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Bolboforma (Phytoplankton Incertae Sedis), *Bachmayerella* and other Calciodinelloidea (Phytoplankton) from the Middle Miocene of the Alpine–Carpathian Foredeep (Central Paratethys)

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ABSTRACT – *Bolboforma* is a microfossil of uncertain origin with affinities to protophytic algae. It generally occurs at high latitudes and/or in cool and temperate waters and has a high stratigraphic potential especially for the Miocene. Calcareous cysts of dinoflagellates represent the 'benthic cyst stage' of unicellular organisms belonging to the marine phytoplankton.

The occurrence of *Bolboforma, Bachmayerella* is documented here and, for the first time, some calcareous cysts of dinoflagellates tentatively attributed to *Alasphaera* and *Pithonella* from Badenian (Langhian–Middle Miocene) sediments in Austrian and Moravian localities. *Alasphaera* and *Pithonella* were previously described from Cretaceous and Danian sediments only, therefore, their range has been extended into the Paratethyan Middle Miocene.

Correlation of *Bolboforma* bioevents with standard geological time-scales allows confirmation, and in some cases refinement, of age assignments based on other microfossil groups, such as foraminifera and calcareous nannofossils, in Paratethyan areas. In particular, this paper presents a case study of the biostratigraphy of the Grund Formation outcropping at its type locality in Lower Austria. Age attribution of the Grund Formation has been uncertain for some time. The recovery of *Praeorbulina glomerosa circularis* and *Uvigerina macrocarinata*, associated with *Bolboforma reticulata*, allows the correlation of the Grund Formation with the Early Badenian (Middle Miocene). As planktonic foraminifera are generally very rare or absent in shelf deposits of many other Austrian and Moravian Middle Miocene sedimentary sequences, *Bolboforma*, and in particular *B. reticulata*, remains an important biomarker to identify lower Badenian sediments.

Additionally, the new species *Bolboforma gneixendorfensis* Spezzaferri & Rögl is described. It is generally double-chambered with a weakly reticulate wall texture and is associated with *Bolboforma reticulata*, *B. bireticulata* and/or *B. moravica*. *J. Micropalaeontol.* **23**(2): 139–152, November 2004.

INTRODUCTION

Bolboforma comprises a group of marine calcareous microfossils of uncertain origin with affinities to protophytic algae. *Bolboforma* specimens are monocrystalline, calcitic hollow-shaped and consist of a spheroidal or subspheroidal single chamber. In some cases the wall may be built of at least three layers (Poag & Karowe, 1987). They may encapsulate a smaller chamber and produce cysts. Cysts are smooth or weakly ornamented and their function is still unknown (Spiegler, 1987; Spiegler & Daniels, 1991). Rare double-chambered *Bolboforma* specimens/species display a septum separating a large chamber from a smaller terminal aperture-bearing chamber (Daniels *et al*., 1981). The wall texture is smooth or strongly ornamented with a short neck or collar generally bordering the aperture. Specimens range in size from 50–250 μm, but their diameter is usually less than 150 μm.

Although recent studies have shown that the isotopic composition of *Bolboforma* is typical of tychoplancton (Spiegler & Erlenkauser, 2001), which include organisms occasionally carried into the plankton by chance factors such as turbulence, the taxonomic position and the life strategy of *Bolboforma* is still poorly known. However, a strong resistance to dissolution and the high stratigraphic potential, especially for the Miocene, make the *Bolboforma* an important and exceptional microfossil group for interpreting the stratigraphy and palaeoceanography of sediments from cool and temperate regions (Spezzaferri & Spiegler, 1998a; Spezzaferri *et al*., 2001; Cooke *et al*., 2002). In many cases *Bolboforma* biostratigraphy may improve upon and, in some cases, supplement the standard zonations based on other microfossil groups from Early Eocene to Early Pliocene sediments (Spiegler & Daniels, 1991).

The existing literature documenting *Bolboforma* is generally restricted to sediments recovered during deep-sea drillings (DSDP and ODP Holes, at latitudes between 30° and 70° (Rögl & Hochuli, 1976; Kennett & Kennett, 1990; Qvale & Spiegler, 1989; Pallant & Kaminski, 1989; Spiegler & Daniels, 1991; Spezzaferri & Spiegler, 1998a; Spiegler, 1999). This microfossil is generally missing in tropical waters. Only a few sites in the central Atlantic and western Pacific, Gulf of Mexico, Mississippi and California contain nearly monospecific *Bolboforma* assemblages (Poag & Karowe, 1986; Spiegler & Daniels, 1991). Rare specimens of *Bolboforma* are also documented in low latitudes in South and North America, Spain (NW Alicante) and northwest Algeria (Spiegler & Daniels, 1991).

