endobenthic animal that actively backfilled its burrow (Lees 1991). *'Eione'* has been described from the Dinantian Yoredale deposits of northern England (Tate 1859; Lees 1991) and from the lower Pennsylvanian Fountain Formation of Colorado (Maples & Suttner 1990). Very similar forms, but under different names, have been reported from other Carboniferous strata: the Pennsylvanian Minturn Formation of Colorado (Lockley *et al.* 1987), the Mississippian of Indiana (Archer 1984) and Alabama (Rindsberg 1994) and the Lower Carboniferous of Sinai (Seilacher 1990b).

Ichnogenus *Fimbritubichnus* igen. n.

Derivation of the name: Latin *fimbriae* – fringes; *tuba* – tube.

Type ichnospecies: *Fimbritubichnus biserialis* isp. n.

Diagnosis. — Loosely meandering, unbranched burrow consisting of a central, cylindrical core surrounded by pellets.

Fimbritubichnus biserialis isp. n.

Figs 9A–E, 10.

Holotype: ZNGPAN A-I-110/108 (Fig. 9A).

Type locality: Kozłowa Góra quarry, Upper Silesia Coal Basin, Poland.

Type horizon: Hrušov Beds, Upper Pendleyian Stage, Lower Namurian, Upper Carboniferous.

Derivation of the name: Latin *bi-series* – having two rows.

Material. — Besides the holotype there are the paratypes ZNGPAN A-I-110/113, A-I-110/127 (Fig. 9B–C), A-I-110/130 (Fig. 9D) and A-I-110/150, and tens of other specimens.

Diagnosis. — *Fimbritubichnus* with bilateral arrangement of pellets the long axes of which lie perpendicularly or obliquely to burrow axis.

Description. — Loosely meandering, unbranched, horizontal burrow, preserved as full relief. It consists of the central, cylindrical, externally, thickly lined cord of pale sediment, and two rows of more or less regularly arranged elongate, mostly rod-like pellets, whose long axes lie perpendicularly or obliquely to the burrow axis. The lined core shows a longitudinal depression and faint transverse striation which continues into the pellet zones. The burrows show presence of stacking pattern of the pellet rows. A maximum of 4 storeys in such a row were observed (Fig. 10). The total width of the burrow is 10 mm and is relatively constant. The diameter of the central core is 2 to 3 mm. The uniform pellets are approximately 1.5–2.0 mm long and 0.5 mm in diameter. The burrows are up to 10 cm in length and occur in the top parts of the tempestite beds.

Discussion. — Baird *et al.* (1986: fig. 2) showed a drawing of a trace fossil that could represent *Fimbritubichnus biserialis* but it was neither described nor commented upon. Hypothetical hyporelief of *F. biserialis* would bear resemblance to *Curvolithus* Fritsch, 1908 (e.g., Heinberg 1970; Dam 1990) whereas epirelief can easily be mistaken for some forms of the *Scolicia* 'group' such as *Archeonassa*
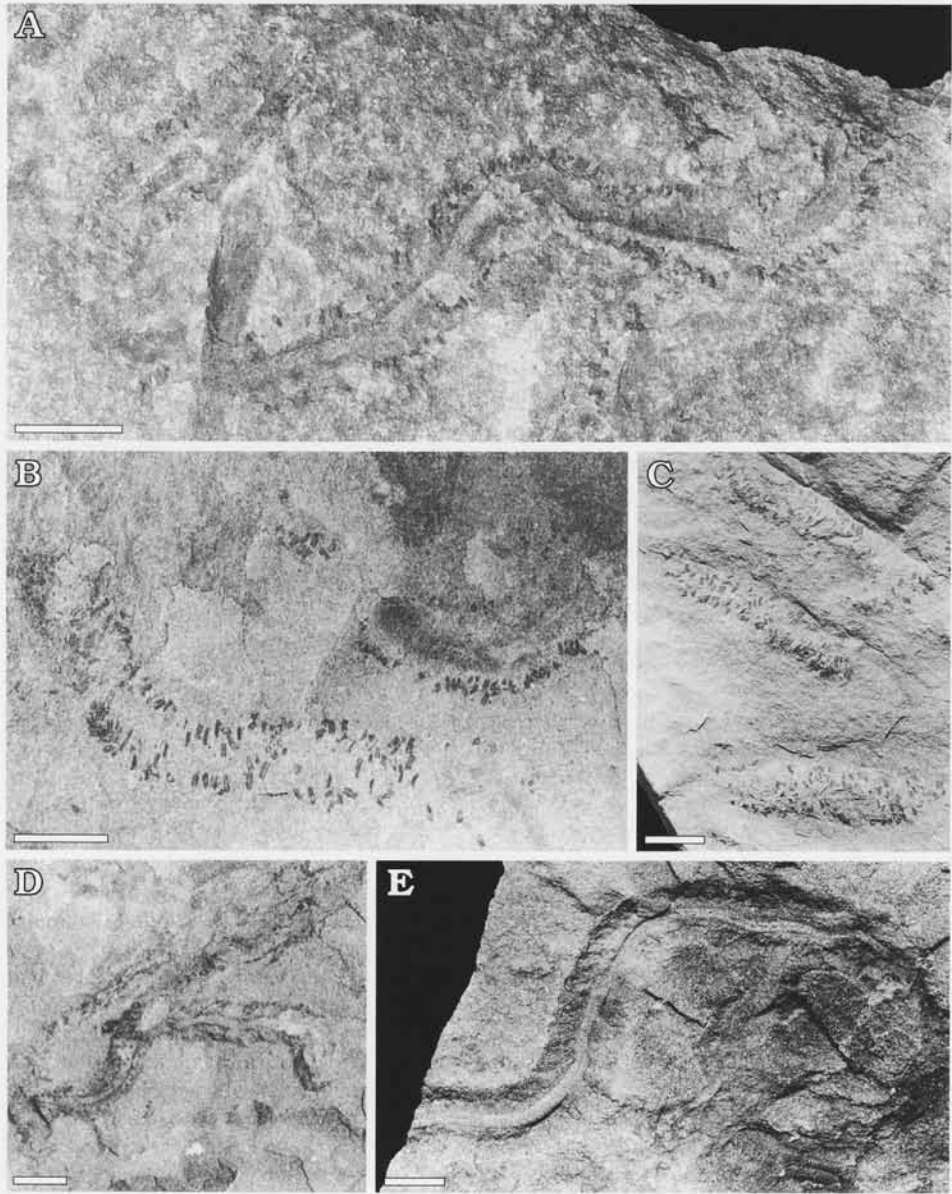
Fig. 9. A–E. *Fimbritubichnus biserialis* igen. et isp. n. A. Holotype (ZNGPAN A-I-110/108), full relief, top view; the specimen is cut by *Cylindrichnus candelabrus*. B. Paratype in bedding plane view (ZNGPAN A-I-110/127), full relief. C. Positive epichnial expression of short burrows (ZNGPAN A-I-110/127). D. Negative epichnial expression (ZNGPAN A-I-110/130, paratype). E. Weathered specimen of *Fimbritubichnus biserialis* igen. et isp. n. on bedding plane (ZNGPAN A-I-110/008), concave epirelief. Scale bars 1 cm.

