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LOWER CAMBRIAN SILICICLASTIC SEDIMENTS IN SOUTHERN MORAVIA (CZECH REPUBLIC) AND THEIR PALEOGEOGRAPHICAL CONSTRAINTS

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Abstract: Petrological, sedimentological and ichnological studies of cores from the Měnín-1 borehole revealed episodic shallow marine influence in the terrestrial clastics underlying the Devonian clastic and carbonate rocks. The organic-walled, acid-resistant microfossils have been recovered from bioturbated beds and have allowed us to determine the age as the earliest Cambrian (most likely Platysolenites antiquissimus Faunal Zone). Several index acritarch species justify a preliminary assignment to the Asteridium tornatum–Comasphaeridium velvetum Acritarch Zone. The microfossils are very well preserved, without any noticeable thermal alteration (thermal alteration index about 1+) or mechanical damage. The ichnoassemblage contains *Diplocraterion* isp., *Skolithos* isp., and *Planolites* isp. The intensity of bioturbation and ichnofabric patterns correspond well to those described from the Cambrian of the East European Platform. The composition of Cambrian acritarch assemblages, of the ichnotaxa, as well the very low thermal alteration of organic-walled microfossils, link this Moravian sedimentary cover of Brunnia (Brunovistulicum in broader sense of the meaning) to the sediments of the same age which rest on other crustal segments in the southern and central part of Poland and even further on the Baltica Paleocontinent. This indicates a connection rather than separation of these Cambrian "Gondwanan parts" and Baltica by the Trans-European Suture Zone.

Key words: Early Cambrian, paleogeography, sedimentology, ichnofossils, acritarchs.

Introduction

Clastic sediments which underlie the Moravian platform carbonates have been penetrated by numerous deep boreholes, most of them drilled by the Moravian Oil Mines, Hodonín (Zádrapa & Skoček 1983). These sediments were informally called the "basal clastics" by Zapletal (1922) and subsequently by other authors. Because of the specific position at the contact of three major orogens of Europe, their origin is significant for the understanding of the pre-Variscan development of Central Europe. Their terrestrial nature, lack of fossil remains, and unmetamorphosed appearance led the previous authors (Skoček 1980; Dvořák 1998) to assign the basal clastics to the Devonian, initiating the Paleozoic sedimentary succession in Moravia. However, Roth (1981) suggested the Cambrian age of the so-called "basal clastics" on the basis of their similarity to paleontologically dated Cambrian sediments in SE Poland (Orłowski 1975, 1985).

The most complete succession of the basal clastics has been recovered in the Měnín-1 borehole situated about 15 km south of Brno (Fig. 1). The present report deals with segments of the cores from the borehole, which are housed in the Moravian Oil Mines Company Hodonín. The previous study by Fatka & Vavrdová (1998) dealt with microfossil content of a single sample from the uppermost parts of the basal clastics in the Měnín-1 borehole, while the present study extends the paleontological (ichnofossils, palynomorphs) and sedimentological studies. The depositional environment, biostratigraphy and paleogeographic interpretation are synthetized. Only incomplete small relics of the drill cores (cores 19-33B from depths between 655.0 m and 2042 m) were available for the renewed study.

Previous research

Zádrapa (1975) and Skoček (1978) started the petrological studies of Paleozoic rocks of the Měnín-1 borehole. Otava (in Skoček 1978) and Zádrapa (1975) investigated heavy minerals. Skoček (1980) and Skoček & Zádrapa (1983) subdivided the sedimentary fill of the borehole into two units, both mineralogically mature (Maštera 2000). A content of feldspar is typical for the lower unit, whereas the upper unit is formed by monomictic-quartzose rocks. Dvořák (1998) subdivided the lower unit into two parts. The basal part consists mostly of coarse-grained poorly sorted subarkoses with beds and lenses of fine-grained conglomerates. The upper part consists mostly of sorted and unsorted, fine-grained and medium-grained, subarkoses and quartzose sandstones.

Bioturbation of sedimentary rocks of the Měnín-1 borehole was observed by Skoček (1980) and described as "vertical shafts filled with a substance of different grain size". In the previous, more detailed manuscript, Skoček (1978) stated that bioturbation was generally quite frequent in the Měnín-1 borehole, and a single type of vertical to oblique passages or tun-

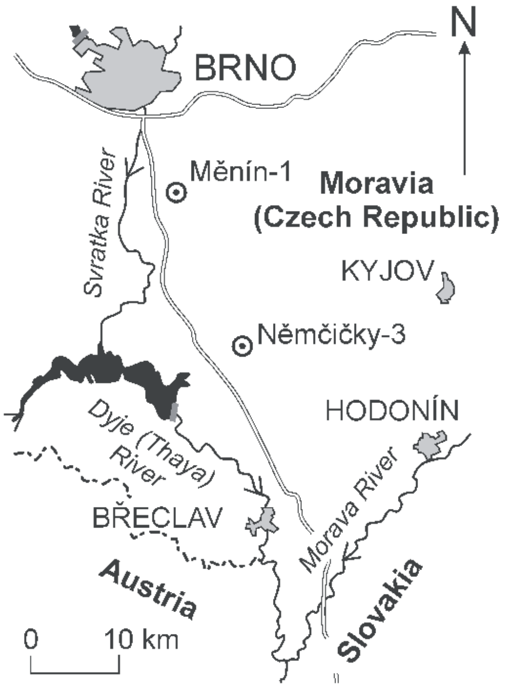

Fig. 1. The sketch/map of Central Europe showing the location of area studied.

nels was present. However, no systematic ichnology was proposed. The first ichnological study of the rocks was presented by Mikuláš & Nehyba (2001).

Palynological investigation of selected samples of the basal clastics provided data for an unequivocal assignment of some siliciclastic sequences underlying Moravian carbonates to the Early Cambrian as suggested by Roth (1981). These results were published by Jachowicz & Přichystal (1997), Vavrdová (1997a), Fatka & Vavrdová (1998), and Vavrdová & Bek (2001). At present, fossiliferous samples of the Early Cambrian age are known from three boreholes: the Měnín-1 borehole (Fatka & Vavrdová 1998), Němčičky-3 borehole (Jachowicz & Přichystal 1997; Vavrdová & Bek 2001) and Němčičky-6 borehole (Vavrdová 1997a; Jachowicz & Přichystal 1997). The bed of fine laminated silty mudstone/shale with Cambrian acritarchs (core 16, depth 473.0–477.5 m) in the Měnín-1 borehole belongs to the basal part ("pelitic formation") of the upper unit (Skoček 1980; Zádrapa 1975). Finds of palynomorphs significantly improved the age assignment, facies interpretation and paleogeography of the basal clastics. In additional to the recognized alluvial deposits, coastal sabkhas and ephemeral lakes of tropical climate (Skoček 1980; Zádrapa & Skoček 1983; Dvořák 1998), the presence of shallow marine environment is indicated by the analysed samples.

Lithofacies study

Several lithofacies have been recognized within the studied cores (Fig. 2). Sandstones strongly dominate in the studied samples. They are mostly classified as quartzose ones. Subarkoses, arkosic and graywacke sandstones were also recognized. Quartz grains totally dominate the sandstones. Their rounding varies between individual samples from subangular or angular to rounded. The latest are quite frequent. Grains of monocrystalic quartz predominate over polycrystalic ones. The occurrence of feldspar grains is relative low, from 5 % to 20 %, rarely about 30 %. Orthoclases usually dominate over plagioclases. The content of micas (both muscovite and biotite) is highly variable. The finer sandstones have a relatively higher proportion of unstable grains, predominantly of acidic plagioclases, than the coarse-grained sandstones.

Fragments of pegmatites and older sandstones were rarely recognized. Grains of stable rocks, mostly silicites or quartzites are rare. Zircone, apatite, tourmaline and garnet grains are present as accessories. The content of sandstone matrix is below 10 %. Clay minerals, sericite and chlorite dominate in the matrix. Carbonate matrix is very rare.

Quartz grains predominantly angular and subangular form also the dominant part of the mudstones. High presence of micas is typical for the mudstones. Muscovite dominates over biotite. Feldspar grains are relatively rare. The matrix is clayey with an important content of hematite.

Lithofacies Sp

Planar cross-bedded sandstones form this lithofacies. It was recognized in the cores 19, 29, 30, 31A, 32, and 33B. Both small-scale ripple cross bedding, with the set thickness of about 5 cm, and large-scale cross bedding, with set thicknesses of tens of centimetres, are present. Reactivation surfaces and sigmoidal bases of laminae are common.

The colour of the sandstones is highly variable, from light green to green-grey, light and dull red-brown, grey, and violet. It is controlled by variations in the content of hematite, grainsize or intensity of silicification. Alternations of horizons of slightly coarser and finer grains are typically reflected in alternation of lighter and darker colours.

Grain size of sandstones is highly variable, from fine to very coarse. The very coarse sandstones can sometimes be in transition/association with lithofacies Gp. Both relatively well-sorted and poorly sorted samples were observed. Coarser grained sandstones are commonly poorly sorted, especially because of the presence of outsized clasts, mostly of quartz. These clasts can be classified mostly as granules, which are 5 to 15 mm in size. Clasts of quartzite, feldspar, granitoid, silicite, quartzose sandstone and mudstone intraclasts are both subordinate and smaller. Intraclasts up to 7 mm in diameter occur. The outsized clasts are commonly subangular and often form thin laminae.

Lithofacies St

Trough cross-bedded sandstones form this lithofacies. They were recognized in the cores no. M-1A and 26A. Small-scale ripple trough-cross bedding is typical. Bedding planes are irregular and the boundaries of sets are erosive.