Bolboforma is described from outcropping sediments only in a few Mediterranean sections (Spezzaferri *et al.,* 2001), in the Paratethys (Szczechura, 1986; Spiegler & Rögl, 1992) and Germany (Daniels & Spiegler, 1974: Spiegler & Gürs, 1996; Spiegler, 2001; Spiegler & Erlenkauser, 2001; Griessemer, 2002; Spiegler, 2002). Spiegler & Gürs (1996) calibrated *Bolboforma* bioevents with the time-scale of Berggren *et al*. (1995) and, therefore, ages are currently available to tie *Bolboforma* zonation to standard zonations based on foraminifera and calcareous nannoplankton.

Dinoflagellates belong to the marine phytoplankton. Within their life cycle they can produce benthic cysts composed of silica or carbonate during 'resting stages' related to environmental conditions. These cysts can be preserved in the fossil record. Specimens, which may belong to the calc-dinocyst group, *Bachmayerella tenuis* and *Bachmayerella laqueata*, were first described by Rögl & Franz (1979) from Middle Miocene sediments in the Central Paratethys. In the eastern Mediterranean these microfossils characterize Pliocene and Pleistocene sediments. Their last occurrence has a high stratigraphic potential, especially within the *Globigerina cariacoensis–Truncorotalia truncatulinoides* Zone in the Pleistocene (Spezzaferri & Spiegler, 1998b). Other spherical calcareous dinoflagellate cysts belong, for example, to *Pithonella* and *Alasphaera* genera.

The aims of this study are: (1) to document the occurrence of *Bolboforma* in Middle Miocene inner shelf to upper bathyal facies from Austrian and Moravian sequences; (2) to refine and confirm an age attribution of the sediments using the distribution of *Bolboforma*; (3) to document for the first time the presence of calcareous cysts of dinoflagellates in these areas.

Bolboforma and calcareous cysts of dinoflagellates are documented in Plates 1–3. The figured material is deposited in the Naturhistorisches Museum Wien, Micropalaeontological Collection, nos. 2003z0047/0001 to 0039.

STRATIGRAPHY AND GEOLOGICAL SETTING

The rising mountain chain extending from the Alps to the Kopet Dag, between Iran and Turkmenistan, triggered the isolation of the northern Mediterranean Tethys margin in the Early Oligocene forming a new palaeogeographical unit termed Paratethys (e.g. Rögl, 1999). From its formation to its closure in the Late Miocene, this area experienced an evolution that was different from that of the Mediterranean region. The development of floras and faunas in the Paratethys was related to palaeogeographical settings and, therefore, separate studies on Paratethyan faunas and floras and their endemism have been produced (Steininger *et al.*, 1990; Cicha *et al.*, 1998 for an overview). In particular, regional stratigraphic stages were introduced for the Oligocene–Miocene interval (Fig. 1).

The Alpine–Carpathian Foredeep, which is part of the central Paratethys, follows the outline of the Bohemian Massif and turns from a west–east-trending basin to northeast, toward Moravia north of the Danube River (Fig. 2). In the investigated part of this basin, marine sedimentation started in Late Oligocene (Egerian ≈ Chattian to Aquitanian). Older Cenozoic sediments are preserved in graben structures in Southern Moravia. Early Miocene (Eggenburgian to Karpatian = Burdigalian) sediments are conformable and extend northeastward in the Carpathian Foredeep. In the Late Ottnangian, brackish conditions prevailed (*Rzehakia* = *Oncophora* Beds) and ended the first Early Miocene marine cycle. The basin was strongly narrowed by the overthrust of Alpine–Carpathian nappes (Kovac *et al.*, 1998).

A late Early Miocene transgression produced the deposition of the Karpatian 'Schlier' (silty-sandy calcareous shales of the Laa Formation) on the Carpathian nappes and the foredeep sediments. A successive regression–transgression cycle triggered the formation of the Middle Miocene Badenian Sea in the whole basin, as described by Jiricek & Seifert (1990), Kovac *et al.* (1998), Stranik & Brzobohaty (2000) and Jiricek (2001). The basin evolution and the geological setting of the Austrian part of the foredeep (Molasse Basin) is described in detail by Roetzel *et al.* (1999a).

Lower Badenian sediments in Austria belong to the Grund and Gaindorf Formation, and consist of marly silts, silts, sands and gravels. The Mailberg Formation consists of corallinacean limestone with some marly intercalations.

In the Moravian part of the foredeep the Lower Badenian started with coarse clastic sediments, followed by the shallow Brno Sands and basinal sediments from the Brno Marl ('Brünner Tegel'). The sea transgressed on the Bohemian Massif, where deeper-water sediments were preserved in graben and valley structures (Brzobohaty *et al.*, 1983; Brzak, 2001; Petrova *et al.*, 2001).

The stratigraphic age of basal Badenian sediments in the foredeep has been dated by calcareous nannoplankton as Zone NN4, and in the Grund Formation as Zone NN5, and by the occurrence of *Praeorbulina glomerosa circularis* as Zone M5b (Rögl & Spezzaferri, 2003; Coric & Rögl, 2004; Spezzaferri, 2004). This contrasts with the interpretation of Cicha (1999) and Svabenicka & Ctyroka (1999) who placed the lower part of the Grund Formation in the Early Miocene Karpatian stage. Therefore, the stratigraphic potential of *Bolboforma* for Miocene sediments is relevant to this study, to clarify the age attribution of the Grund Formation and solve the debate.