Fenton & Fenton, 1937 (Buckman 1994a) or *Psammichnites* Torell, 1870 (Häntzschel 1975: fig. 62, 2b) (see Fig. 9E). There is some resemblance to *Crossopodia* McCoy, 1851 (= *Olivellites*) trails or burrows with a wide central (superior) faecal string and muddy lateral segments (compare Fig. 9B).
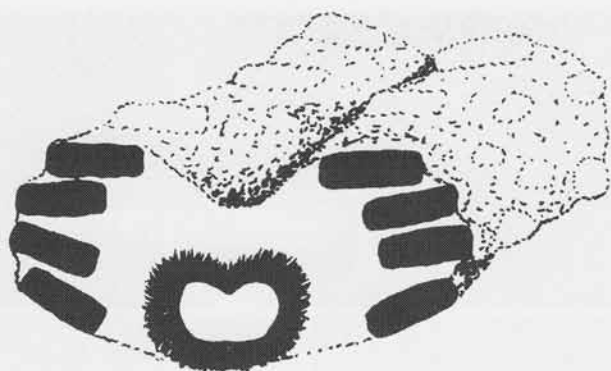
Fig. 10. Reconstruction of three-dimensional appearance of *Fimbritubichnus biserialis* igen. et isp. n.

The producer of the trace fossil exploited a freshly deposited sediment for food at a shallow depth below the sea floor, expelling faeces bilaterally and leaving the medial sediment cord behind its body. It is clear that this shallow burrow has been preserved owing to a favourable taphonomic situation. Thus, it may be a representative of a mixed layer of a frozen tier profile.

There is some evidence to suggest that a deposit-feeding bellerophont gastropod was the producer of the burrow. Small ellipsoidal pellets are known from animals such as worms, gastropods and bivalves (Häntzschel *et al.* 1968), but a line of pellets was indicated by Schäfer (1972) to be specific to gastropods because only gastropods are able to move and expel faeces at the same time. Subsequently, the bilobed burrow points to a link with bilateral symmetry of an animal. Among gastropods, only bellerophonts remained symmetrical in terms of shell morphology and supposingly internal anatomy (Cox 1960). The anatomy is hardly known, so that the manner in which the animal burrowed and expelled faeces remains speculative. The arrangement of pellets may have been forced by an internal organisation of mantle cavity in the vicinity of anus, if the anus itself was not paired. This is a tentative hypothesis and together with formation of the medial sediment cord between the pellet rows it needs further study. No modern analogues are known.

Ichnogenus *Lennea* Kräusel & Weyland, 1932
Lennea schmidti Kräusel & Weyland, 1932
Fig. 12A, B.

Material. — Three specimens and field observations.

Description. — Relatively large, full-relief burrow system. It is composed of horizontal or oblique, straight to slightly curved, dichotomously branched burrows, and of fragments of vertical or almost vertical burrows. The vertical burrows are thicker (up to 1 cm in diameter). They branch multidirectionally at an average angle of 55 degrees along the entire burrow extent. Subsequently, at the distance of 1.5 to 2 cm the branches deviate about 10 degrees from the main tunnel. Then they run within the sediment occasionally taking on a horizontal arrangement or are even directed upwards. The greatest length observed for the lateral penetrations is 22 cm. The tunnels observed on surfaces close to the bedding plane branch dichotomously at an angle of 40 to 50 degrees. The cylindrical or slightly flattened burrows, 3 to 5 mm in diameter, have relatively thick and dark lining and are filled with sandy sediment lithologically similar to the host rock but a bit darker and finer-grained. Some parts of the infill are packed as backfill menisci. The filling of the vertical burrow seems to be structureless.