The colour of the sandstones is light green-grey or red-brown. Alternation of laminae of slightly finer (also darker) and coarser (also lighter) grains makes the bedding distinct.

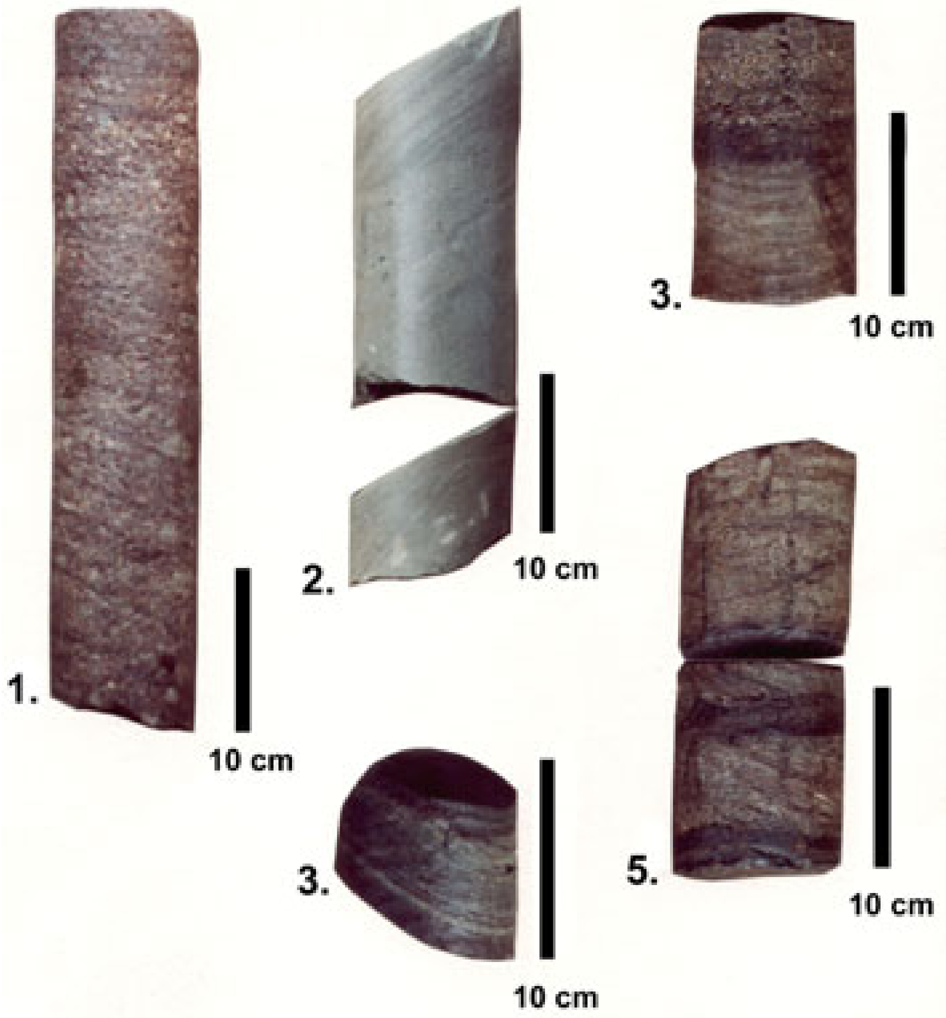

Fig. 2. Fragments of drill cores showing the characteristic lithofacies. **1** — Lithofacies Gp (core no. 33B); **2** — lithofacies SP (core no. 19); **3** — sharp contact of lithofacies Gp and Sp; **4** — lithofacies H (core 21); **5** — lithofacies Sl (rhythmite, alternation of sandstone and mudstone laminae, core no. 29).

Fine-grained beds are also characterized by a higher content of micas (especialy biotite) and hematite. The content of hematite increases especially in the matrix.

The sandstones are fine- to coarse-grained and relatively poorly sorted. Especially coarse-grained sandstones are characterized by the presence of outsized clasts up to 4 mm in diameter. Locally recognized thin intercalations of mudstones in sandstones reflect the transition/association of facies St and H.

Lithofacies Sm

The lithofacies is formed by a massive sandstone and was recognized in the core no. 27. Intensive silicification obscured probable primary sedimentary structures.

The sandstone is medium- to fine-grained, green grey coloured and relative well sorted. Quartz and feldspars are the dominant grains. Micas are rare.

Lithofacies Sl

Parallel-laminated sandstones form this lithofacies. They were recognized in the cores no. 21 and no. 23. Horizontal to low angle lamination occurs. Rhythmic alternation of distinct lighter and darker laminas is connected with several factors, such as locally relatively common occurrence of micas (both biotite and muscovite) with iron oxides and hydroxides or alternation of sandstone and mudstone laminae (rhythmites). The occurrences of often bioturbated mudstone laminae reflect the transition/association of the facies Sl and H.

The sandstones are fine- or medium-grained. The fine-grained sandstones are micaceous. Grey or red-brown colours are the most typical.

Lithofacies H

Lithofacies H is characterized by heterolithic bedding, where sandstone beds alternate with mudstones. This facies was recognized in the cores nos. 20B, 23, 27A, 29, 30, and M-1A. The thickness of individual beds varies from several milimetres up to several centimetres. Lenticular, flaser or wavy bedding, based on the relative abundance of sandstones and mudstones occurs. The dominance of sandstone over mudstone is more common. Bedding planes with load or flame structures are typical. Bioturbation is relatively common. Transition/association of facies H to facies Sl or Sr can sometimes be recognized.

Sandstones are usually light grey, red-brown to violet in colour. Ripple cross-bedding is common, whereas horizontal lamination is rare. Grain size of sandstones is variable, mostly fine to medium. Micaceous, coarse- and very coarse-grained sandstones, with outsized grains up to 0.5 cm in diameter are also recognized. Mudstone intraclasts, up to 10 mm in diameter, occur locally. Sorting of the sandstones varies from relatively good to poor.

Mudstones (micaceous siltstone to silty claystone) are typically pale green grey, dark grey and dark red brown in colour. Sandy siltstones occur locally with the higher presence of micas. Horizontal stratification together with preferred orientation of micas is common.

Lithofacies Gp

Granule-sized conglomerates, massive, horizontally stratified to cross-bedded were observed in the cores no. 27A, 29, 32, and 33B. The conglomerates display sharp contacts with sandstones.

The conglomerates are red to pink-violet in colour. Quartz granules and pebbles up to 8 mm, but 2.5 mm in average diameter are dominant. The quartz is pink, brown yellow, brown, light green and grey in colour. The quartz clasts are rounded to subrounded and very similar to the quartzes observed in the sandstones. Granules of quartzites, feldspars and mudstone intraclasts are rare. Intraclasts are up to 5 mm in diameter. Granules and pebbles of stable minerals and rocks represent about 97–98 %. Medium-grained quartz sandstone forms the matrix.

Interpretation of the lithofacies

The lithofacies Sp, Sr and Gp can be explained as products of the tractional currents. They are produced by migration of both relatively low bedforms (ripples) and bars. The existence of larger foresets is problematic. Rapid and probably episodic migration of bedforms led to the formation of sharp and often erosive contacts between sets or lithofacies. There is no direct evidence of wave or tidal action.

The lithofacies Sl reflects relatively rapid flow (upper flow regime) and episodic deposition. Lithofacies H is also connected with episodic deposition and relatively flat bedding planes. In this case, deposition from relatively rapid tractional currents alternated with relatively quieter periods. The quieter periods of deposition were suitable for biotic colonization. Moreover, fine-grained sediments (mudstones, siltstone, very fine-grained sandstones) are both mineralogically and texturally more mature than coarse-grained ones. This can be explained by multiple source and variations in transport. Sole marks reflect the plastic consistence of the sediments. It is important that all trace fossils and microfossils occur in the lithofacies H. The lithofacies H is associated with facies Sr and Sl.

Ichnology

Trace fossils occur in a few samples (cores no. 20B, 21, 27A, 29 and M-1A) only in lithofacies H (heterolithic bedding).

Diplocraterion Torell, 1870
Diplocraterion isp.
Fig. 3.1,2

Material: About twenty horizontal and vertical cross-sections of biogenic structures were found in a 7 cm long core sample of grey micaceous siltstone from the Měnín-1 borehole, at the level of 1565–1566 m. A dozen shorter, less conspicuous structures were found at the depth of 856.2 m in dark-grey to light-grey laminated siltstones to sandstones.

Description: The ichnofossils have the appearance of 10–25 mm long and 3–5 mm wide bars on bedding planes. The bars show widened terminations, interpreted as sections of vertical tubes. Vertical sections of the ichnofossils are

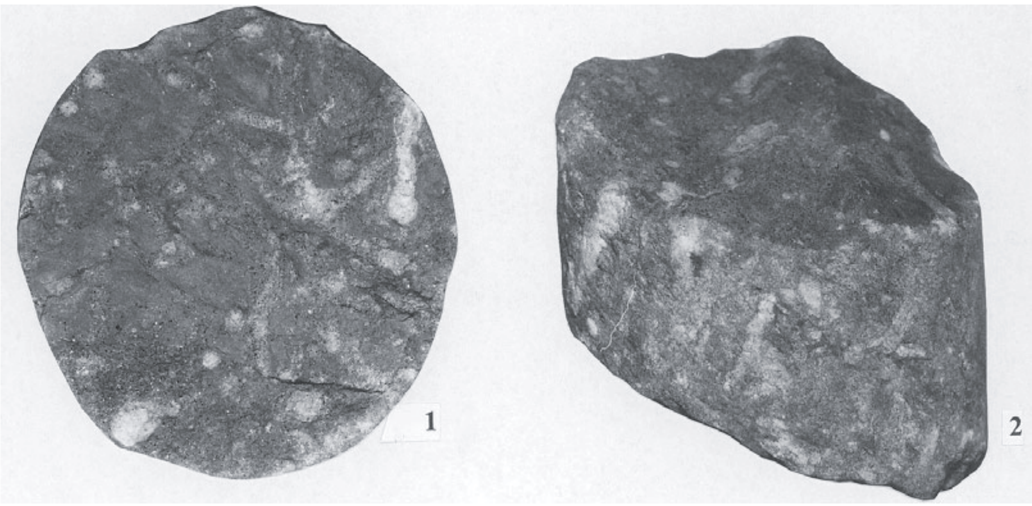

Fig. 3. 1, 2 — *Diplocraterion* isp.: The Měnín-1 borehole, interval 1565.0–1566.0 m. The core diameter is 9 cm.

perpendicular or nearly perpendicular to the bedding, with vertical extent is 15–35 mm, show a meniscate lamination (spreiten-structure). The filling of the biogenic structures is lighter and composed of sandy matrix. The samples from the depth of 866.2 m clearly show that the infilling comes from the overlying bed; the same has been observed in the sample from the level 1565.0–1566.0 m.