MATERIAL AND METHODS

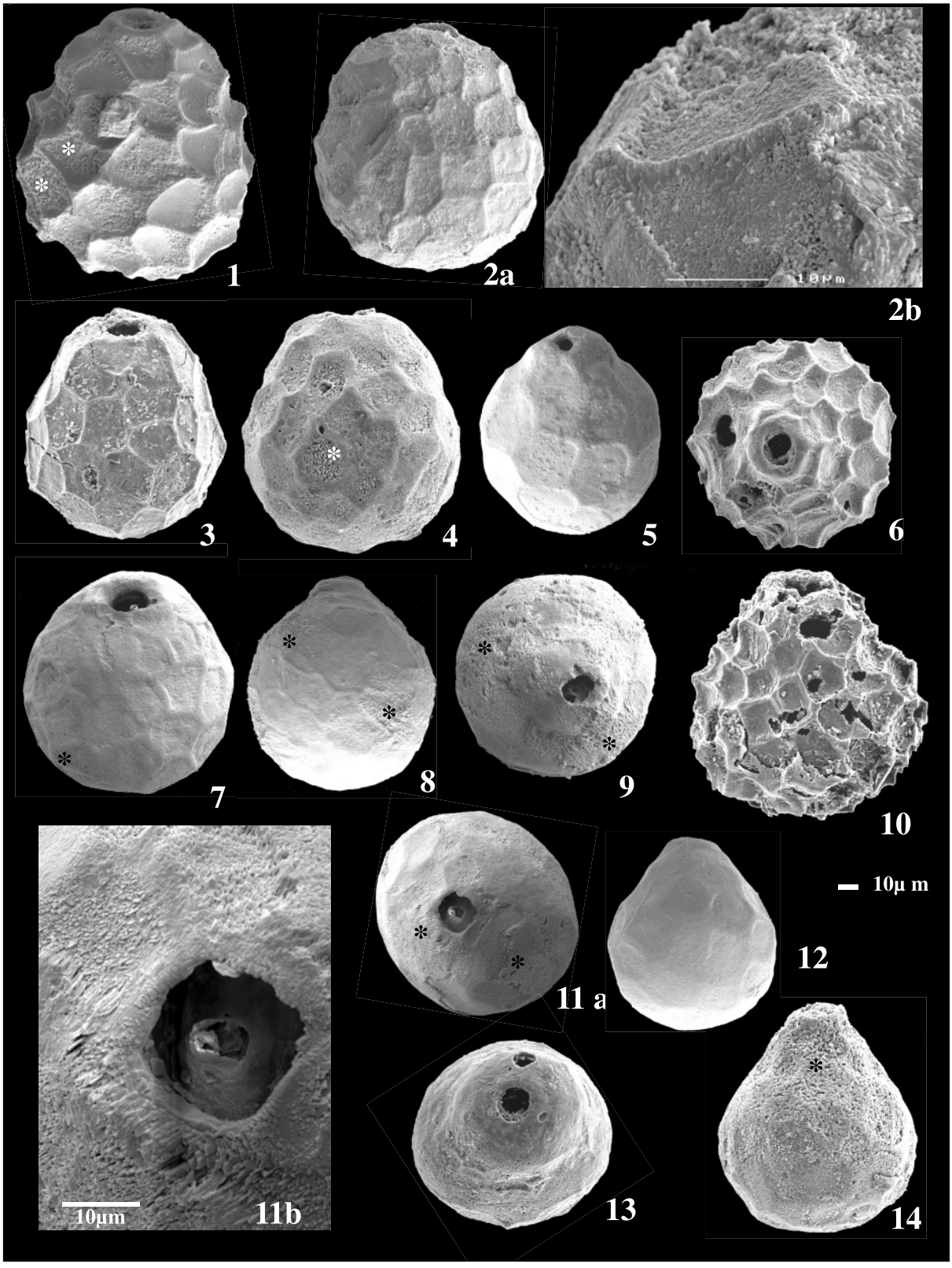
Samples were washed using standard techniques for foraminiferal preparation. For each sample, 200 g of sediment were soaked in hydrogen peroxide for several hours, then soaked in warm water and washed under running water through >250 μm, >125 μm and >63 μm mesh sieves. *Bolboforma* and calc-dinocyst specimens were analysed under a binocular microscope, identified and picked from the >125 μm and >63 μm size fractions. Selected specimens were also observed using a scanning electronic microscope (SEM).

THE LOCALITIES

Bolboforma species were previously documented in sediments from several Austrian sections (Spiegler & Rögl, 1992). *Bachmayerella* species were described for the first time from an Austrian section (Rögl & Franz, 1979). Calciodinelloidea were unknown from the Paratethys Miocene. Occurrence of these organisms is restricted to isolated samples only and a continuous record is unavailable. Therefore, only a short description of the localities (Fig. 1) and sediments in which they occur – and not complete lithological logs – is given below. Table 1 shows the distribution of *Bolboforma*, *Bachmayerella* and other calcareous cysts of dinoflagellates in the investigated sections. Only the samples containing these microfossils are listed.