Discussion. — This rarely described trace fossil was formerly known only from the Devonian of Germany (e.g., Fischer & Paulus 1969). Miller & Knox (1985) distinguished ?*Lennea*, though not unequivocally, in Pennsylvanian coal-bearing strata of Tennessee. In addition to the single ichnospecies known, Goldring & Langenstrassen (1979) illustrated but did not describe or name another
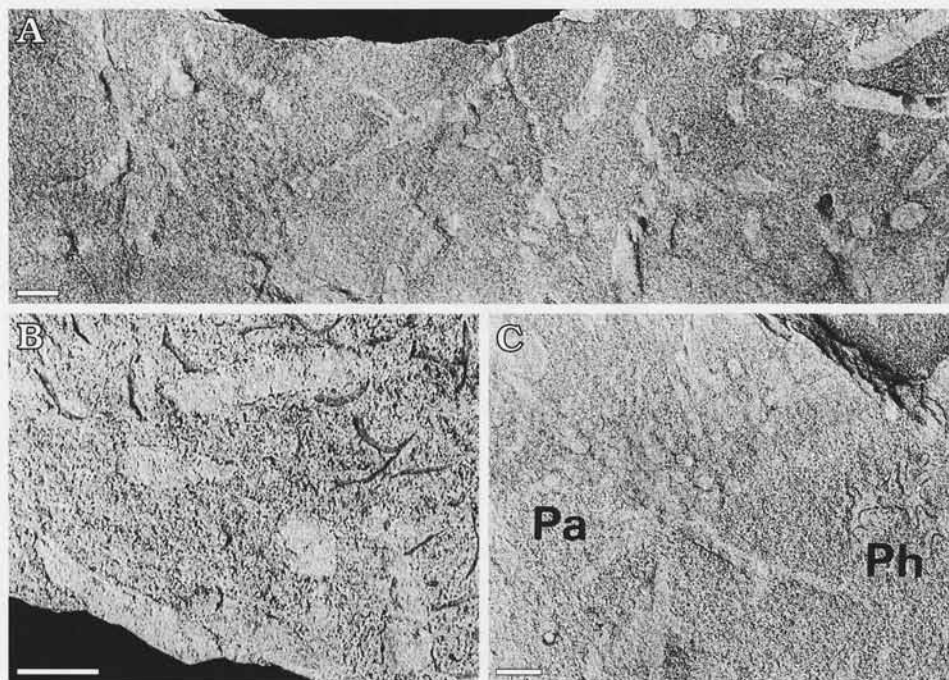
Fig. 11. **A**, **B**. *Macaronichnus segregatis*. **A**. Bedding plane view of concentrated *Macaronichnus segregatis* (ZNGPAN A-I-110/117), full relief. **B**. Epichnial expression of *Macaronichnus segregatis* and *Chondrites recurvus* (ZNGPAN A-I-110/007), full relief. **C**. Top view of *Parahaentzschelinia ardelia* (Pa) and *Phycosiphon incertum* (Ph) on bedding surface (ZNGPAN A-I-110/082), full relief. Scale bars 1 cm.

form of *Lennea*. The overall morphology of *Lennea* is very close to that of *Chondrites* but the latter is smaller.

The ethology of *Lennea* has not been studied yet. Originally it was interpreted as root remains (Kräusel & Weyland 1932). Subsequently, it was regarded as a burrow (Kräusel & Weyland 1934). Lately, Miller & Knox (1985: p. 86) suggested that *Lennea* may be a passively filled dwelling structure. The thick lining, active filling and branching of the specimens from Upper Silesia suggests that *Lennea* could represent an open burrow system, in which tunnels were actively filled by the producer shortly after using them as a dwelling?, cache? or gardening? structure.

Ichnogenus *Macaronichnus* Clifton & Thompson, 1978
Macaronichnus segregatis Clifton & Thompson, 1978

Fig. 11A, B.

Material. — Several hundreds of specimens and field observations.

Description. — Horizontal to oblique, straight to curved, cylindrical burrows preserved as full relief. The thin but distinct wall together with meniscate filling, visible owing to weathering, are the most characteristic features of the burrows. The burrow diameter varies from 2 to 6 mm with the mode of 5 mm. The wall thickness is chiefly 0.1 mm and rarely exceeds 1 mm. The maximum length of the burrow is 12 cm. Typically, the burrows lie horizontally or almost horizontally to the bedding plane. Their concentrations appear commonly as bunches of burrows. Terminations of many burrows are characteristically tapered. Interpenetration of burrows is common. Branching has not been observed. The burrows occur within siltstone, very fine- to fine-grained sandstones and are typically filled with either an identical or a little coarser, paler and better sorted sediment than the matrix. The walls are
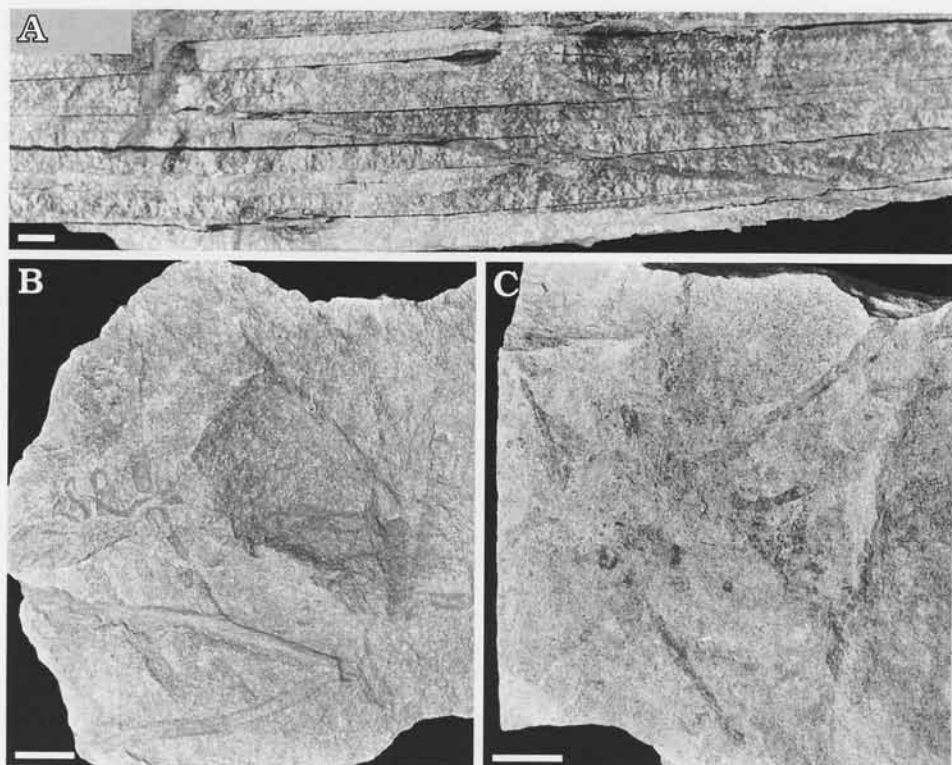
Fig. 12. **A**, **B**. *Lennea schmidti*. **A**. Full relief endichnial expression of *Lennea schmidti* (field photograph), vertical surface. **B**. Horizontal and oblique branches of *Lennea schmidti* and a fragment of large *Phycosiphon incertum* (ZNGPAN A-I-110/166). **C**. Bedding plane view of *Micatuba* isp. (ZNGPAN A-I-110/093), full relief.

composed of finer and more clayey sediment than that of the filling and are enriched in dark mineral detritus. The menisci are emphasized by very thin clayey streaks.

