Two benthic microbial assemblages from the Měnín-1 borehole (Early Cambrian, Czech Republic)

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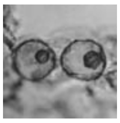

Diverse, well preserved benthic microbial assemblages are described from two stratigraphic levels of the Měnín-1 borehole from southern Moravia. Abundant cyanobacterial sheets, acritarchs, prasinophytes, and acid-resistant tissues, together with the ichnological and petrological evidence, indicate a shallow marine environment with occasional terrestrial influence. A sheltered depositional environment enabled the preservation of algal coenobia and intracellular structures. A palynological assessment contributed to the more accurate biostratigraphy of the Early Cambrian sediments in southern Moravia and confirmed the large extent of the basal Cambrian deposits. Some microfossils suggest the possible presence of undisturbed marine sediments of Ediacaran age. The tectonic position of the Brunovistulicum in pre-Variscan Europe is discussed. • Key words: Early Cambrian, acritarchs, biostratigraphy, Southern Moravia.

VAVRDOVÁ, M. 2006. Two benthic microbial assemblages from the Měnín-1 borehole (Early Cambrian, Czech Republic). *Bulletin of Geosciences 81(2)*, 115–122 (3 figures). Czech Geological Survey, Prague. ISSN 1214-1119. Manuscript received December 5, 2005; accepted in revised form March 28, 2006; issued June 30, 2006.

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Siliciclastic sediments of variable thickness and various petrological characteristics, the so-called "basal clastics" or "Basal Clastic Series", overlay the Neoproterozoic Brno Massif of the alleged Cadomian provenance (Breemen *et al.* 1982, Belka *et al*. 2000). The Brno Massif is formed by heterogeneous units of metamorphosed and plutonic rocks that were accreted onto the eastern margin of the Bohemian Massif during the Variscan Orogeny (Dvořák 1968, Jelínek & Dudek 1993, Hanžl & Melichar 1997). Granodiorites of the Thaya (Dyje) Terrane in the west and high-grade paragneisses of the Slavkov Terrane in the east (Finger *et al*. 2000) are separated by the roughly N/S trending Central Metabazite Zone. The sedimentary cover of the strongly metamorphosed plutonic rocks consist of sediments of the Early Palaeozoic and possibly Ediacaran age. Well preserved and abundant organic-walled microfossils from the basal clastics enabled the relatively precise age assignment of these specimens to the Early/Middle Cambrian and Early/Middle Devonian, and the elucidation their palaeoenvironmental and palaeogeographic affinities. Known acritarch assemblages of Early Cambrian age from southern Moravia have so far been described from the three boreholes Měnín-1, Němčičky-3, and Němčičky-6, all of which are situated between Brno and Hodonín (Fig. 1). Deposits of Early Cambrian age in the Měnín-1 borehole, situated in the Carpathian foredeep 15 km SSE from Brno, lay relatively close to the surface. In the two other boreholes Early Cambrian strata occur at depths of more than 5 km, underneath West Carpathian nappes (Fig. 1).

The Měnín-1 borehole occupies an unique position among the numerous boreholes drilled during oil exploration by Morava Oil Mines Company, Hodonín. Although it reached a depth of 2100 m, no crystalline basement was encountered. A Givetian rugose coral fauna has been identified at the base of the carbonate sequence, at a depth of 397.6–398.9 m (Galle *in* Zukalová *et al*. 1981). Siliciclastic sediments underlying the carbonates of Devonian age and overlying the Brno Massif attain thicknesses of at least 1683 m in the borehole. Palynological analysis proved to be a suitable method for the biostratigraphical evaluation of clastics that are devoid of other palaeontological evidence.

Early Cambrian associations of organic-walled microfossils described independently by Jachowicz & Přichystal (1997) and Fatka & Vavrdová (1998) from core No. 16 (depth 473.0 to 477.5 m) have been supplemented by an older, basal Cambrian fossil biota from depths of 856.2 m and 1565.0–1566.5 m (Vavrdová *et al*. 2003). Recently, siliciclastics from a depth of 468.8 to 469.1 m (core No. 15) yielded abundant fragments of Devonian fossil flora (Trimerophytina, Algae). Abundant and well preserved miospores from the same stratigraphic level indicated late Emsian to early Eifelian ages. Floral fossil remains suggest a close palaeogeographic relationship between Moravia and southern Poland (Purkyňová *et al*. 2004).