Austria

- **Locality Grund**, sediments outcrop close to the wine cellars, about 8 km NNW of Hollabrunn, Lower Austria. Excavation trenches with sections A to H were opened by the Institute of Paleontology, University of Vienna from 1998 to 1999 (Roetzel *et al.*, 1999b; Pervesler & Roetzel, 2002). The Grund Formation at the type locality shows a sequence of bedded


1
2a
2b
3
4
5
6
7
8
9
10
10µ m
11 a
12
13
14
10µm
11b

fine sands and pelites which are cut by channels with coarse clastic infilling, mainly comprising mollusc shells. These sediments are attributed to the Lower Badenian based on *Praeorbulina glomerosa circularis*, planktonic foraminiferal Zone M5b (Berggren *et al*., 1995) and nannoplankton Zone NN5 of Martini (1971) as in Rögl *et al.* (2002).

- **Locality Windmühlberg** is 2 km NW of Grund, near the main road B2, between the villages of Grund and Guntersdorf. Sediments consist of yellowish fine sands and pelitic layers and belong to the Grund Formation, Lower Badenian.
- **Locality Kalladorf** is 9 km north of Hollabrunn, Lower Austria. An excavation was carried out in 1987 for a gas pipeline by NIOGAS Comp. at the wine cellars about 100 m east of the village. Sediments consist of alternating yellowish fine sands and grey-brown pelites with incised small channels filled with coarse sand and mollusc shells and belong to the Grund Formation. They are attributed to the Lower Badenian based on *P. glomerosa circularis* and *Orbulina suturalis* (basal Zone M6).
- **Roggendorf 1** is a deep drilling of OMV AG SSW of Maria Roggendorf, 7 km NE of Hollabrunn (Coric & Rögl, 2004). Two metres of Quaternary sediments cover 270 m of clayey silty marls and sands of the Grund Formation (Zone NN5, basal Zone M6). These sediments overlay a sequence of Lower Badenian (Zone NN4 to NN5) sand, gravels and conglomerates, which are transgressive on the Laa Formation (Early Miocene, Karpatian, Zone NN4).
- **Locality Locatelliwald** is 3 km NNW of Immendorf, NNE of Hollabrunn, in an old quarry (Spiegler & Rögl, 1992). Sediments consist of a corallinacean limestone with intercalated yellowish brown marl layers and belong to the Mailberg Formation (Lower Badenian).
- **Locality Buchberg** is in an old quarry 1.5 km SW of Mailberg, NE of Hollabrun, in Lower Austria (Spiegler & Rögl, 1992). Sediments of the Mailberg Formation consist of corallinacean limestone with intercalated yellowish brown marl layers and are attributed to the Lower Badenian, based on *P. glomerosa circularis* and *O. suturalis* (basal Zone M6).
- **Locality Kautendorf** near Staatz, Lower Austria, building site at lot no. Pz-1966/11. Light grey to yellowish marl with rich foraminiferal fauna of deeper water ('Badener Tegel'), in front of the Jurassic klippen of Staatz, Waschberg Unit (Grill, 1968). Sediments are attributed to the Lower Badenian, Lower Lagenidae Zone based on *P. glomerosa circularis* and *O. suturalis* (basal Zone M6).
- **Locality Gneixendorf**, exploration well NÖ-06 by GKB (1987), Krems embayment, Lower Austria (Spiegler & Rögl, 1992). The marine sequence belongs to the Gaindorf Formation, which is transgressive on crystalline basement. The occurrence of *O. suturalis* in the upper part (from the top of the drilled hole down to 92.3 m) and *P. glomerosa circularis* in the lower part allow an age attribution to the Lower Badenian, Zones M5b to M6.
- **Locality Diendorf–Hadersdorf am Kamp**, exploration well NÖ-07 by GKB (1987), Krems embayment, Lower Austria. The sedimentary sequence from 34.3 m to 260.4 m belongs to the Gaindorf Formation and contains a rich foraminiferal fauna, with *O. suturalis* and *P. glomerosa circularis*. Lower Badenian, Zone M5b to M6.

Moravia–Czech Republic

- **Locality Kralice nad Oslavou** 30 km north of Brno (Redinger, 1992). Sediments consist of alternating calcareous clays, marls and detrital limestones. The occurrence of *Orbulina suturalis* indicates a Lower Badenian age (Zone M6).
- **Locality Zidlochovice** is an old brickyard north of the town in Southern Moravia, the facies stratotype of the Lower Badenian (Moravian Substage). Sediments consist of grey to blue-grey and greenish marl to clayey and silty-sandy marls, topped by corallinacean limestone (Cicha in Papp *et al*., 1978). They contain *P. glomerosa circularis*, *O. suturalis* and *Globigerinoides bisphericus* and are attributed to the basal part of Zone M6.