Remarks: The ichnofossils can be interpreted almost certainly as U-shaped vertical "limbs" each connected with a lamina of reworked sediment, that is spreite and classified as *Diplocraterion* isp. (e.g. Fürsich 1974; Häntzschel 1975; Fillion & Pickerill 1990) *Diplocraterion* represents dwelling burrows of filter feeders, typical of high energy depositional settings.

Planolites Nicholson, 1879
Planolites isp.
Fig. 4.2,3

Material: One specimen in a sample from the depth of 776.0–778.0 m. Several cross-sections of tunnels in a sample from the depth of 1298.0 m.

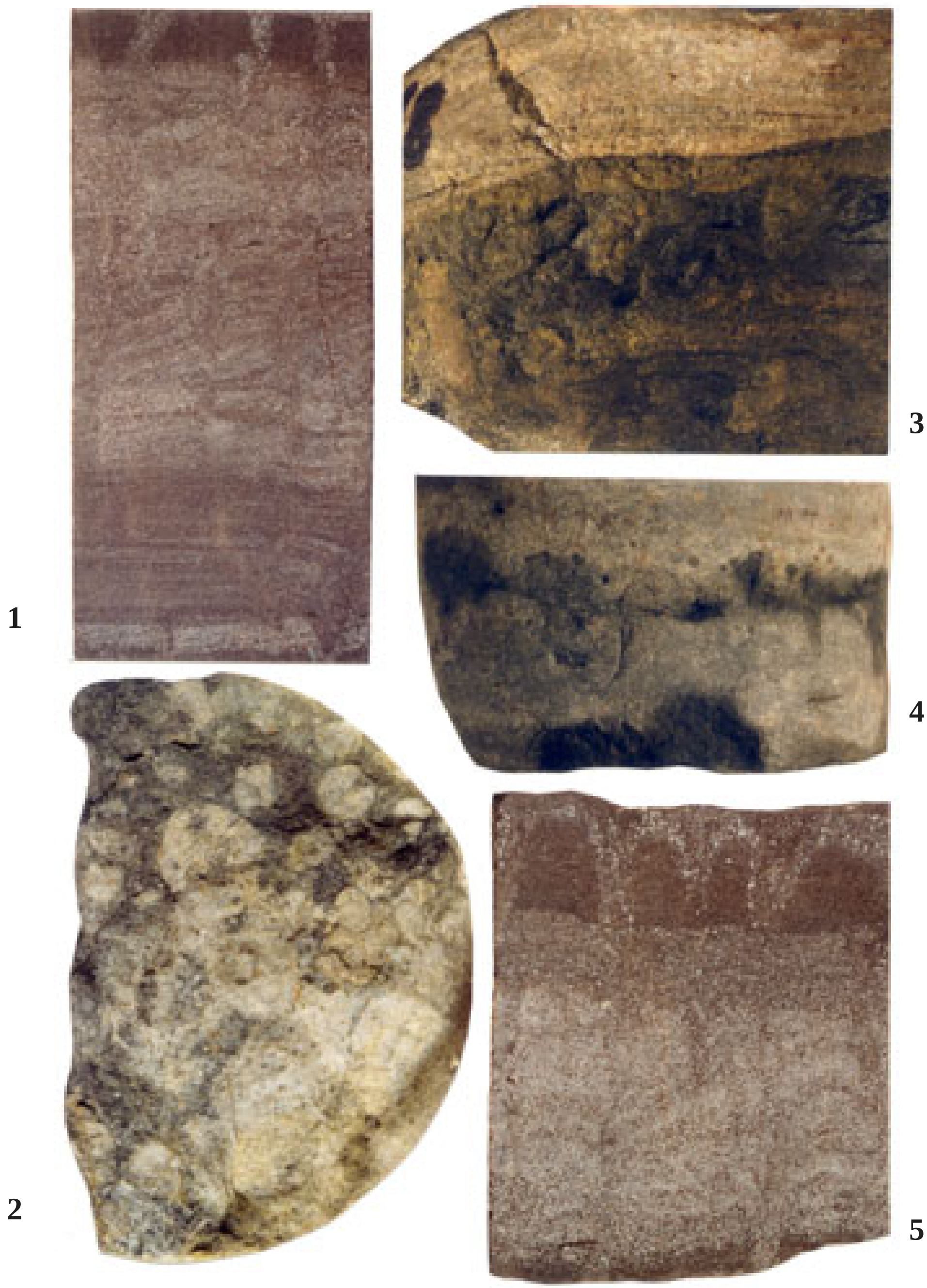

Fig. 4. 1, 4, 5 — *Skolithos* cf. *linearis* Haldemann, 1840; 1, 5: The Měnín-1 borehole, interval 776.0–778.0 m; 4: Měnín-1 borehole 1370.5 m; **2, 3** — *Planolites* isp.: The Měnín-1 borehole at the depth of 1298.0 m. The core diameter 9 cm.

Description: Subhorizontal tunnels, circular to elliptical in outline, filled with material contrasting with the surrounding rock. Tunnel diameter is 2–6 mm; observable segments are short but probably exceeding several centimetres in length.

Remarks: Ichnotaxonomic determination of the trace fossils follows the paper by Pemberton & Frey (1982). *Planolites* is usually interpreted as a trace of sediment feeding or a locomotion in-fauna trace.

Skolithos Haldemann, 1840
Skolithos cf. *linearis* Haldemann, 1840
Figs. 4.1,4,5

Material: Several tens of vertical shafts or their sections from the Měnín-1 borehole, depth 776.0–778.0 m; 1370.5 m; and 1565.0 m samples.

Description: Circular cross-sections of vertical shafts, usually 2.5–4.0 mm in diameter. One sample (1350.5 m) shows at least three larger cross-sections, reaching 8, 12 and 16 mm in diameter. Vertical aspect of the trace can be observed in only one of the samples (Fig. 4.4).

Remarks: For the systematic ichnology of *Skolithos* see, for example, Osgood (1970), Alpert (1974, 1975), Fillion & Pickerill (1990). Most of *Skolithos* are interpreted as dwelling burrows of filter feeding organisms.

Ichnological interpretation

The ichnoassemblage consists of ichnotaxa with wide stratigraphic ranges. The ichnogenera *Diplocraterion*, *Planolites* and *Skolithos* are known from Proterozoic to Recent sediments. Nevertheless, the ichnofossils enable us to interpret certain parameters of sedimentary settings. The Cambrian bioturbation is generally considered to be quite different from the rest of the Phanerozoic; recently, the term "Cambrian substrate revolution" was introduced (Bottjer et al. 2000; Dornbos & Bottjer 2000). The "pre-revolutionary phase" is characterized by a low quantity and shallowness of bioturbation of soft bottoms. In contradiction to the theory, however, relatively strongly bioturbated (but not repeatedly mixed) siltstones and sandstones bearing the *Diplocraterion* and *Skolithos* ichnofabric were described from the Lower Cambrian of the East European Platform sediments (e.g. Lendzion 1972). Paczesna (1996, 2001) distinguished several assemblages of trace fossils from the paleontologically well-dated Cambrian strata of eastern Poland. The ichnoassemblages described by this author, including *Skolithos*, *Monocraterion*, *Bergaueria* and *Planolites* are very close to the ichnofossils recognized in the Měnín-1 borehole in the ethological and environmental sense as well as in the lithology of host substrates.

The Cambrian ichnological record is limited almost exclusively to shallow sea. The only Cambrian assemblage that has been interpreted as brackish is very specific in its composition (cf. Mikuláš 1995). The described ichnofossils and the spectrum of their ethological functions points to origins in shallow marine settings with high dynamics of sedimentation and erosion. We may also identify the "kraksten-structure" of Eastern Europe (e.g. Lendzion 1972) and the *Diplocraterion* ichnofabric from the Měnín borehole.