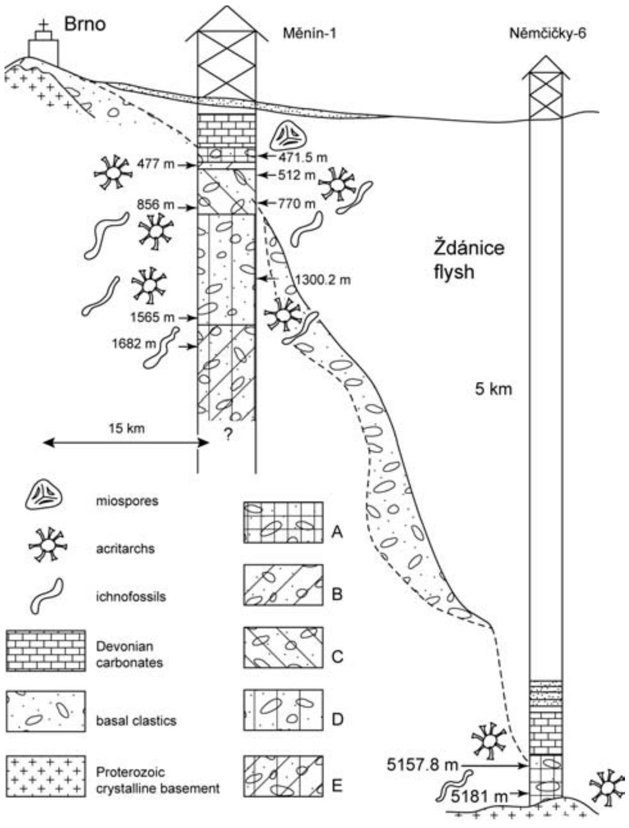


Figure 1. Stratigraphic position of selected samples and approximate extensions of the palynozones of Early Cambrian age in the Měnín-1 (Carpathian foredeep) and Němčičky-3 boreholes (Carpathian flysh). • A – basal clastics of the *Volkovia dentifera – Liepaina plana* palynozone (*Protolenus*). • B – basal clastics of the *Heliosphaeridium dissimilare – Skiagia ciliosa* palynozone (*Holmia*). • C – basal clastics of the *Skiagia ornata – Fimbriaglomerella membranacea* palynozone (*Schmidtielus*). • D – basal clastics of the *Asteridium tornatum – Comasphaeridium velvetum* palynozone (*Platysolenites*). • E – basal clastics of Ediacaran and unspecified Early Cambrian age.

Palynological studies enabled the recognition of the Early Palaeozoic age of the deposits, and the estimation of their thickness. The Cambrian and Ediacaran strata attain at least 1628 m of thickness in the Měnín-1 borehole. Such unusual thickness of the basal clastics can be ascribed either to tectonic repetition of the siliciclastic successions or to the presence of an extensive Cambrian and probably also Vendian sedimentation. Additional palynological analyses have eliminated the possibility of repeating the Early Cambrian deposits.

Materials and methods

Samples of basal clastics have been collected from the core repository of the Morava Oil Mines Company, Hodonín. Most of the basal clastics are comprised of quartzose sandstones and monomictic, red to pink-violet conglomerates. Siltstones and mudstones are less common, alternating with coarser sediments in beds that are several millimetres to several centimetres thick. The studied rocks are grey to greenish grey, fine-grained psammites and aleurolites. Rock samples of the basal clastics of reddish, pinkish, green, and violet colour have been found to be barren. The samples have been collected at a level of 512 m from predominantly light grey claystones with slight bioturbation, and from dark psammites from a depth of 1300.2 m, which are more intensively bioturbated, mostly by *Planolites* (Mikuláš & Nehyba 2001).