SYSTEMATIC DESCRIPTIONS

Family **Bolboformaceae** Spiegler, 1987

Genus *Bolboforma* Spiegler & Daniels, 1974

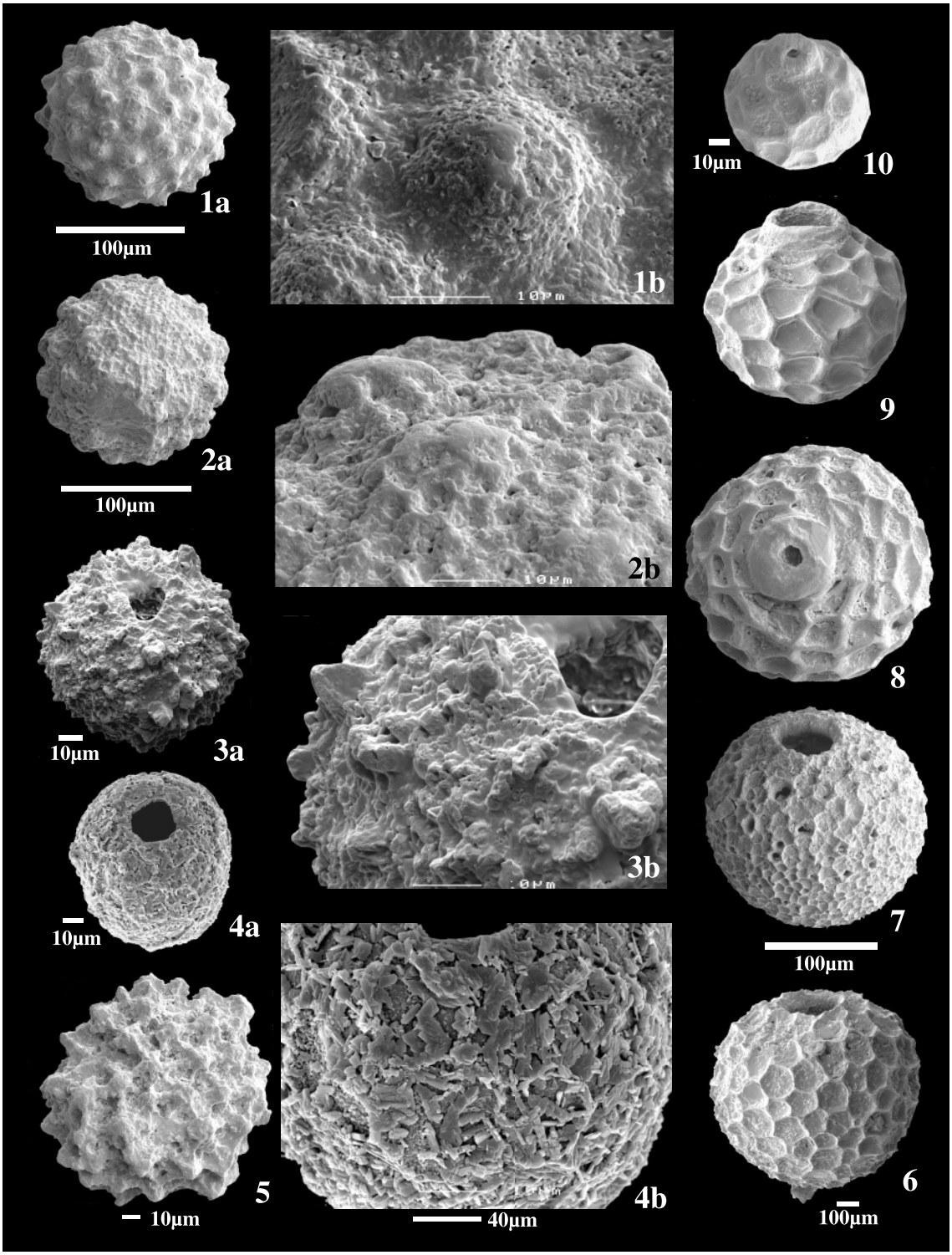
Bolboforma gneixendorfensis n. sp.

(Pl. 1, figs 5, 7–9, 11–14; Pl. 3, figs 1–2, 5–7)

1992 *Bolboforma* sp. F nova forma Spiegler & Rögl: 88, pl. 4, figs 8–9.