Remarks. — *M. segregatis* has been interpreted as the work of a marine, deposit-feeding polychaete feeding on bacteria and organic matter concentrated on the surface of sand grains (Clifton & Thompson 1978). The mode of grain selection has been detected recently among living polychaete worms (Tom Saunders personal communication 1997).

The known occurrences of *M. segregatis* have delineated the zone of its depositional setting, from the subtidal through intertidal to the beach one (Clifton & Thompson 1978; Curran 1985; Pollard *et al.* 1993). The Carboniferous occurrences of *M. segregatis* have been reported from storm sandstones of the Yoredale facies of southern Scotland and northern England (Lees 1991), and the Fountain Formation, Colorado (Maples & Suttner 1990). Their characteristics and occurrence are comparable with those from Upper Silesia.

Ichnogenus *Micatuba* Chamberlain, 1971
Micatuba isp.
Figs 6, 12C.

Material. — Seven specimens.

Description. — Complex burrow system composed of the vertical bunched tunnels and radiating horizontal tunnels which are straight to slightly curved. The distal parts of the horizontal tunnels turn

upwards and are hard to follow. Both vertical and horizontal burrows are filled with the sandy material that is lithologically similar to the host sediment. The wall is composed of a thin and dark muddy film. The concentrically arranged lining is best observed in cross-sections of the vertical burrows. Some tunnels reveal the inversion concerning the wall and filling materials. The filling is structure-less. Some nonplastically collapsed horizontal burrows can be observed as the pairs of parallel ridges. Sandy streaks are also observed suggesting fractures along the muddy walls (Fig. 6). The continuity between one vertical burrow and its horizontal counterpart was detected in only one case. In the remaining cases, the horizontal branches appear in the distance larger than 5 mm from the central zone. Branching of the horizontal tunnels is rarely observed. If present, branches are arranged in flat bunches. The total width of a burrow system is from 25 to 50 mm. The width of an individual burrow is up to 5 mm (av. 1 to 3 mm) and is constant. Its length is up to 11 cm. The vertical burrows can be thicker (up to 8 mm in diameter including the core which is up to 5 mm).

Remarks. — The type material of *Micatuba verso* Chamberlain, 1971 from the Ouachita Mountains (Chamberlain 1971) comprises semirelief forms, so that it is difficult to ascertain whether the Silesian specimens fit the ichnospecies. If the collapsed horizontal tunnels had been preserved as hyporelief double ridges, they would have mimicked other ichnotaxa, for example *Gyrochorte* Heer, 1865. *Micatuba* has been interpreted as a combined feeding-dwelling structure of unknown producer which may have lived in an open burrow system (Chamberlain 1971) or may have systematically mined the surrounding sediment while living in the central dwelling burrow (Lockley *et al.* 1987). The observed nature of the specimens described confirms Chamberlain's interpretation (Chamberlain 1971).

This ichnotaxon is rarely reported. Previous occurrences are known from the Pennsylvanian of Oklahoma (Chamberlain 1971) and Colorado (Lockley *et al.* 1987). Similar forms were described from the Upper Jurassic of India as *Radiituba* Badve & Ghare, 1978 (see Badve & Ghare 1978).

Ichnogenus *Nereites* MacLeay, 1839
Nereites missouriensis (Weller, 1899)

Figs 13A, B.

Material. — Several tens of specimens.

Description. — Large forms (Fig. 13B): full relief, loosely meandering, unbranched burrows with segmented infill surrounded by the zone of reworked sediment. The burrows curve in all directions. The filling structure is the most characteristic feature of the burrows. It is formed by irregular, dark, fine-grained menisci separated by lighter sediment similar to the host rock in terms of lithology. The distance between menisci is not constant. It is relatively small or even zero in the horizontal parts of the burrow increasing in the oblique parts. The zone of reworked sediment is commonly faded but still paler than the surrounding sediment and may reveal presence of the transverse structure. The width of the meniscate filling is between 4 and 5 mm. The total width of the burrow is 10 mm. The maximum preserved length is 12 cm.

Small forms (Fig. 13A, B): winding, horizontal and unbranched burrows, typically preserved as full relief but also as concave hyporelief. The burrows have a dark meniscate filling but menisci are poorly distinguishable making of the infill appear as structureless. Some menisci are separated by sandy films. The infill is framed by the zone of reworked sediment that is paler than the host one. Internal, leaf-shaped striation can be detected within the best developed lateral parts of the zone. The total width of the burrows is 4 to 9 mm. The faecal core diameter is 1 to 3 mm and is constant along a single burrow. The length can reach 20 cm.