Palynology

Prokaryotic filamentous and coccoid cyanobacteria, fungi, eukaryotic algal planktonic microfossils (acritarchs and prasinophytes), algal sheats, metazoan fossil remains, fragments of algal tissues have been recorded in the fine-grained portions of subsurface clastic sediments in the boreholes SE of Brno, between Brno and Hodonín. Microfossils were studied in permanent strew slides (Fig. 8) and thin sections, as well as by scanning electron microscopy (SEM; Figs. 5–7). The Lower Cambrian palynomorph assemblages from southern Moravia reflect the increasing diversity of planktonic eukaryotic protists following the Vendian/Cambrian transition (Vidal & Moczydłowska 1992; Moczydłowska 1999). Two main types of fossil assemblages have been distinguished: the upper Lower Cambrian (*Holmia*/*Protolenus*) diversified associations, recovered in the Němčičky-3, Němčičky-6 and in the upper part of Měnín-1 borehole, depth 473.0–477.5 m (25 genera and 53 species) and basal Cambrian assemblages of low density and low diversity (11 genera and 16 species), isolated from the bioturbated sequences in the lower part of Měnín-1 borehole (depth 1565.0–1566.5 m and 865.2 m). The upper Lower Cambrian samples from boreholes Němčičky-3 and Němčičky-6 yield assemblages dominated by acanthomorphic types of acritarchs, especially of genus *Skiagia* Downie, 1982. Planktonic microfossils display various elaborate means to enlarge vesicle surface such as long tubular processes (Fig. 5.3), irregularly branched (Fig. 5.4), distally expanded (Fig. 6.1) or connected (Fig. 6.4) or provided with outer membranes enveloping the central body (Fig. 7.1). Most common are the following species: *Skiagia* sp. indet. aff. *S. compressa* (Volkova) Downie, 1982 (Fig. 6.1,2; Fig. 7.3); *Skiagia scottica* Downie, 1982 (Fig. 6.3,4), *Skiagia ciliosa* (Volkova) Moczydłowska, 1991 (Fig. 5.1,2); *Skiagia ornata* (Volkova) Downie, 1982 (Fig. 5.3). The late Early Cambrian age is documented by the presence of species *Vogtlandia yankauskasii* (Fensome et al.) Sarjeant et Vavrdová, 1997 (Fig. 5.4), *Estiastra minima* Volkova, 1979 (Fig. 7.4), *Sagatum priscum* (Kirjanov et Volkova) Vavrdová et Bek, 2001 (Fig. 7.1) and others.

Investigations of samples from the levels 856.2 m (core number 21) and 1565–1566.5 m (core number 29) in the Měnín-1 borehole revealed the presence of evidently much older assemblages of palynomorphs. Palynological residuum contained well preserved, but sparse acritarchs and prasinophytes of low diversity and filamentous sheats of presumed cyanobacterial origin. Ribbon-shaped, irregularly twisted and folded, compressed filamentous sheets occur relatively frequently in the palynological residuum (Fig. 8.12). They are characterized by having a smooth surface and elastic wall of light to dark yellow colour. Acritarchs are dominated by leiospheres and forms with inconspicuous ornamentation of vesicle surface, such as low grana, solid thorns and short hairs (Fig. 8). Rarely present are tasmanitids (Fig. 8.3), fragments

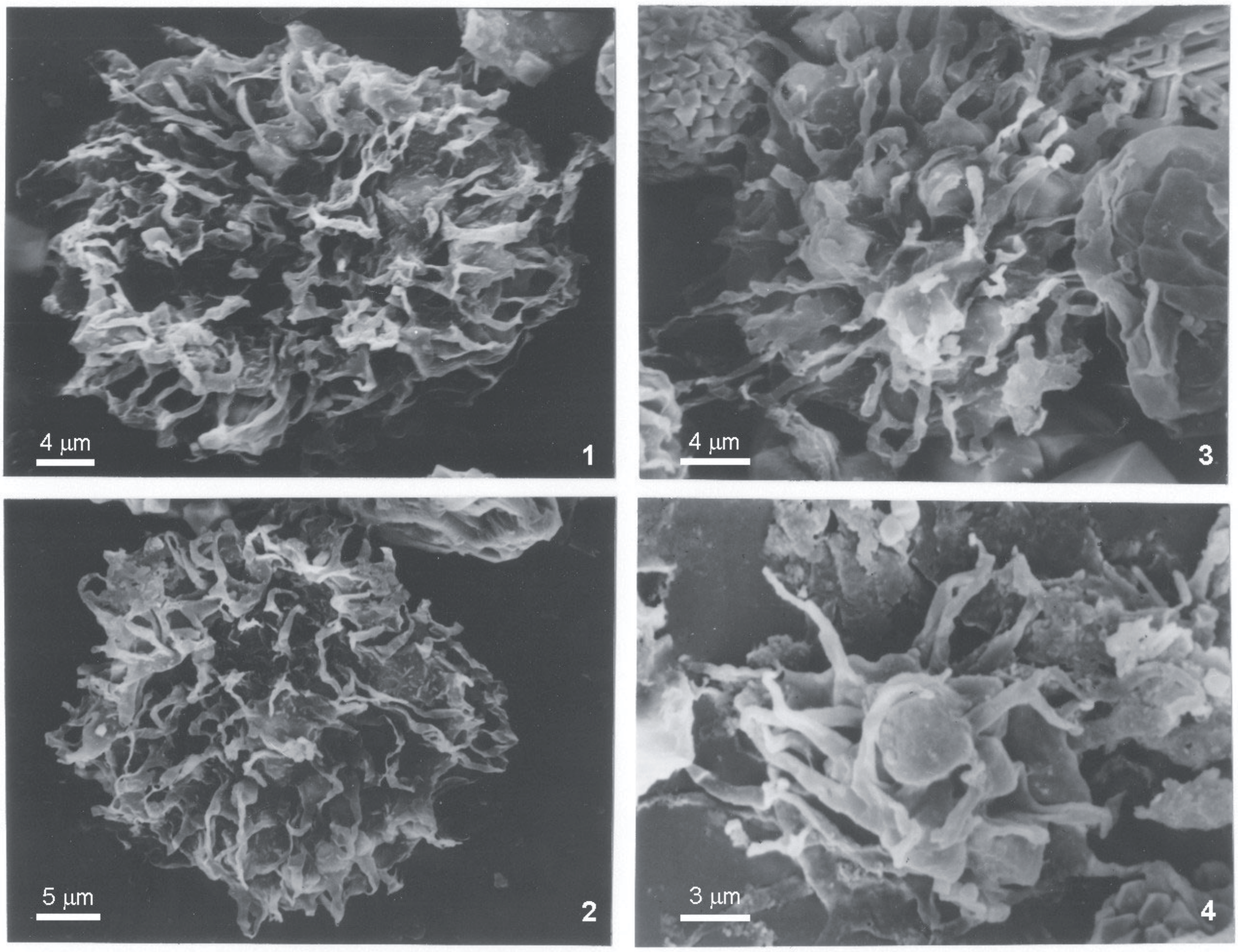

Fig. 5. SEM image JEOL, Němčičky-3 borehole, at the depth 5396.0 m. **1, 2** — *Skiagia ciliosa* (Volkova) Downie, 1982; **3** — *Skiagia ornata* (Volkova) Downie, 1982; **4** — *Vogtlandia yankauskasii* (Fensome et al.) Sarjeant et Vavrdová, 1997.

of relatively large-sized, possible Neoproterozoic phytoplankton (cf. *Tanarium*), fragments of hydrozoan stolons, various tissues and unidentifiable fragments. The following species have been identified so far: *Archaeotrichion* spp. (Fig. 8.12), *Asteridium lanatum* (Volkova) Moczydłowska, 1991, *A. tornatum* (Volkova) Moczydłowska, 1991 (Fig. 8.12), *A.* sp. indet., *Comasphaeridium agglutinatum* Moczydłowska, 1988, *Comasphaeridium molliculum* Moczydłowska et Vidal, 1988 (only at the depth 865.2 m), *C. velvetum* Moczydłowska, 1988 (Fig. 8.11), *Leiosphaeridia* sp. (Fig. 8.1), *Leiovalia tenera* Kirjanov, 1974, *Lophosphaeridium bacilliferum* Vanguestaine, 1974 (Fig. 8.2,4,6), *Lophosphaeridium tentativum* Volkova, 1968, *L.* sp. indet, aff. *L. truncatum* Volkova, 1968 (Fig. 8.5,7), *?Myxococcoides staphylidion* Lo, 1980 (only at depth 856.2 m), *Pterospermella velata* Moczydłowska, 1988 (only at depth 865.2 m), aff. *Tanarium* sp. indet. (Fig. 8.10), aff. *Tasmanites tenellus* Volkova, 1968 (Fig. 8.3), and *Ceratophyton vernicosum* Kirjanov in Volkova et al., 1979.

Fragments of microfossils provisionally assigned to Neoproterozoic large-sized process-bearing acritarchs (aff. *Tanarium*) were ascertained in the Měnín-1 borehole samples. So far they have been reported from the Khamaka Formation (Vendian to Cambrian) of eastern Siberia (Yakutia, Nepa Botuoba region) and Ediacaran Pertatataka Formation, Amadeus Basin, Australia (Moczydłowska et al. 1993).