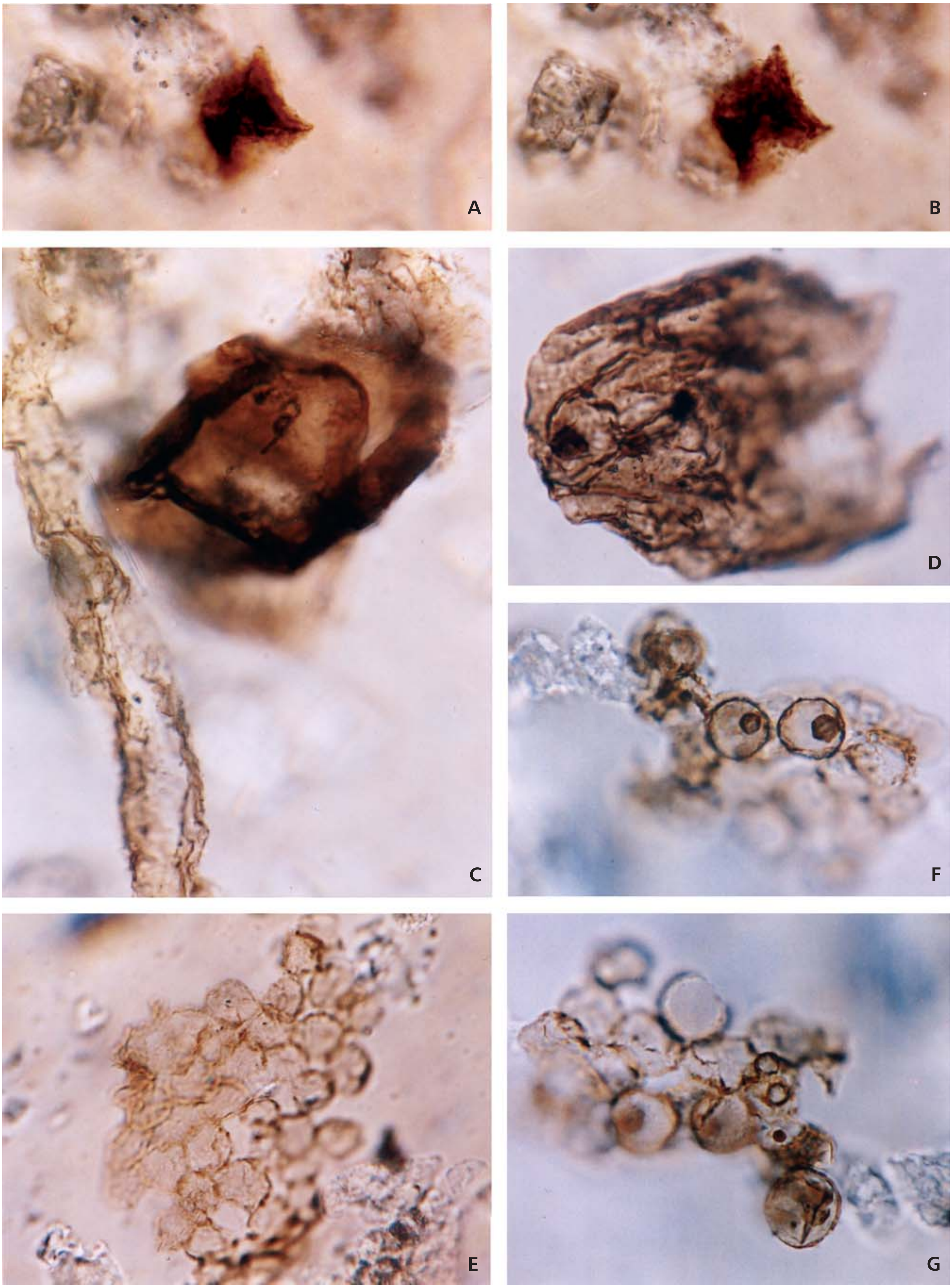
Organic-walled microfossils (OWM) from cores No. 27A (depth 1300.2 m) and No. 17 (depth 507–512 m) from the Měnín-1 borehole have been isolated using a standard palynological procedure for removing inorganic particles with diluted hydrochloric acid and concentrated fluoric acid, followed by sieving the residuum. The palynological associations contained organic-walled microfossils, mostly acritarchs, leiospheres, and filamentous nematoclasts. The specimens are unusually well preserved, mostly of a light yellow colour, with a very low thermal alteration index (1 to 1+). The soft walls of these microfossils are frequently distorted by microcrystals of pyrite. The microfossils were studied in palynological slides, in thin sections, and by the SEM techniques. The rock samples and their documentation are deposited at the Institute of Geology ASCR, Rozvojová 135, Prague.