Remarks. — The small forms prevail in the material studied. The large forms have a more distinct meniscate filling. Also, the vertical component of burrow direction is more frequent among the large burrows. This would be explained by lower energy loss of a relatively larger animal, digging through the sediment, in comparison to a smaller one. *N. missouriensis* has been interpreted as the work of a worm-like, deposit-feeder (Seilacher & Meischner 1965; Conkin & Conkin 1968; Chamberlain 1971; Häntzschel 1975) or other organisms such as mollusks, arthropods, or holothuroids (Rindsberg 1994).
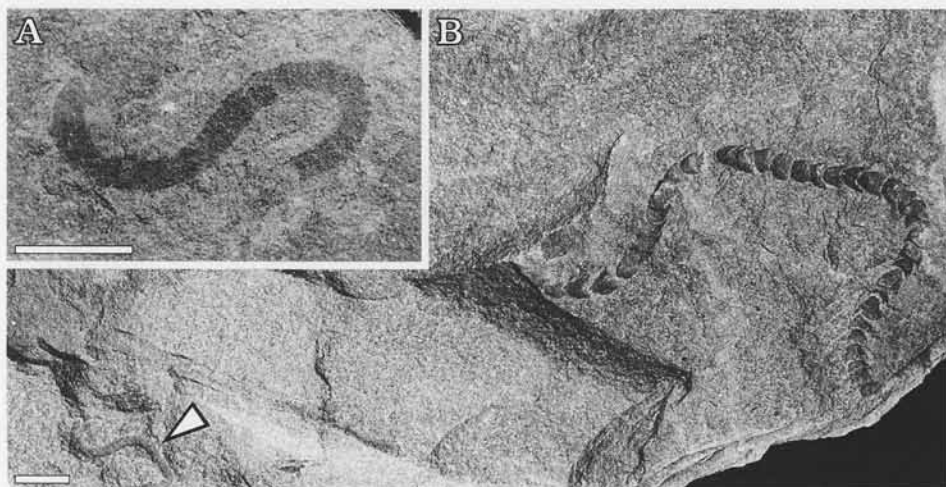
Fig. 13. **A**, **B**. *Nereites missouriensis*. **A**. Endichnial horizontal burrow (small form) with segmented infill surrounded by the zone of reworked sediment (ZNGPAN A-I-110/154), full relief. **B**. Endichnial horizontal large and small (arrow) forms of *Nereites missouriensis* (ZNGPAN A-I-110/115), full relief. Scale bars 1 cm.

Ichnogenus *Parahaentzschelinia* Chamberlain, 1971
Parahaentzschelinia ardelia Chamberlain, 1971

Fig. 11C.

Material. — Five specimens.

Emended diagnosis. — *Parahaentzschelinia* with unlined, meniscate tunnels.

Description. — Full-relief burrow system consisting of sand-filled tunnel bunches. Cross-sections, as seen on the bedding plane, show the circular and oval burrow outlines set in dense, circular groups or 'rosettes'. Some of the outer, vertical burrows change their direction going horizontally outward as short, straight and branching tunnels. The longest fragments of such tunnels observed on the bedding plane are up to 35 mm. All the burrows are filled with the same sandstone as the host rock. Some bedding planes show very fine, concentric filling of the vertical burrows and delicate meniscate filling of the horizontal ones. A careful study of the meniscate filling showed that branching is of the primary successive style. The wall consists of a thin, dark muddy film. The burrow diameter is relatively constant from 3 to 5 mm. The diameter of the rosette is up to 9 cm (average 3 cm).

Discussion. — *Parahaentzschelinia* is the burrow system composed of number of vertical tunnels spreading upwards and sideways in the shape of a bunch of flowers from one, parent burrow. Two ichnospecies of *Parahaentzschelinia* are known: *P. ardelia* Chamberlain, 1971 and *P. surlyki* Dam, 1990. Since Dam (1990) defined thickly lined *P. surlyki*, the diagnosis of *P. ardelia* (Chamberlain 1971) has remained unspecific but is emended here as unlined and with meniscate infill.

The horizontal parts of the burrow system of *P. ardelia* are identical to the burrows of *Macaronichnus segregatis* from the same locality. This suggests close relationships between these two ichnotaxa. They may be behavioural variations of the same organism. The ethology of the Silesian specimens can be best understood following the explanation given by Chamberlain (1971). He regarded *P. ardelia* as the product of the systematic penetration of the sediment by a wormlike, deposit-feeding, endobenthic organism.

Fig. 14. Bedding plane view of a mass occurrence of *Phycosiphon incertum* (ZNGPAN A-I-110/063), full relief; the dark burrow on the right side of the photograph is a secondarily penetrated burrow which may originally belong to various ichnotaxa. Scale bar 1 cm.

P. ardelia was originally described from the Pennsylvanian of Oklahoma (Chamberlain 1971). Similar, but smaller structures were described by Lees (1991) from the Yoredale sandstones. He did not, however, detect the presence of menisci. The lack of menisci could be due to poorer preservation. The possible relationships between *P. ardelia*, *Hartsellea sursumramosa* Rindsberg, 1994 and *Asterichnus lawrencensis* Bandel, 1967 need further study.

Ichnogenus *Phycosiphon* Fischer-Ooster, 1858
Phycosiphon incertum Fischer-Ooster, 1858

Figs 14, 11C, 4A, 12B.

Material. — Several tens of specimens.

Description. — Very regular burrow system composed of small U-shaped lobes of second orders. Typically, they are oriented horizontally to the bedding plane resembling an antler. The oblique orientation of the lobes results in the characteristic rough relief of the bedding surface. Spreiten are poorly visible but the U-shaped faecal-filled ones are characteristic. Two size classes of the burrows are distinguishable. The larger burrows form lobes 3 mm wide 1 cm (maximum 1.5 cm) long and have a dark core 1 mm in the diameter. The smaller burrows are 1.5 mm wide, 1 cm long and 0.4 mm in diameter, respectively. Mass occurrences of the burrow systems on the bedding planes are common.

Remarks. — *Phycosiphon* has been found in various sedimentary facies and is interpreted as the work of a marine, often opportunistic deposit-feeder (Fu 1991; Goldring *et al.* 1991 (=*Anconichnus* Kern, 1978); Wetzel & Bromley 1994). *Phycosiphon* has been described from coal-bearing Carboniferous sequences in the United States as *Helminthopsis* Heer, 1877 (Miller & Knox 1985; Bjerstedt 1988).

Ichnogenus *Rhizocorallium* Zenker, 1836
Rhizocorallium jenense Zenker, 1836

Fig. 15.

Material. — Six specimens and field observations.

Fig. 15. *Rhizocorallium jenense* (ZNGPAN A-I-110/053), full relief. Scale bar 1 cm.

Description. — Elongate, relatively short, unbranched, U-shaped protrusive burrows with spreiten. They are arranged obliquely to the bedding plane but in particular cases they were observed lying on the upper surfaces of hummocks. All the specimens have broadening in distal parts of the U-form where there is also an increase in diameter of the marginal tunnel. The burrows possess thick lining and are filled with similar or finer sediment than the matrix. The most typical feature of the burrow is presence of the vertical retrusive component affecting the distal part of the burrow structure. The maximum length of the burrow is 17 cm. The width varies from 2 to 7 cm. The marginal tube diameter is 5 mm to 10 mm and increases along the distal part up to 31 mm.