Interpretation of palynomorphs

Age correlations are based on palynozones established by Moczydłowska (1991) within Early Cambrian subsurface successions in SE Poland (Lublin Slope). The presence of index species *A. tornatum* and *C. velvetum* as well as an absence of species frequent in younger Cambrian zones allows us to assign the sample from the depth of 1565.0–1566.5 m to the Asteridium tornatum–Comasphaeridium velvetum Acritarch Zone, as defined by Moczydłowska (1991) from southeastern Poland. This zone, contemporaneous with the oldest skeletal fauna, corresponds to the basal, lower Lower Cambrian or to the "Lontova horizon" in EEP (Volkova et al. 1983; Moczydłowska 1991, 1988; Vidal & Moczydłowska 1992) and to the Mazowsze Formation and uppermost part of the Włodawa Formation in the Lublin Slope, Poland. The assemblage recovered from the depth of 856.2 m is distinguished from the lower level by the presence of the species *Comasphaeridium*

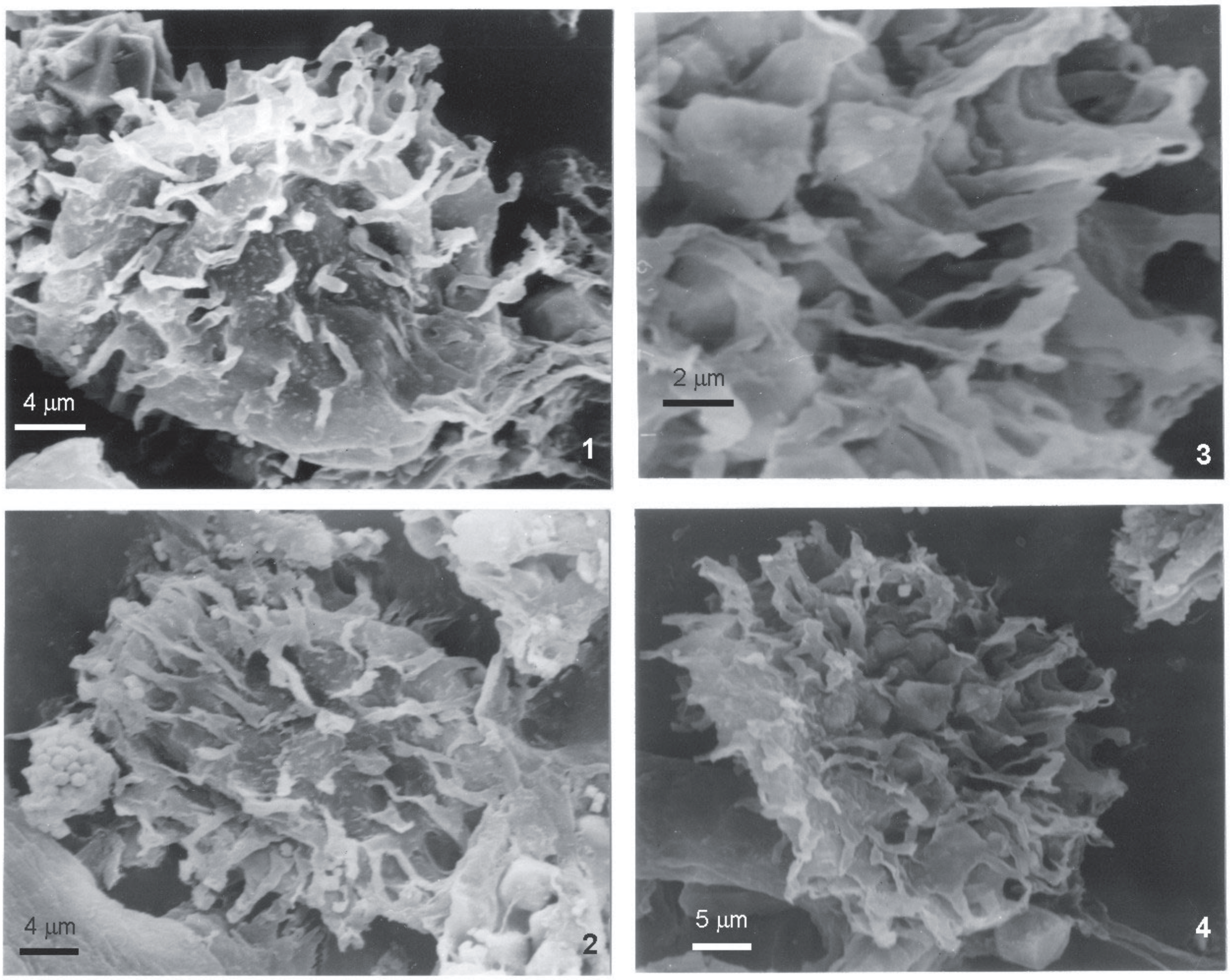

Fig 6. SEM image JEOL, the Němčičky-3 borehole at the depth of 5396.0 m. **1, 2** — *Skiagia* sp. indet. aff. *S. compressa* (Volkova) Downie, 1982; **3, 4** — *Skiagia scottica* Downie, 1982.

molliculum Moczydlowska et Vidal, 1988, which, according to Moczydlowska (1991), appears in the subsequent Skiagia ornata–Fimbriaglomerella membranacea Acritarch Zone. However, other species, typical for the Skiagia/Fimbriaglomerella Zone, have not been recorded in the assemblage. Therefore, the age assignment of the upper sample is determined as early Early Cambrian. The substance of acritarch vesicles, not affected by thermal alteration, precludes involvement in metamorphic processes.

Interpretation of depositional environment

The interpretation of depositional environment based on lithofacies study alone is limited, mostly because of the highly insufficient amount of cores available for sedimentological study (about 10 m) compared to the total thickness of the studied sediments (more than 1500 m). Facies associations were in such a case very difficult to establish.

Previous authors, who had the possibility to study the complete core material, can add some additional data. The majority of the studied deposits lack any visible bedding according to previous authors (Dvořák 1998; Skoček 1980; Zádrapa 1975). Cross-bedding was described as relative common. Trough cross-bedding predominates and was characterized as small- or medium-scale one. Horizontal stratification and grain-size grading are rare. Erosional contacts of beds are common (Zádrapa & Skoček 1983). Facies from the Měnín-1 borehole significantly differ from those recognized in Brno — Červený kopec Hill (Nehyba et al. 2001). Cathodoluminescence studies confirm these differences (Leichmann & Nehyba 1998).

The studied drill cores show a mixture of terrestrial and marine influences. Previous authors (Dvořák 1998; Skoček 1980; Zádrapa & Skoček 1983, etc.) interpreted an exclusively terrestrial environment. Indeed, the most often recognized facies (Sp, Sr, Gp) fits in well with alluvial or fluvial environments. However, trace fossils can help in tracing marine influences in the depositional environment (cf. Reading 1996). Trace fossils not only helped us to identify and interpret the sedimentary environment, but also to define the interaction between the biotic assemblage and the abiotic factors of the environment. It is also necessary to bear in mind that sedi-

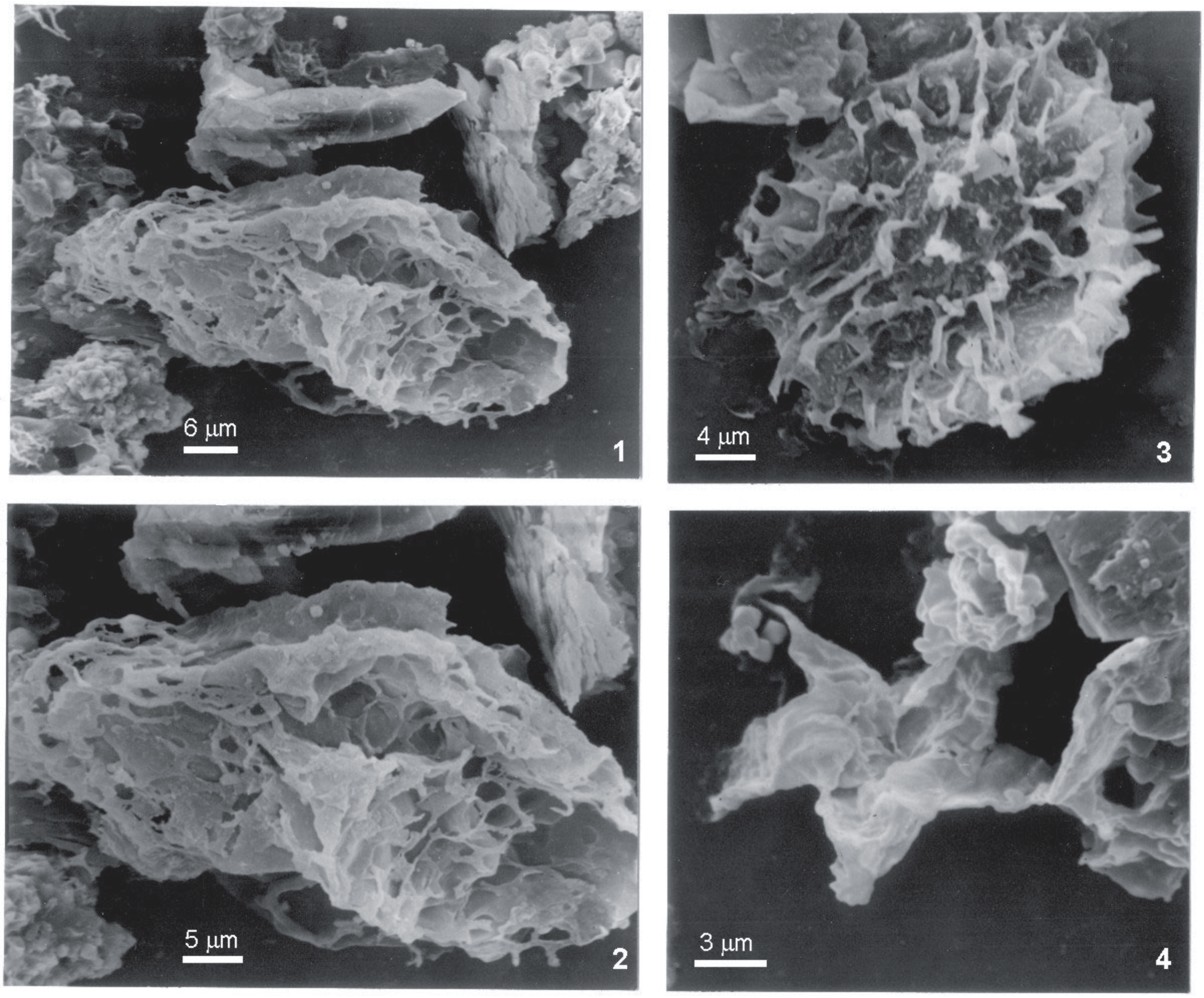

Fig. 7. SEM image JEOL, locality Němčičky-3 borehole, depth 5396.0 m. **1, 2** — *Sagatum priscum* (Kirjanov et Volkova) Vavrdová et Bek, 2001; **3** — *Skiagia ciliosa* (Volkova) Downie, 1982; **4** — *Estiastra minima* Volkova, 1979.

mentary processes and environments may have been very different before the appearance of abundant metazoans and land plants. Before land plants appeared, rivers were predominantly braided (Schumm 1968; Cotter 1978) and eolian action was enhanced (Dalrymple et al. 1985). These non-actualistic effects also played an important role in the continental margin successions (MacNaughton et al. 1997).