Palynology

Core No. 27A (depth 1300.2 m)

Organic-walled, single-celled microfossils with smooth surfaces and thin walls, and of small dimensions (5–19 micrometres), predominate the assemblage (approx. 80 % of the total number of palynomorphs). Filamentous fossil remains are frequent, constituting 8–10 % of the residuum. Ribbon-like and thread-like trichomes vary between very thin (1–2 μm), irregularly twisted and curled empty

Figure 2. A, B – *Octoedryxium truncatum* Rudavskaja, 1973. Slide 3/1, coord. 20.4 x 120.6, size 21 μm. Měnín-1, depth 1300.2 m. • C – *Leiosphaeridia* and *Siphonophycus robustum* (Schopf) Knoll *et al*., hollow thin-walled tubular sheath, length 300 μm, diameter 15 μm. Slide 3/1, coord. 8 x 121.5. Měnín-1, depth 1300.2 m. • D – *Tasmanites tenellus* Volkova, 1968. Slide 5/1, coord. 22.3 x 117, size 75 μm. Měnín-1 borehole, depth 1300.2 m. • E – fragment of planar coenobium with 24 regularly disposed cells (coenocytes) in 8 rows. Slide 5, coord. 20.4 x 98.7. Size of cells about 8 (6–10) μm, overall 80 micrometres. Měnín-1, depth 512 m. • F, G – Partially disintegrated coenobium (*Synsphaeridium* sp. indet.) with small dark inner bodies. Slide 5, coord. 17.1 x 102.8; size of cells 10 μm, overall 60 μm. Měnín-1, depth 512 m. All micrographs x 1000. Photos by M. Vavrdová.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sheets, such as *Archaeotrichion contortum* Schopf, 1968 (Fig. 3A) and *Eomycetopsis* spp., to relatively robust species of *Siphonophycus*, such as *S. kestron* Schopf, 1968, *S. inornatum* Zhang, 1981 (Fig. 3B), *S. capitaneum* Nyberg & Schopf, 1984, and *S. robustum* (Schopf) Knoll *et al.*, 1991 (Fig. 2C). Large clusters of filaments usually contain trichomes of an identical diameter.

Most of the ribbon-like trichomes were originally various non-branched, multicellular, uniseriate cyanophyta, although the septae marking the elongate cells are only occasionally preserved (aff. *Cyanonema* Schopf, 1968, Fig. 3B). Trichomes forming loose spiral coils can be assigned to the species *Anabaenopsis johnsonii* Schopf, 1968 (Fig. 3C).

Sphaeromorphic acritarchs include several species of the genera *Protoleiosphaeridium* Timofeev, 1959, and thick- and thin-walled forms of the genus *Leiosphaeridia* spp. Eisenack, 1958 (Fig. 2C), *Stictosphaeridium brayense* Gardiner & Vanguestaine, 1971, *Symplassosphaeridium* sp. indet. Timofeev, 1959, and *Tasmanites tenellus* Volkova, 1968 (Fig. 2D). Polygonomorphic planktonic acritarchs are represented by the species *Octoedryxium truncatum* Rudavskaja, 1973 (Figs 2A, B).

The sculptured vesicles of acritarchs are very rare, forming less than 1 % of the total number of recovered palynomorphs. The species *Asteridium lanatum* (Volkova) Moczydłowska, 1991 occurs rarely.

Core No. 17 (depth 512 m)

Palynomorphs were found to be well preserved but very rare in the analyzed samples from this core. Filamentous organic-walled microfossils and small-sized smooth leiospheres prevail, often in clusters (Figs 2F, G). The rare occurrence of planktonic marine species such as *Archaeodiscina umbonulata* Volkova, 1968, *Sagatum priscum* (Kirjanov) Vavrdová & Bek, 2003, *Skiagia orbiculare* (Volkova) Downie, 1982, *S. pura* Moczydłowska, 1991, and *Tasmanites volkovae* Kirjanov, 1974 indicated the middle Early Cambrian age (*Holmia* faunal zone). *Skiagia pura* is at present known only from Poland, confirming the close affinities between the Moravian and Upper Silesian Cambrian planktonic associations.