Discussion. — Chisholm (1970) and later Buckman (1992) described U-shaped *Teichichnus*-like burrows that show a strong, vertical, retrusive component. Buckman (1994b) suggested that *Teichichnus repandus* Chamberlain, 1977 (U-shaped *Teichichnus*) should be included in the ichnogenus *Rhizocorallium*.

Rhizocorallium jenense has been interpreted as a domicile of a suspension feeder (Fürsich 1974). The thick lining of specimens from Silesia suggests active movement and wall packing of a suspension feeder. Identically developed protrusive *Diplocraterion parallelum* Torell, 1870 is regarded as the expression of the simple behaviour in the stable bottom conditions (Bromley & Hanken 1991). The *Rhizocorallium* animal, however, shifted upwards the distal part of the burrow structure. In addition, the burrows are not filled with the dark mudstone that is present above the sandstone containing *Rhizocorallium*. The mode of the burrow stuffing suggests that they were successively reworked but remained open and subjected to bottom water irrigation affecting the lining development. The burrows have been enlarged to accommodate the growth of the producer.

In contrast to the above, an alternative model of the burrow formation is also possible. The only trace fossil present in the *Rhizocorallium* bed is *Chondrites intricatus* (later deeper tier) which gains its maximum development within *R. jenense* burrows. This suggests an overall poor access to nutrients within this sediment layer (e.g., Fu 1991). Unless the *R. jenense* animal was a suspension feeder, the gardening model (compare Seilacher 1977) would be a good explanation of the ethology of *R. jenense* from Silesia. Its producer would have reworked the former tunnel wall whose mucus film had attracted microorganisms but in contrary to the graphoglyptid case the open burrows were constructed deeper in the sediment subjected to relatively shallow, energetic water conditions.

Similar *Rhizocorallium* have been observed in the coal-bearing Carboniferous of Ireland (Buckman 1992), Scotland and northern England (Chisholm 1970; Lees 1991), and Colorado (Maples & Suttner 1990).
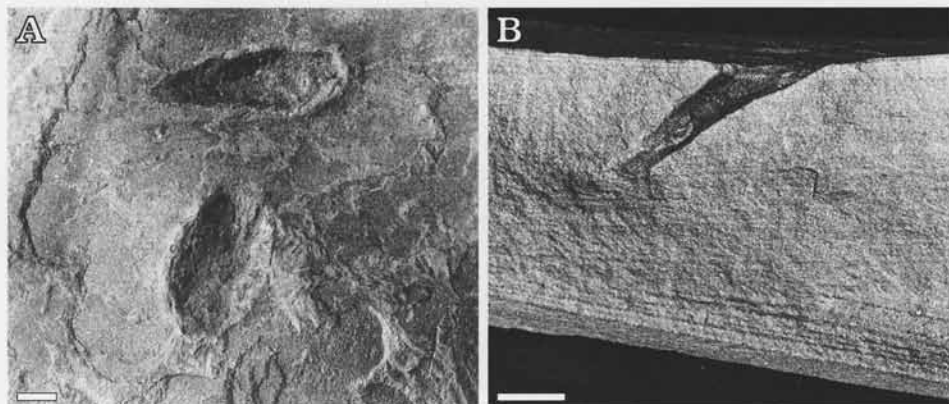
Fig. 16. **A, B**. *Rosselia socialis*. **A**. Burrow apertures on top surface of a hummock (ZNGPAN A-I-110/060), full relief. **B**. Full relief endichnial expression (ZNGPAN A-I-110/060), vertical surface. Scale bars 1 cm.

Ichnogenus *Rosselia* Dahmer, 1937
Rosselia socialis Dahmer, 1937

Fig. 16A, B.

Material. — Eight specimens.

Description. — Funnel-shaped, full-relief burrows consisting of concentrically piled funnels. The burrows lie obliquely to the bedding plane at about 40 degrees. Individual funnels consist of sand of the same lithology as the host sediment. They are separated from each other by a thin muddy lining. They surround the sandy core of the average diameter of 4 mm. The funnel diameter ranges from 4 to 25 mm. The total length of the burrows is up to 35 mm. The burrow apertures, preserved on the upper surfaces of *HCS* sandstone beds, have the shape of oval bowls andoccasionally reveal more than one sandy core.

Remarks. — *R. socialis* occurs within the storm beds together with *Cylindrichnus candelabrus*. It is possible that it represents apertures of *Cylindrichnus* but definite proof of that has not been found yet. *R. socialis* has been traditionally interpreted as a dwelling-feeding structure of a polychaete (Chamberlain 1971) and has been frequently reported from the Carboniferous of the United States (e.g., Chamberlain 1971; Miller & Knox 1985; Bjerstedt 1988; Martino 1989; Rindsberg 1990a, 1994; Greb & Chesnut 1994) and the United Kingdom (Lees 1991).

Ichnogenus *Zoophycos* Massalongo, 1855
Zoophycos isp.

Fig. 17A.

Material. — Six specimens and field observations.