The studied deposits were very probably deposited under a strong influence of a fluvial environment (braided river?). Relatively rare occurrence of silt fraction can be explained by wind action. This action was strong without the protective effect of land plants, especially in episodically flooded areas. The preferred removal of fine material would help in producing bedload-dominated rivers. The rapid transport, high content of transported material in bedload, arid to semiarid conditions(?), non-cohesive unstable banks, probably high width: depth ratios and steep channel gradient, led to rapid switching of the channels. Braidplains were enormous (McCormick & Grotzinger 1993) and shorelines were dominated by rapid shifting of river mouths (MacNaughton et al. 1997). The deposition in the studied case was affected by the marine action in marginal or distal areas (interdistributary area, braid delta?) mainly during reduced fluvial input or channel shifting. Shallow marine conditions close to the shoreline can be supposed. Wind action could also add "exotic" fine-grained (silt-sized) material, especially into a marine depositional environment (Dalrymple et al. 1985). Multiple sources for sandstone with grain-size bimodality are evident. Clay deficiency in the studied deposits can be connected with rock provenance or type of weathering (climate).

Recurring alternation of terrestrial/fluvial and marine influences through the sediment succession can be supposed. Evolution of sedimentary environments upward through the succession is in question. Various petrological criteria can reflect the evolution of the source area or climatic differences (Skoček 1980). These criteria are: 1. The upper unit is mineralogically more mature (quartzose sandstone), whereas the lower unit has a higher content of less stable components (feldspar, etc.). 2. The upper unit has strong dominance of monocrystalline quartz grains and the proportion of quartz is generally higher than in the lower one. The content of monocrystallic and aggregate quartz grains is very irregular in the

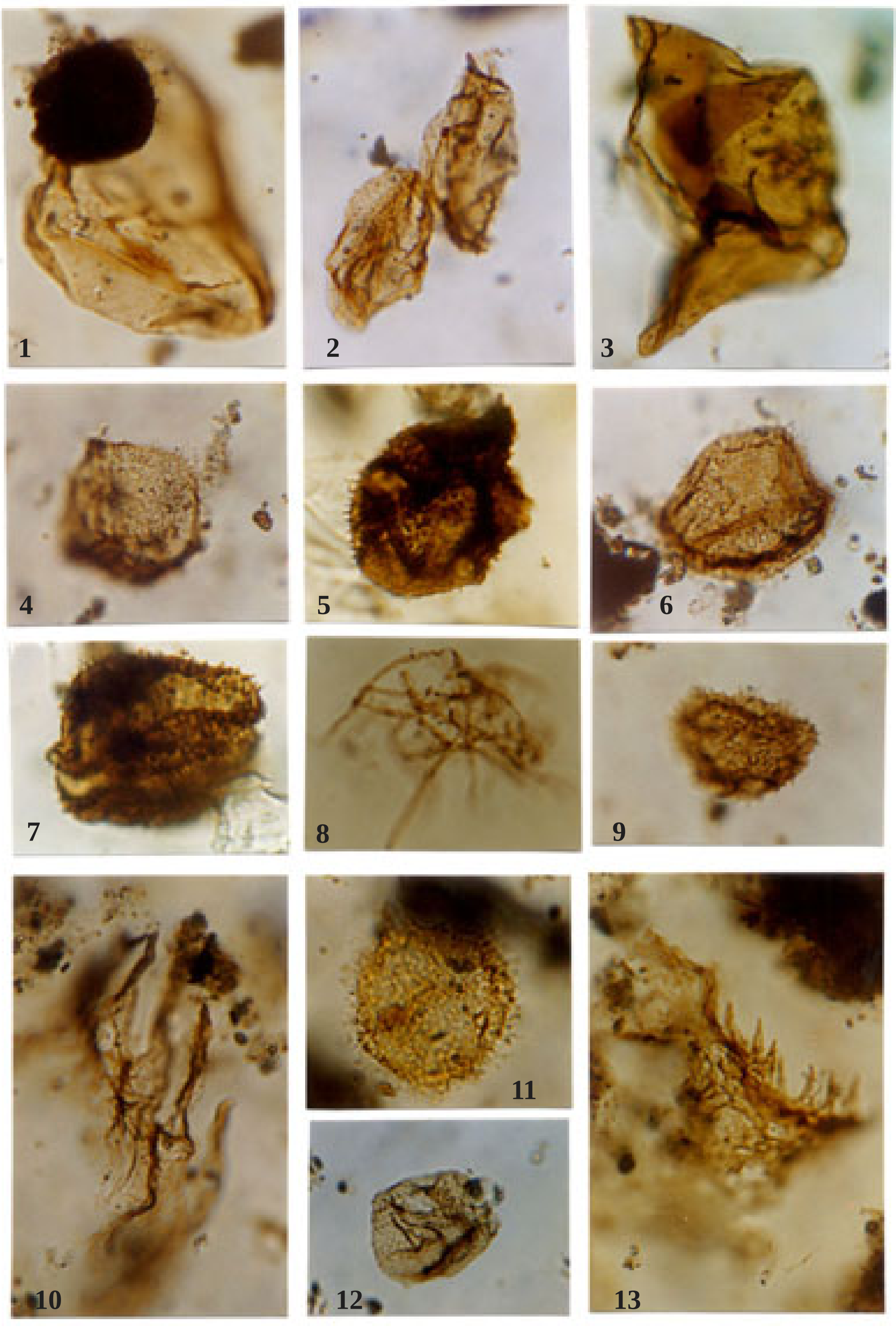

Fig. 8. Acritarchs from the Měnín-1 borehole. **1** — *Leiosphaeridia* sp.; depth 856.2 m, size 60 µm. **2** — two specimens of *Lophosphaeridium bacilliferum* Vanguestaine, 1974, surface covered with extremely delicate outgrowths; depth 856.2 m, size 30 µm. **3** — aff. *Tasmanites tenellus* Volkova, 1968, wall finely perforated; depth 1565.0 m, size 65 µm. **4, 6** — *Lophosphaeridium bacilliferum* Vanguestaine, 1974; depth 856.2 m and 1565 m, size 34 and 27 µm. **5, 7** — *Lophosphaeridium* sp. indet., aff. *L. truncatum* Volkova, 1968; depth 1565–1566.5 m, size 35 and 39 µm. **8** — *Archaeotrichion* sp. indet.; depth 1565 m, size 44 µm. **9** — *Asteridium lanatum* (Volkova) Moczydłowska, 1991; depth 1565 m, size 27 µm. **10** — Fragment of ?*Tanarium* sp., aff. *Tanarium conoideum* Kolosova, 1991; depth 1565–1566.5 m, size 70 µm. **11** — *Comasphaeridium velvetum* Moczydłowska, 1988; depth 1565–1566.5 m, size 37 µm. **12** — *Asteridium tornatum* (Volkova) Moczydłowska, 1991; depth 1565.0–1566.5 m, size 23 µm. **13** — Fragment of ?*Tanarium* sp., aff. *T. irregulare* Moczydlowska et al., 1993; depth 1565.0–1566.5 m, size 105 µm.

lower layer (Maštera 2000; Zádrapa & Skoček 1983). 3. The content of stable minerals in the heavy mineral spectra generally increases to the top of the sedimentary succession. Especially the amounts of garnet and apatite distinctly increase at the expense of zircon (Dvořák 1998). It can be supposed that the hypothetical evolution of the source area also affected the depositional area (Blair & McPherson 1994). The abundant presence of subrounded quartz grains can be connected with prolonged transport or multiple redeposition.

Paleogeography

The unicellular microfossils presented here were extracted from the sediments, which form the basal member of the clastic cover of the Brunovistulicum (Dudek 1980) or Moravo-Silesian terrane (Pharaoh 1999). The Brunovistulicum extends from northern Austria to southern Poland (Upper Silesia). It is reworked into para-autochthonous nappes along the eastern termination of Variscides on its western side and concealed under the Carpathian and Alpine orogenic belts in the east (Jelínek & Dudek 1999).

The present position of the Brunovistulicum south of the Trans-European Suture Zone points to its Gondwanan, Pan-African affinity (Nehyba et al. 2001). A collage of blocks forming the Trans-European Fault Zone is generally regarded as a suture of the former Tornquist Ocean, dividing the southern margin of Baltica from peri-Gondwanan terranes. Gondwanan affinity is explicit for such microcontinents as Perunica, Iberoarmorica and Avalonia. The region of E Moravia and SE Poland, including the Łysogóry and Małopolska blocks, is distinguished by autonomous geological, paleontological and petrological record (Franke 1995; Żelaźniewicz 1998). Previously, affinities of the Moravo-Silesian Zone to the East European Platform and to the Ukrainian block have been suggested (e.g. Suk et al. 1984; Havlíček et al. 1994).