Two types of fossil coenobia have been observed in the assemblage: planar sheets composed of more or less tightly packed individual cells, arranged in regular rows in a criss-cross pattern; and oval to vase-shaped cells arranged in short chains, thickened at the points of junction. Planar sheets are preserved in fragments consisting of 20 to 40 cells. Individual cells are circular to subcircular, deformed if tightly packed, with psilate surface, and without visible apertures (Fig. 2E).

Well preserved specimens show small subpolygonal darkened bodies inside of the cells (Figs 2F, G, 3C). These appear to be remnants of the intracellular structures, such as possible pyrenoid bodies.

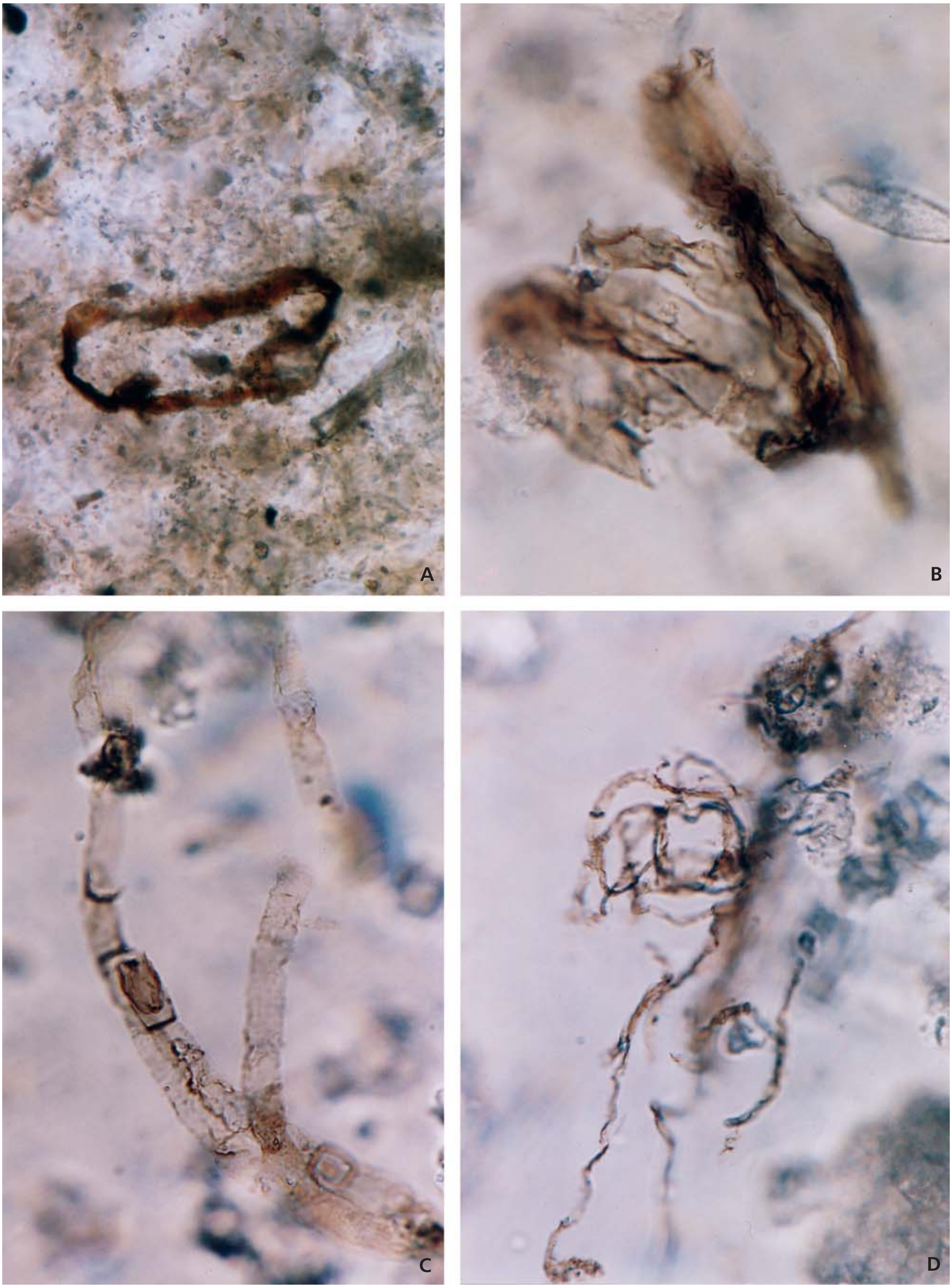
Algal coenobia

Acritarchs are a heterogeneous group of organic-walled microfossils, mostly cysts of unicellular protists, at present not assignable to any known group of organisms. Their morphology and distribution support the interpretation of their being the resting cysts of marine eukaryotic phytoplankton. The group is distinguished by a highly resistant polymeric wall, closely related to the sporopollenin (Wicander 2002). The majority of acritarchs consist of a single cell, although irregular clusters of monospecific agglomerations of several tens of cells are not uncommon in palynological slides. The number of similar accumulations increases with the age of the samples, namely from the Tremadocian onwards. These agglomerations usually do not show any regular pattern of arrangement or a differentiation of individual coenocytes at the margins.

Agglomerations with regular internal organization form multicellular algal coenobia, varying from several cells to relatively large colonies with a planar or concentric organization (Evitt 1963, Wood & Miller 1997a). Most of the fossil algal coenobia known so far are attributed to green algae; to the families Hydrodictyaceae: *Deflandrastrum* Combaz, 1962, and Scenedesmaceae: (?*Scenedesmus*) and Zygnemataceae (Batten 1996).

Monospecific agglomerations with a regular internal organization of small sphaeromorphs indicate occasional terrestrial influence in a shallow marine environment, most probably seasonal flooding or lacustrine transport (Batten & Grenfell 1996, Wood & Miller 1997b). Fresh-water unicellular algae could become mixed with redeposited specimens of Ediacaran age such as *Octoedryxium* in a near shore marine environment. A benthic origin is similarly indicated by the common presence of algal sheets, which are usually compared with various extant Cyanobacteria: Oscillatoriaceae, Rivulariaceae, and Nostocaceae (Schopf