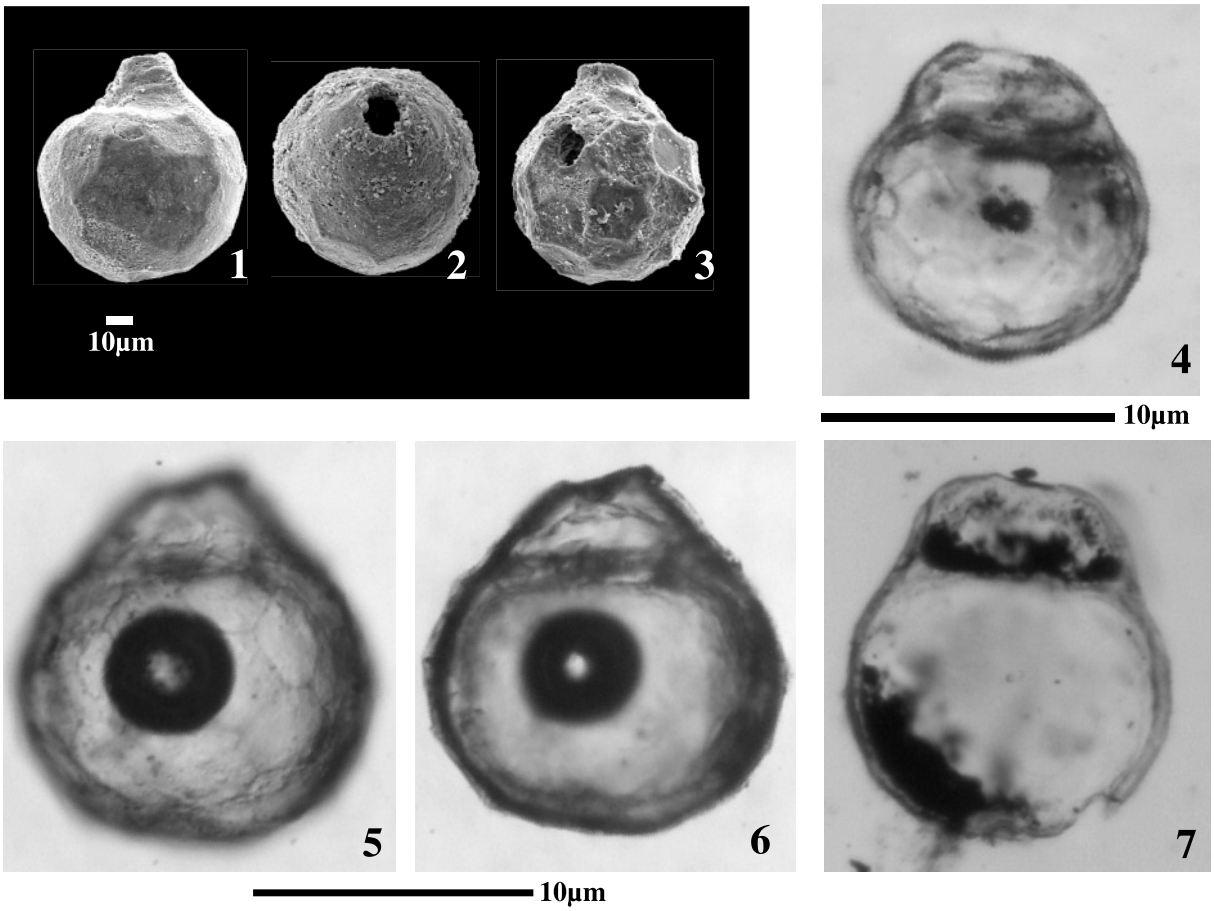
Explanation of Plate 1.

fig. 1. *Bolboforma bireticulata* Spiegler, sample W-3, Windmühlberg, × 500. **figs 2a–b.** *Bolboforma bireticulata* Spiegler, sample 104.7–104.8 m, Gneixendorf, × 500: **2a**, this specimen displays evidence of slight corrosion in the wall texture. However, the less marked reticulation where the wall texture is well preserved should also be noted. This specimen seems to be transitional to those in figs 5, 7, 8, 9, 11, 12 and 13; **2b,** detail of the wall texture – the edges are still well preserved, while the wall texture in the depressions is corroded**. fig. 3**. *Bolboforma bireticulata* Spiegler, sample 104.7–104.8 m, Gneixendorf, × 500. This specimen resembles that of fig. 2; the wall texture is, however, better preserved and displays almost no evidence of corrosion. **fig. 4**. *Bolboforma bireticulata* Spiegler, sample 104.7–104.8 m, Gneixendorf, × 500. This specimen resembles that of figs 2, 3 – the wall texture is strongly corroded, although the edges are still evident and seems to be better preserved. **fig. 5**. *Bolboforma gneixendorfensis* Spezzaferri & Rögl, sample 104.7–104.8 m, Gneixendorf, × 500. **figs 6, 10.** *Bolboforma moravica* Redinger, sample 104.7–104.8 m, Gneixendorf, × 500. The wall texture of specimens in fig. 10 is strongly corroded; however, the marked reticulation typical of this species is still preserved. **fig. 7.** *Bolboforma gneixendorfensis* Spezzaferri & Rögl, holotype, double-chambered specimen, sample 104.7–104.8 m, Gneixendorf, × 500. **fig. 8.** *Bolboforma gneixendorfensis* Spezzaferri & Rögl, sample 104.7–104.8 m, Gneixendorf, × 500. **fig. 9.** *Bolboforma gneixendorfensis* Spezzaferri & Rögl, sample 104.7–104.8 m, Gneixendorf, × 500. In this specimen the neck of the cyst inside the aperture is visible. **figs 11a–b.** *Bolboforma gneixendorfensis* Spezzaferri & Rögl, sample 104.7–104.8 m, Gneixendorf, × 500: **11b,** detail of the aperture with the neck of the cyst, × 2000. **figs 12–13**. *Bolboforma gneixendorfensis* Spezzaferri & Rögl, sample 104.7–104.8 m, Gneixendorf, × 500. The specimen in fig. 13 displays a double-chambered test. **fig. 14.** *Bolboforma gneixendorfensis* Spezzaferri & Rögl, sample 104.7–104.8 m, Gneixendorf, × 500. This specimen shows a strongly corroded test. The * in all figures marks the areas with evidence of corrosion and/or dissolution.