Description. — All the specimens studied are fragmentary and consist of a coiled surface covered with parallel grooves and ridges, spreading outwards from a central zone. The outer edge is not preserved. The surface is in fact a cleavage surface formed by the burrow structure. The surface morphology can be compared to the cockerill's tail, so that these traces were described in nineteenth-century literature as *'cauda galli'* markings. The structure preserved in semirelief shows distinct primary ribs, whereas inter-rib filaments are less well defined. Sets of at least two ridges separated by a groove are conspicuously arranged in steps. The possible radius diameter of the structure measured along the length of ribs is at least 200 mm. The width of the set of two ridges separated by groove is approximately 4 mm. The total height of the structure reaches 2 cm.
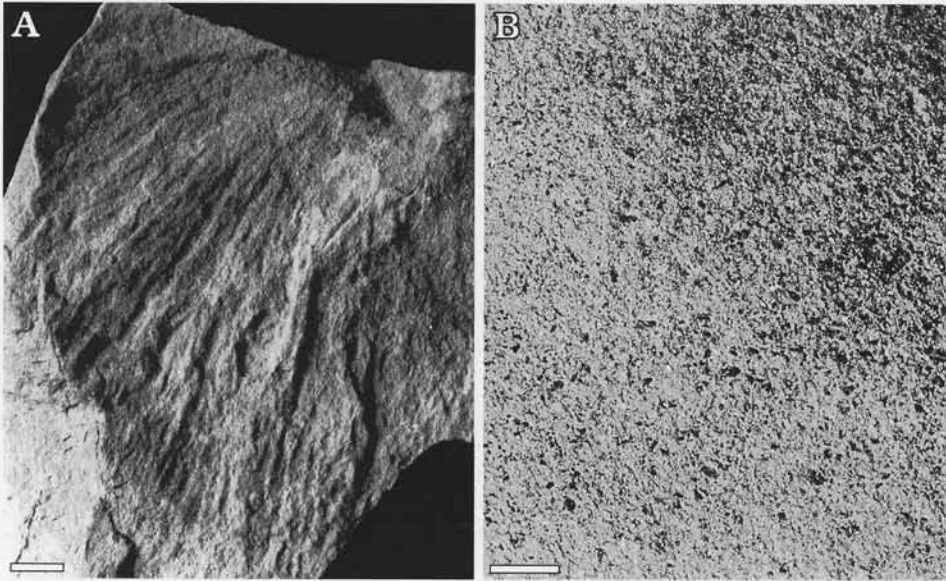
Fig. 17. **A**. *Zoophycos* isp. (ZNGPAN A-I-110/099), endostratal semirelief. **B**. Faecal pellets in mass occurrence covering a stratification surface (ZNGPAN A-I-110/075), full relief. Scale bars 1 cm.

Discussion. — Ekdale (1992: p. 153) distinguished two basic forms of *Zoophycos*: the simple and the composite. The simple forms, which include the specimens described here, are common in Paleozoic shallow-marine deposits (e.g., Ekdale 1992 and the references therein). Moreover, the simple forms are well represented in coal-bearing strata of the Pennsylvanian of the United States (Ekdale 1992: p. 154; Bandel 1967; Miller & Knox 1985; Maples & Suttner 1990; Rindsberg 1990a; Miller 1991) and the Namurian of the United Kingdom (Eagar *et al.* 1985).

The detailed observation of the Silesia specimens has led to conclusion that the sets of ridges result from the collapse of empty tunnels. This expression is similar to *Zoophycos (Spirophyton)* cf. *Z. cauda-galli* of Eagar *et al.* (1985) regarded as a complex feeding structure, involving successive tunnelling of a series of feeding probes of a worm-like animal.

Other biogenic structures

Escape and equilibrium structures

These structures are typically expressed as vertical or near-vertical shafts or zones of disturbed or homogenised sediment (fugichnia) and of series of superimposed U- or V-shaped depressions (equilibrichnia). Escape shafts were observed in the neighbourhood of micro-hummocky lenses, where they appear as sand-filled, screw-like but strongly deformed columns, and below hummocky cross-stratified sandstone beds. Equilibrium structures are common within the sediment that separates beds with *HCS*.

Faecal pellets

Fig. 17B.

These structures appear as isolated lumps of various shape (chiefly rods) and size (less than 2 mm) forming mass occurrences of thousands of specimens on bedding planes within hummocky cross-stratified sandstone beds. They consist of darker and finer sediment than the matrix. Similar faecal pellets may have been extracted by washing burrow infillings of *Fimbritubichnus biserialis* away.

Environmental significance of the trace fossils

The distribution of the trace fossils within the section (Fig. 2) reflects the history of changes of ecological parameters. The marine deposits surrounding the storm sequence mark the background sedimentation. They contain several ichnotaxa dominated by *Phycosiphon incertum*. The range of occurrence of this ichnospecies has been studied extensively in Jurassic offshore siliciclastic facies by Goldring *et al.* (1991), who showed that it was formed by opportunistic burrowers in soft-ground sediment (fine to very fine-grained siliciclastic sediments between upper offshore to lower shoreface) associated with rapid, event-bed deposition (storms, tidal currents). Sedimentary structures and distribution of *Phycosiphon incertum* in the Kozłowa Góra section suggest an identical paleoenvironmental range. In addition, the low ichnodiversity suggests that the muddy shelf had unfavourable ecological parameters such as low oxygenation (e.g., Ekdale & Mason 1988) or substrate softening (Wignall 1993). A similar environmental range of *Phycosiphon incertum* has been reported in Carboniferous coal-bearing deposits of the United States (Miller & Knox 1985; Bjerstedt 1988). Bjerstedt (1988) identified *Phycosiphon incertum* from outer shelf storm sandstones and in black shale drapes on wave-rippled sandstones from tidal inlet facies.

The sudden increase in ichnodiversity and bioturbation intensity within the part of the storm sequence containing *HCS* sandstone beds (Fig. 2) marks a dramatic change of ecological parameters. The influx of nutrients, which followed well-aerated storm waters, could have caused a flourishing of benthic life. Intensive burrowing developed under the fair-weather conditions and the sedimentation from suspension prior to a next storm event. Thus, the upper surface of each tempestite can be identified as the colonization surface from which trace fossils originate (Frey & Goldring 1992). The ichnofossil assemblage reflects a variety of behavioural categories (see above), pointing to a link with well-aerated, relatively shallow- and calm-water sediment that provided suspension and deposit feeders, as well as predators, with an abundance of nutrients.