Figure 3. A – *Archaeotrichion contortum* Schopf, 1968. Slide 4/1, coord. 13.6 x 113, size 150 micrometres, diameter 1.2 μm. Měnín-1 borehole, depth 1300.2 m. • B – aff. *Cyanonema* sp. indet. and *Siphonophycus inornatum* Zhang, 1981. Slide 5, coord. 18 x 106.6, size 140 and 150 micrometres. Měnín-1 borehole, depth 512 m. • C – *Anabaenopsis johnsonii* Schopf, 1968. Slide 5/1, coord. 20 x 120.4. Size 93 micrometres, diameter 10 μm. Měnín-1 borehole, depth 1300.2 m. • D – aff. *Anabaenopsis johnsonii* Schopf, 1968. Thin section No. 915 A, size 50 micrometres, diameter 5 μm. Němčičky-3 borehole, depth 5396 m.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1968). Filamentous ribbons and threads differ from cyanobacterial trichomes in an acid-resistant, polymeric wall. Similar tubular sheets, devoid of the original cellular contents, occur frequently in modern cultures of Oscillatoriacean cyanobacteria (Schopf 1968).

Three successive palynozones have been recognized in the Měnín-1 borehole, which roughly correspond to the three Early Cambrian faunal zones: *Platysolenites antiquissimus*, *Schmidtielus*, and *Holmia*. Of the more than 1628 m of Early Cambrian deposits, approximately 38.5 m can be referred to as the *Holmia* faunal zone (in the interval 471.5–ca 510 m), and 350 m to the *Schmidtielus* zone (in the interval ca 510–860 m). The remaining 1200 m or so of mostly continental deposits (860–2100 m) is of basal Cambrian and most probably Ediacaran age (Fig. 1).

The late Early Cambrian acritarch assemblages of the *Volkovia dentifera–Liepaina plana* palynozone, an equivalent of the *Protolenus* faunal zone, have been identified in the Němčičky-3 and Němčičky-6 boreholes (Gilíková *et al*. 2004). Rare, age-diagnostic acritarchs such as *Archaeodiscina umbonulata, Fimbriaglomerella membranacea, Sagatum priscum, Tasmanites volkovae*, and *Skiagia pura* were isolated from a depth of 512 m (core No. 17), allowing a preliminary assignment to the *Skiagia ornata–Fimbriaglomerella membranacea* palynozone.