In the provenance study of detrital zircons in Cambrian sediments, Belka et al. (2000) proposed the Early Paleozoic (before mid-Cambrian) docking of the Małopolska Massif and Upper Silesia to the Eastern European Platform. Moczydłowska (1997, 1998, 1999) and other authors proposed the position of Upper Silesia within Eastern Avalonia, in a close proximity to Iberia. The Avalonian composite terrane (McKerrow & Cocks 1995; Nance & Murphy 1996), rifted from Gondwana in the Early Cambrian, was finally accreted to the Trans-European Suture Zone (the final docking to Laurussia).

Recently, the presence of detrital zircons of "Cadomian" age in the Okuniew IG-1 borehole situated within the EEP part of Poland, led Valverde-Vaquero et al. (2000) to dispute the role of radiometric ages as a sole criterion for determination of terrane provenance.

The peri-Gondwanan belt of microcontinents (Avalonia, Armorica, Iberia, Perunica, Hungary, Turkey, Karakorum, Yangtze Platform) is distinguished in the Arenig/Llanvirn time interval by "Mediterranean" fossil marine microplankton, by clastic sedimentation with common oolitic iron ores and an absence of carbonates. The geographical differentiation of acritarch assemblages in the Early Ordovician (Vavrdová 1997b; Servais & Fatka 1997) is well documented. Assemblages of plant microfossils described by Jachowicz (in Buła & Jachowicz 1992 i.e. *Baltisphaeridium–Ordovicidium–Peteinosphaeridium* assemblage) represent unequivocal evidence of the low-latitude, warm-water latitudinal position of Upper Silesia in the Early Ordovician.

The Early Cambrian fossil record of unicellular marine microplankton is not yet known in sufficient detail to allow a definition of fossil phytoplankton bioprovinces comparable to the well recognized Early Ordovician acritarch provincialism. Moczydłowska (Moczydłowska & Vidal 1992; Moczydłowska 1991, 1998) maintains worldwide uniform distribution of Early Cambrian acritarchs. However, the composition of Early Cambrian assemblages of palynomorphs from the Měnín-1 borehole is closely similar to coeval microplankton populations known from Baltoscandia, from Eastern Europe (Latvia, Estonia), and eastern Poland and Ukraine (Fatka &Vavrdová 1998; Vavrdová & Bek 2001). Some acritarch species common in southern Moravia such as *Sagatum priscum* (Kirjanov) Vavrdová et Bek, 2001 and *Liepaina plana* Jankauskas et Volkova in Volkova et al., 1979 have not been recorded outside Baltoscandia and the Eastern European Platform. The Baltic affinity of Brunovistulicum is supported both by the Early Cambrian macrofaunal fossil record (Early Cambrian Baltic types of trilobites in Goczałkowice borehole, Upper Silesia; Orłowski 1975, 1985), geological structure (Dvořák 1968) and sedimentological development, namely the presence of platform carbonates in the Arenig of Upper Silesia, Małopolska and Łysogóry blocks (Belka et al. 2000; Valverde-Vaquero et al. 2000). The Brunovistulicum, like Baltica, was apparently translated from the high southern latitudes in the Early Cambrian to the low-latitude warm-water realm in which the Early Ordovician carbonates originated (Fig. 9). On the other hand, microplates of the peri-Gondwanan origin drifted in opposite direction, from warm and temperate water masses in Early Cambrian to the subpolar position in the Arenig/Llanvirn (Cocks & McKerrow 1995; Cocks et al.

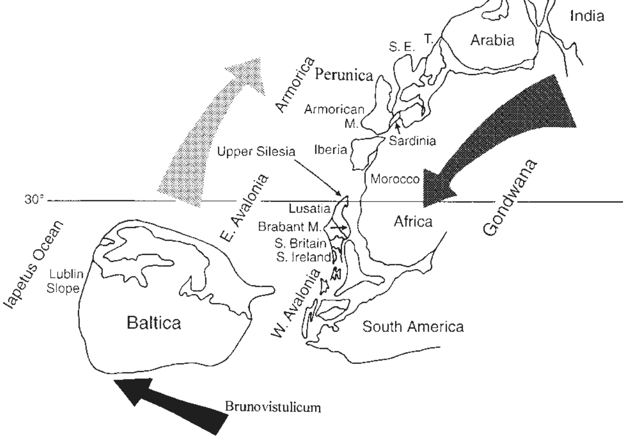

Fig. 9. Position and translation of peri-Gondwanan (dark arrow) and Baltica-related (light-grey arrow) terranes at the Baltica/Gondwana interface in the Early Cambrian. Position of Upper Silesia as proposed by Moczydłowska (1997). T = Turkey, S. E. = Southern Europe.

1997; Pharaoh 1999). Apparently, geological, petrological, faunal and microfloral data put some doubts on the Trans-European Fault Zone as a suture of the former Tornquist Ocean (Cocks et al. 1997; Berthelsen 1998).

Conclusions

Stratigraphy. The newly recovered microfossils allow us to determine the age of marine transgression in southern Moravia as the Early Cambrian (Platysolenites antiquissimus Faunal Zone). The basal transgressive deposits represent the oldest succession so far recognized in the eastern margin of the Bohemian Massif.

Environment. Lithofacies and ichnofossils indicate the presence of shallow marine deposits in the units previously regarded as exclusively terrestrial.

Palaeogeography. New data further support the affinities of the Moravo-Silesian Zone to the Baltica.

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References

Alpert S.P. 1974: Systematic review of the genus *Skolithos*. *J. Palaeont*. 48, 661–669.

Alpert S.P. 1975: *Planolites* and *Skolithos* from the Upper Precambrian-Lower Cambrian White-Inyo Mountains, California. *J. Palaeont*. 49, 508–521.

Belka Z., Ahrendt H., Franke W. & Wemmer K. 2000: The Baltica-Gondwana suture in central Europe: evidence from K-Ar ages of detrital muscovites and biogeographical data. In: Franke W., Haak V., Oncken V. & Tanner D. (Eds.): Orogenic processes: Quantification and modelling in the Variscan belt. *Geol. Soc. London, Spec. Publ.* 179, 87–102.

Berthelsen A. 1998: The Tornquist Zone northwest of the Carpathians: an intraplate pseudosuture. *Geol. Fören. Förh.* 120, 223–230.

Blair T.C. & McPherson J.G. 1994: Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes, and facies assemblages. *Sed. Researche* 54, 3, 450–489.

Bottjer D.J., Hagadorn J.W. & Dornbos S.Q. 2000: The Cambrian substrate revolution. *GSA Today* 10, 9, 1–9.

Buła Z. & Jachowicz M. 1996: The Lower Paleozoic sediments in the Upper Silesian Block. *Geol. Quart.* 40, 3, 299–336.

Cocks L.R.M., McKerrow W.S. & Staal C.R. van 1997: The margins of Avalonia. *Geol. Mag*. 134, 627–636.

Cotter E. 1978: The evolution of fluvial style, with special reference to the central Appalachian Paleozoic. In: Miall A.D. (Ed.): Fluvial sedimentology. *Mem. Can. Soc. Petrol. Geol*. 5, 361–383.

Dalrymple R.W., Narbone G.M. & Smith L. 1985: Eolian action and the distribution of Cambrian shales in North America. *Geology* 13, 607–610.

Dornbos S.Q. & Bottjer D.J. 2000: Evolutionary paleoecology of the earliest echinoderms: Helicoplacoids and the Cambrian substrate revolution. *Geology* 28, 9, 839–842.

Dudek A. 1980: The crystalline basement block of the Outer Carpathians in Moravia: Bruno-Vistulicum. *Rozpr. Čs. Akad. Věd, Ř. Mat. Přír. Věd* 90, 1–85.

Dvořák J. 1968: Tectogenesis of the Central European Variscides. *Czech Geol. Survey Bull.* 43, 465–473.

Dvořák J. 1978: Geology of the Paleozoic beneath the Carpathians in the area SE of the Drahany Upland. *Zemní Plyn Nafta* 23, 2, 185–203 (in Czech).

Dvořák J. 1998: Lower Devonian basal clastics Old Red Formation, Southern Moravia, Czech Republic. *Czech Geol. Survey Bull.* 73, 4, 271 – 279.

Fatka O. & Vavrdová M. 1998: Early Cambrian Acritarcha from sediments underlying the Devonian in Moravia (Měnín borehole, southern Moravia). *Czech Geol. Survey Bull.* 73, 1, 55–60.

Fillion D. & Pickerill R.K. 1984: Ichnology of the Upper Cambrian to Lower Ordovician Bell Islands and Wabana groups of eastern Newfoundland, Canada. *Palaeontographica Canad.* 7, 1–119.

Franke D. 1995: The Caledonian terranes along the southwestern border of the East European platform — evidence, speculations and open questions. In: Gee D.G & Beckholmen M. (Eds.): The Trans-European suture zone: EUROPROBE in Liblice 1993. *Stud. Geophys. Geodet.* 39, 241–256.

Fürsich F.T. 1974: Ichnogenus *Rhizocorallium*. *Paläont. Z.* 48, 1–2, 16–28.

Havlíček V., Vaněk J. & Fatka O. 1994: Perunica microcontinent in the Ordovician — its position within the Mediterranean province, series division, benthic and pelagic associations. *Sbor. Geol. Věd, Geol.* 46, 23–56.

Häntzschel W. 1975: Trace fossils and problematica. In: Teichert C. (Ed.): Treatise on Invertebrate Paleontology, Part W (Miscellanea). Suppl. 1, *Univ. Kansas & Geol. Soc. Amer. Press.,* Lawrence, W1–W269.

Jachowicz M. & Přichystal A. 1997: Lower Cambrian sediments in deep boreholes in south Moravia. *Czech Geol. Survey Bull.* 72, 4, 329–332.