Furthermore, some of the ichnotaxa are regarded to have a narrow environmental range of occurrence. *Macaronichnus segregatis* has been described exclusively from high-energy, shallow-marine sandstones (Clifton & Thompson 1978; Curran 1985; Saunders & Pemberton 1990; Pollard *et al.* 1993). Maples & Suttner (1990) made some relevant suggestions concerning the relationships of *Macaronichnus* to *Curvolithus* in the coal-bearing Pennsylvanian of Colorado. If *Macaronichnus* was dominant, it could indicate that the environment was dominated by wave formed processes, whereas *Curvolithus*, which is absent in the Kozłowa Góra deposits, may have proliferated in fluvially dominated environments.

Vertically oriented burrows such as *Rosselia socialis* and *Cylindrichnus candelabrus* are present in the highest portions of *HCS* sandstone beds. Vertical burrows have frequently been reported from deltaic and shoreface facies and have always been associated with high-energy sedimentation (e.g., McCarthy 1979; Crimes & Anderson 1985; Stanistreet 1989). *Rosselia* and other vertical burrows occurring in Carboniferous coal-bearing strata have been linked to tidal channel and distal tidal deltaic (Miller & Knox 1985), wave-dominated deltaic (Lees 1991) or estuarine (Greb & Chesnut 1994) environments.

Regional implications

The regional significance of the trace fossils documented in the present paper results from their close relationship with the sedimentary processes. The trace fossils can be thus utilized in sedimentary analysis of the core material from the paralic segment of the Upper Silesia Coal Basin succession. They may be used to detect settings similar to Kozłowa Góra and recognise tempestites in cores where appropriate sedimentary structures are hard to ascertain or have been obliterated.

Although there is no simple and direct relationship between trace fossils and salinity (Bromley 1996), there are certain features of the recorded ichnoassemblage from the Kozłowa Góra quarry that undoubtedly point to its marine origin (see above). Moreover, a comparison of the continental (Głuszek 1995a) and the Kozłowa Góra trace fossil assemblages reveals that none of the ichnofossils present in the Kozłowa Góra locality is present in the continental deposits (with exception of fugichnia and equilibrichnia). Diversity and density of the burrows in the storm deposits are not matched by any continental ichnoassemblage.

Paleontological evidence has been used to distinguish between marine and non-marine deposition within the Paralic Series of the Upper Silesia Coal Basin (see Bojkowski 1972; Řehoř & Řehořová 1972 for summary). The so called 'marine horizons' have been established on the basis of marine fauna and are in fact only body fossil horizons. The present study shows that the marine incursions are marked not only by the appearance of shelly faunas but also by an increase of the trace fossils diversity and density (such relationship seems to occur also in other paralic coal-bearing strata, see Pollard 1988). Moreover, in some sections the marine trace fossils have been detected in horizons lacking body fossils (Głuszek 1995b). The trace fossils described in the present paper are thus a promising tool in detecting marine influences in the Upper Silesia Coal Basin, especially in the beds devoid of marine shelly fauna.

Summary and conclusions

An ichnofossil suite of 18 ichnospecies: *Arthrophycus* isp., *Asterichnus lawrencensis*, *Asterosoma radiciforme*, *Chondrites intricatus*, *Chondrites recurvus*, *Cladichnus* isp., *Cylindrichnus candelabrus* isp. n., *'Eione' moniliformis*, *Fimbritubichnus biserialis* igen. et isp. n., *Lennea schmidti*, *Macaronichnus segregatis*, *Micatuba* isp., *Parahaentzschelinia ardelia*, *Phycosiphon incertum*, *Rhizocorallium jenense*, *Rosselia socialis*, *Nereites missouriensis*, *Zoophycos* isp. as well as equilibrichnia, fugichnia and faecal pellets is present in storm deposits from the Franciszka X marine horizon of the Hrušov Beds (Pendleian), exposed at the Kozłowa Góra quarry (Upper Silesia Coal Basin, Poland).

The distribution of the trace fossils within the Kozłowa Góra section containing storm deposits reflects the history of sedimentation under changing ecological parameters. The marine deposits surrounding the storm sequence contain a *Phycosiphon incertum* – dominated, poor assemblage and mark the background sedimentation in the zone between upper offshore to lower shoreface that was characterised by unfavourable ecological parameters for endobenthic organisms. The sudden increase in ichno-

diversity and bioturbation intensity within the storm sequence marks the inflow of nutrients, which followed well-aerated waters connected with the storm conditions.

The ichnotaxonomical composition together with the distribution of the trace fossils in the section have some important regional implications. First of all, they can be utilized in sedimentary environment analysis based on core material throughout the coal basin. Theycould help to identify tempestites in cores where sedimentological evidence is not satisfactory owing to the limited dimensions of samples available. Additionally, since they mark marine influence, they can be utilized to discern marine versus nonmarine deposition within the Paralic Series of the Upper Silesia Coal Basin where body fossil evidence is insufficient or equivocal.

Acknowledgements

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Ślady działalności organizmów ze sztormowych osadów późnego karbonu Górnego Śląska

ARKADIUSZ GŁUSZEK

Streszczenie

W pracy opisano zróżnicowany i stosunkowo dobrze zachowany zespół śladów
działalności życiowej rozmaitych bezkręgowców morskich zachowanych w sztor-
mowych osadach późnego karbonu (Namur A, horyzont Franciszka X, warstwy
gruszowskie) w odsłonięciu Kozłowa Góra na obszarze Górnośląskiego Zagłębia
Węglowego. Zidentyfikowano 18 ichnogatunków (w tym dwa nowe) należących
do 17 ichnorodzajów, ponadto rozpoznano niesklasyfikowane formalnie ślady rów-
nowagi (equilibrichnia), ślady ucieczki (fugichnia) oraz grudki fekalne. Opisano
dwa nowe ichnogatunki: *Cylindrichnus candelabrus* isp. n. oraz *Fimbritubichnus
biserialis* igen. et isp. n., ten ostatni interpretowany jako ślad jakiegoś osadożernego
ślimaka bellerofontowego. Zaproponowano korektę diagnozy *Parahaentzschelinia
ardelia*. Zespoły śladów działalności morskich bezkręgowców mogą być użytecz-
nym narzędziem dla rozpoznawania morskich ingresji w osadach górnego karbonu
Górnośląskiego Zagłębia Węglowego.