Microfossils isolated from the level of 1300.2 m provide contrasting biostratigraphical evidence. Some filamentous, organic-walled microfossils from the sample, such as the genera *Cyanonema* Schopf or *Anabaenopsis* Schopf, are so far known only from Precambrian deposits (Bitter Spring Formation, Australia, Schopf 1968). Similarly, the occurrence of the planktonic species *Octoedryxium truncatum* Rudavskaja, 1973 is limited to strata of Precambrian age (Vidal 1979). However, rare specimens of *Asteridium lanatum* (Volkova) Moczydłowska, 1991 and *Tasmanites tenellus* Volkova, 1968 indicate an earliest Cambrian age for the same assemblage (Moczydłowska 1991). Because the underlying siltstones from the depth of 1565 m contain diverse assemblages of the earliest Cambrian acritarchs, the older microfossils were probably redeposited. Nevertheless, their occurrence suggests the existence of Ediacaran marine strata in southern Moravia.

The position of the Brunovistulicum

Recently published studies suggest that the Brunovistulicum was associated with the northern margin of Gondwana, either in its present North African or South American region (Breemen *et al.* 1982, Belka *et al*. 2000, Finger *et al*. 2000, Raumer *et al*. 2001). The main reason for this assignment is the presence of Cadomian basement and its position south of the Teisseyre-Tornquist lineament. However, the age estimations of the Central Basic Belt (Finger *et al*. 2000) point to an older, late Riphean age (ca 733 Ma). In the northern part of the Brunovistulicum, Żelaźniewicz (*in* Bylina *et al.* 2000) reported Archaean U-Pb zircon ages from the amphibolites of the Rżeszotary horst (2.51–2.67 Ga), showing a close relationship to Baltica. The fossil record of the flora (Fatka & Vavrdová 1998, Vavrdová & Bek 2003) and fauna (Orlowski 1975) favours a relationship with the East European Platform rather than with the Pan-African belt of microcontinents.

Fatka & Vavrdová (1998) emphasized the Baltic affinity of the organic-walled microfossils recovered in southern Moravia. The presence of high-latitude acritarch assemblages, resembling the Baltoscandinavian Early Cambrian microflora, are in accord with the ichnological investigations and with petrology (an absence of carbonates). The intensity of bioturbation and the ichnofabric patterns correspond well with those known from the Early Cambrian from the Eastern European Platform (Mikuláš & Nehyba 2001). Similar affinities have been claimed for the trilobite fauna recovered in the Goczalkowice-1 borehole in southern Poland (Orlowski 1975).

The identification of Baltic province trilobites from Upper Silesia has recently been questioned by Nawrocki *et al*. (2004). Paleomagnetic studies of the Early Cambrian red beds suggest a nearly equatorial position for Baltica, in a paleolatitude of cca 7°. According to Nawrocki *et al.* (2004), the Brunovistulian terrane was accreted onto Baltica in the Cambrian period, during the drift along the Cadomian margin of Gondwana. However, the composition of Brunovistulian microplankton assemblages indicates drift in an opposite direction, from high southern latitudes in the early Cambrian to low-latitude warm waters in the Early Ordovician (Vavrdová *et al*. 2003).

Conclusions

Palynomorphs isolated from samples of the so-called basal clastics are important for the biostratigraphical evaluation of the otherwise unfossiliferous successions. Associations of organic-walled microfossils indicate shallow marine environments, with unusually suitable conditions for the preservation of intracellular structures and the coenobial arrangement of unicellular algae. Three successive palynozones have been identified within the Měnín-1 borehole, all of which are older than the Early Cambrian acritarch assemblages recovered underneath the outer Western Carpathian nappes (boreholes Němčičky-3 and Němčičky-6). Palynological investigations have shown that the large thickness (more than 1683 m) of basal clastics in the Měnín-1 borehole is not caused by a tectonic repetition, but represents the original Early Cambrian succession. The possible presence of marine Ediacaran strata in southern Moravia can therefore be inferred.

Acknowledgements

This research is part of the research programme of the Institute of Geology ASCR, No. AV0Z 30130516. Access to the core material of the Morava Oil Mines Co., Hodonín is greatfully acknowledged. Thanks are expressed to R. Mikuláš and H. Gilíková for help and cooperation. The samples were processed by A. Tichá in laboratories of the Czech Geological Survey, Prague-Barrandov. Numerous corrections considerably improving the manuscript from M. Moczydłowska-Vidal are gratefully acknowledged.

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