Jelínek E. & Dudek A. 1993: Geochemistry of subsurface Precambrian plutonic rocks from the Brunovistulian complex in the Bohemian massif, Czechoslovakia. *Precambrian Res.* 62, 103–125.

Leichmann J. & Nehyba S. 1998: The red beds on the eastern margin of the Bohemian Massif: its bearing to unravel the tectonic evolution. *Acta Univ. Carolinae, Geologica* 42, 2, 296–297.

Lendzion K. 1972: Stratigraphy of the Lower Cambrian from the area of Podlasie. *Instytut Geologiczny, Biuletyn* 232, 69–157 (in Polish).

Lo S.C. 1980: Microbial fossils from the lower Yudoma suite, earliest Phanerozoic, eastern Siberia. *Precambrian Res.* 13, 109–166.

MacKerrow W.S. & Cocks L.R.M. 1995: The use of biostratigraphy in the terrane assembly of the Variscan belt of Europe. *Stud. Geophys. Geodet*. 39, 269–275.

MacNaughton R.B., Dalrymple R.W. & Narbonne G.M. 1997: Early Cambrian braid-delta deposits, MacKenzie Mountains, northwestern Canada. *Sedimentology* 44, 587–609.

Maštera L. 1993: Paleozoic clastics near Borotice eas of Znojmo. *Zpr. geol. Výzk. R. 1992,* 1–68 (in Czech).

Maštera L. 2000: Lithological revision of Lower Cambrian clastics from borehole Měnín-1. *Zpr. geol. Výzk. R. 1999,* 59–63 (in Czech).

McCormick D.S. & Grotzinger J.P. 1993: Distinction of marine from alluvial facies in the Paleoproterozoic (1,9 GA) Burnside Formation, Kilohigok Basin, N.W.T., Canada. *J. Sed. Petrology* 63, 398–416.

Mikuláš R. 1995: Trace fossils from the Paseky Shale (Early Cambrian, Czech Republic). *J. Czech Geol. Soc*. 40, 4, 37–45.

Mikuláš R. & Nehyba S. 2001: Trace fossils in rocks of presumed Lower Cambrian age in borehole Měnín-1 in South Moravia. *Geol. Výzk. Mor. Slez. v R. 2000*, 47–50 (in Czech).

Moczydłowska M. 1988: New Lower Cambrian acritarchs from Poland. *Rev. Palaeobot. Palynol*. 54, 1–10.

Moczydłowska M. 1991: Acritarch biostratigraphy of the Lower Cambrian and the Precambrian-Cambrian boundary in southeastern Poland. *Foss. Strata* 29, 1–127.

Moczydłowska M. 1997: Proterozoic and Cambrian successions in Upper Silesia: an Avalonian terrane in southern Poland. *Geol. Mag*. 134, 679–689.

Moczydłowska M. 1998: Cambrian acritarchs from Upper Silesia, Poland biochronology and tectonic implications. *Foss. Strata* 46, 1–121.

Moczydłowska M. 1999: The Lower-Middle Cambrian boundary recognized by acritarchs in Baltica and at the margin of Gondwana. *Boll. Soc. Paleont. Ital. (Pisa)* 38, 207–225.

Moczydłowska M. & Vidal G. 1992: Phytoplankton from the Lower Cambrian Laesa Formation on Bornholm, Denmark. *Geol. Mag*. 129, 17–40.

Moczydłowska M., Vidal G. & Rudavskaja V.A. 1993: Neoproterozoic (Vendian) phytoplankton from the Siberian platform, Yakutia. *Palaeontology* 36, 3, 495–521.

Nance R.D. & Murphy J.B. 1996: Basement isotopic signatures and the Neoproterozoic paleogeography of Avalonian–Cadomian and related terranes in the circum-North Atlantic. In: Nance R.D. & Thompson M.D. (Eds): Avalonian and related Peri-Gondwanan Terranes in the Circum-North Atlantic. *Geol. Soc. Amer., Spec. Pap.* 304, 333–346.

Nehyba S., Kalvoda J. & Leichmann J. 2001: Depositional environment of the "Old Red" sediments in the Brno area (south-eastern part of the Rhenohercynian Zone, Bohemian Massif). *Geol. Carpathica* 52, 4, 195–203.

Orłowski S. 1975: Lower Cambrian trilobites from Upper Silesia (Goczalkowice borehole). *Acta Geol. Pol*. 25, 377–383.

Orłowski S. 1985: Lower Cambrian and its trilobites in the Holy Cross Mts. *Acta Geol. Pol*. 35, 231–250.

Osgood R.G. (Jr.) 1970: Trace fossils of the Cincinnati area. *Palaeontographica Amer*. 6, 41, 281–444.

Paczeńna J. 1996: The Vendian and Cambrian ichnocoenoses from the Polish part of the Wast-part of the East-European platform. *Prace Panstw. Inst. Geol*. 152, 1–77.

Paczeńna J. 2001: An application of trace fossils in the facies analysis and high-resolution sequence stratigraphy — an example from the Cambrian of the Polish part of the East European Craton. *Przegl. Geol*. 49, 1137–1146 (in Polish).

Palacios T. & Vidal G. 1992: Lower Cambrian acritarchs from northern Spain: the Precambrian-Cambrian boundary and biostratigraphic implications. *Geol. Mag*. 4, 421–436.

Pharaoh T.C. 1999: Palaeozoic terranes and their lithospheric boundaries within the Trans-European Suture Zone (TESZ): a review. In: Thybo H., Pharaoh T. & Guterch A. (Eds.): Geophysical investigation of the Trans-European suture zone. *Tectonophysics* 314, 17–41.

Pemberton S.G. & Frey R.W. 1982: Trace fossil nomenclature and the *Planolites–Palaeophycus* dilemma. *J. Paleont*. 56, 4, 843–881.

Reading H.G. (Ed.) 1996: Sedimentary Environments: Processes, Facies and Stratigraphy. *Blackwell Sci. Publ.,* 1–593.

Roth Z. 1981: Lower Cambrian in Moravia? *Čas. Mineral. Geol*. 26, 1, 1–6 (in Czech).

Servais T. & Fatka O. 1997: Recognition of the Trans-European Suture Zone (TESZ) by the palaeobiological distribution pattern of early to middle Ordovician acritarchs. *Geol. Mag*. 134, 5, 617–625.

Schumm S.A. 1968: Speculations concerning paleohydrologic controls of terrestrial sedimentation. *Bull. Geol. Soc. Amer*. 79, 1573–1588.

Skoček V. 1978: Additional sedimentological assessment of Paleozoic (including Devonian basal clastics) from new and older boreholes of MND Hodonín in the sectors South, Centre and North. *Manuscript*, *Czech Geological Survey,* Praha (in Czech).

Skoček V. 1980: New information on the lithology of the Devonian basal clastics in Moravia. *Czech Geol. Survey Bull*. 55, 1, 27–37 (in Czech).

Suk M., Blížkovský M., Buday Z., Chlupáč I. & Cicha I. 1984: Geological history of the territory of the Czech Socialist Republic *Ústř. Úst. Geol*., Praha, 1–396.

Valverde-Vaquero P., Dorr W., Belka Z., Franke W., Wiszniewska J. & Schastok J. 2000: U-Pb single-grain dating in the Cambrian of central Poland: implications for Gondwana versus Baltica provenance studies. *Earth Planet. Sci. Lett.* 184, 225–240.

Vavrdová M. 1997a: Acritarchs of Cambrian age from the terrigenous sediments underlying Moravian Devonian (borehole Němčičky-6). *Zemní Plyn Nafta*, 42, 31–32 (in Czech).

Vavrdová M. 1997b: Early Ordovician provincialism in acritarch distribution. *Rev. Palaeobot. Palynol*. 98, 33–40.

Vavrdová M. & Bek J. 2001: Further palynomorphs of Early Cambrian age from clastic sediments underlaying the Moravian Devonian. *Bull Czech Geol. Survey* 76, 2, 113–126.

Vidal G. & Moczydłowska M. 1992: Patterns of phytoplankton radiation across the Precambrian-Cambrian boundary. *J. Geol. Soc. London* 149, 647–654.

Vidal G. & Moczydłowska M. 1995: The Neoproterozoic of Baltica stratigraphy, palaeobiology and general geological evolution. *Precambr. Res*. 73, 197–216.

Volkova N.A., Kirjanov V.V., Piscun L.V. & Pashkevichiene L.T. 1983: Plant microfossils. In: Urbanek A. & Rozanov A.Yu. (Eds.): Upper Precambrian and Cambrian palaeontology of Eastern European Platform. *Wydawnictwa Geologiczne*, Warszawa, 7–46.

Yin Leiming 1986: Acritarchs. In: Chen Jun-Yuan (Ed.): Aspects of Cambrian-Ordovician boundary in Dayangcha, China. *China Prospect Publ. House,* Beijing 314–373.

Zádrapa M. 1975: Sedimentary petrography of the borehole Měnín-1. *Manuscript*, *Moravian Oil Mines,* Hodonín (in Czech).

Zádrapa M. & Skoček V. 1983: Sedimentological assessment of basal Devonian clastics and Paleozoic carbonates in the sector South. *Zemní Plyn Nafta* 28, 267–289 (in Czech).

Zapletal K. 1922: Geological structure of Moravian Karst. *Čas. Morav. Zem. Mus*. 20, 220–256 (in Czech)

Żelaźniewicz A. 1998: Rodinian-Baltican link of Neoproterozoic orogen in southern Poland. In: Erdtmann B.D. & Kraft P. (Eds.): Prevariscan terrane analysis of "Gondwanan Europe". *Acta Univ. Carol., Geol.* 42, 3–4, 509–515.