Explanation of Plate 2.

figs 1a, b. *Alasphaera* sp. 1, sample G-10, Grund, ×350. Specimen without archaeopyle: **1b,** detail of the wall texture. **figs 2a, b.** Incertae Sedis (radiolarian?), sample G-1, Grund, ×350: **2b,** detail of the wall texture with reticulate pattern. **figs 3a, b.** Calcareous cyst of dinoflagellate, Incertae Sedis, sample Rö 80-77, Buchberg bei Malberg, ×600: **3b,** detail of the wall texture with pustule-like structures. **fig. 4.** *Pithonella* sp., sample 104.7–104.8 m, Gneixendorf, ×500: **4b,** detail of the wall texture composed of crystallites. **fig. 5**. *Alasphaera* sp. 2, sample 1, 7–10 m, Roggendorf, ×500. **fig. 6.** *Bachmayerella laqueata* Rögl & Franz, sample Stü 11/87, Kralice, ×350. **fig. 7.** *Bachmayerella tenuis* Rögl & Franz, sample Stü 11/87, Locatellivald. ×600. **fig. 8.** *Bolboforma reticulata* Daniels & Spiegler, sample G-8, Grund, ×500. **fig. 9.** *Bolboforma reticulata* Daniels & Spiegler, sample G-8, Grund, ×500. **fig. 10.** Cyst of *Bolboforma reticulata* Daniels & Spiegler, sample 1, 2–7 m, Roggendorf 1, ×500. Note the weakly marked reticulations.



Explanation of Plate 3.

fig. 1 Possible cyst of *Bolboforma gneixendorfensis* Spezzaferri & Rögl, sample 104.7–104.8 m, Gneixendorf, × 500. **fig. 2**. Possible cyst of *Bolboforma gneixendorfensis* Spezzaferri & Rögl, sample 104.7–104.8 m, Gneixendorf, × 500. **fig. 3.** Cyst of *Bolboforma bireticulata* Spiegler, sample 104.7–104.8 m, Gneixendorf, × 500. **fig. 4.** *Bolboforma bireticulata* Spiegler, sample 104.7–104.8 m, Gneixendorf. The specimen is figured in transmitted light to see the septum separating the two chambers. Still evident is the reticulation of the wall texture. **figs 5–6**. *Bolboforma gneixendorfensis* Spezzaferri & Rögl, sample 104.7–104.8 m, Gneixendorf. The two figures show the same specimen figured in different depth of focus: **5**, the weak reticulation of the wall texture is still evident; **6**, the septum separating the two chambers is more clearly visible. **fig. 7**. *Bolboforma gneixendorfensis* Spezzaferri & Rögl, sample 104.7–104.8 m, Gneixendorf. This specimen shows the septum between chambers. The wall texture appears rather smooth. Figs 4 and 7; 5 and 6 at the same magnification.

Derivation of name. From the locality Gneixendorf, Lower Austria.

Diagnosis. Tests are spherical, double-, very rarely single-chambered. The wall texture is very weakly ornamented with widely spaced reticulations. The aperture is circular, bordered by a collar placed in a polygonal depression and surrounded by a smoother area. The encapsulated cysts are single-chambered and smooth to very weakly ornamented (Pl. 3, figs 1–2).

Holotype. Illustrated in Plate 1 (fig. 7) and double-chambered. It is housed in the Geology Department, Micropalaeontological collection of the Natural History Museum in Vienna, Inv. No. 2003z0047/0007.

Paratypes. Housed in the Geology Department, Micropalaeontological collection of the Natural History Museum in Vienna.

Material. More than 50 specimens.

Locality and horizon. Exploration well Gneixendorf, NÖ-06 by GKB (1987), Krems embayment, Lower Austria. Horizon 104.7–104.8 m, Gaindorf Formation.

Dimensions. Diameter about 90 µm, and approximately 112 µm high.

Remarks. This species has also been found in the Mediterranean Sea DSDP Leg 42A-372, 9–13 m (Spiegler & Rögl, 1992).

Bolboforma gneixendorfensis differs from *B. reticulata*, *B. bireticulata* and *B. moravica* in having a remarkably weaker ornamented wall texture. Under the light microscope it appears nearly smooth. Spiegler & Rögl (1992) have described this form as a possible cyst and not as a species. However, several specimens (Pl. 1, figs 9 and 11a–b) show the presence of encapsulated cysts inside the test. This indicates that *B. gneixendorfensis* is a species able to produce cysts and is not a cyst itself.

It has also been concluded that the weak reticulation shown by *B. gneixendorfensis* is not an artefact due to corrosion and/or

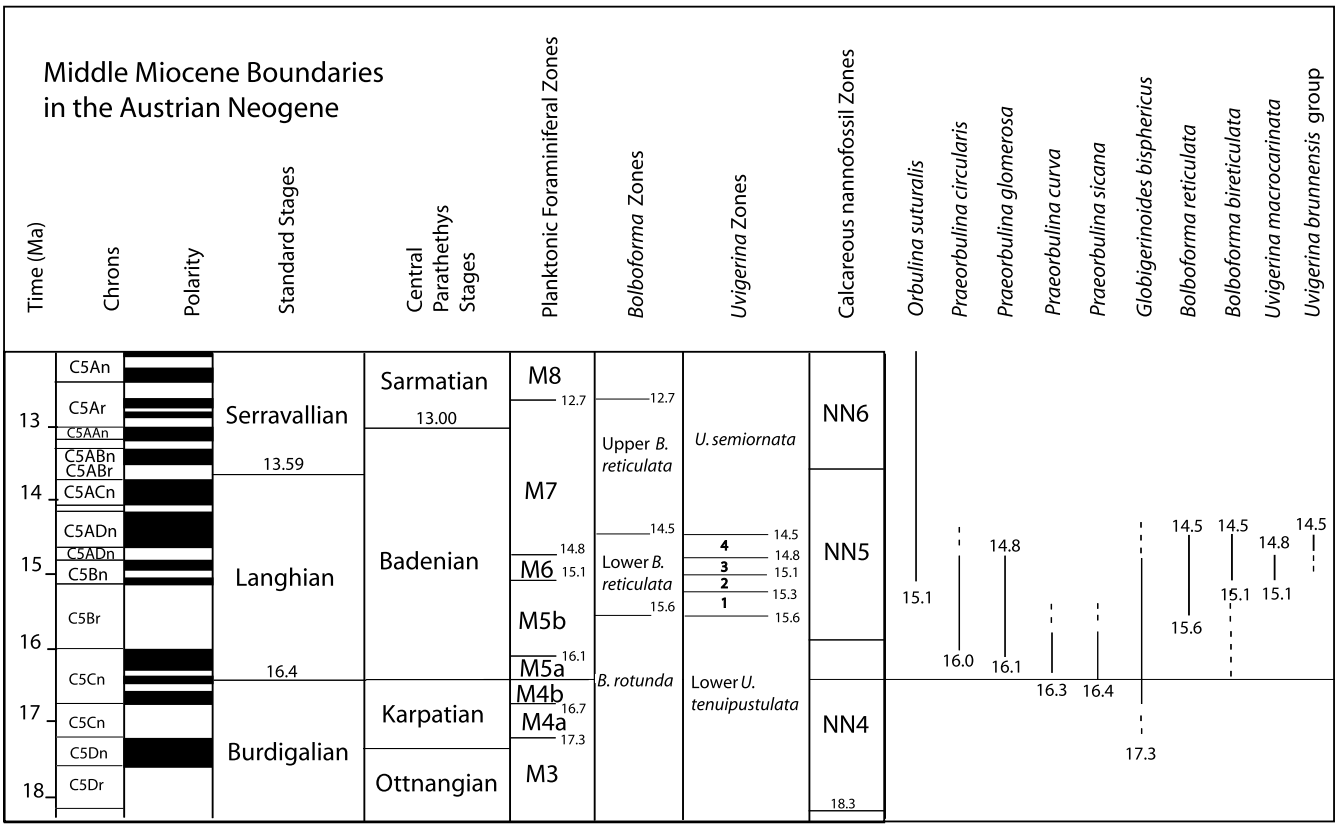


Fig. 1. Correlation of regional Paratethyan stages Ottnangian (Burdigalian) to the Sarmatian (Serravallian) and the standard stages plotted versus the main foraminiferal, *Bolboforma* and *Uvigerina* bioevents. 1, Upper *U. tenuiseptata* Zone; 2, *U. acuminata* Zone; 3, *U. macrocarinata* Zone; 4, *U. brunnensis* Zone. The standard zonation of Berggren *et al.* (1995) is used for the chronostratigraphy and planktonic foraminifera, Martini (1971) and Rio *et al.* (1997) for the calcareous nannofossils, and Spiegler (2002) for *Bolboforma* and *Uvigerina* Zones. The Langhian–Serravallian boundary is placed at 13.59 Ma (after Fornaciari *et al.*, 1996) and as established during the workshop of the European Science Foundation Project 'Environments and Ecosystem Dynamics of the Eurasian Neogene (EEDEN)' held in Parma in September 2002.

dissolution of *B. reticulata*, *B. bireticulata* and *B. moravica*. Within the same sample, *B. gneixendorfensis* has been observed with different degrees of dissolution and corrosion of the wall texture; from well preserved (Pl. 1, figs 5, 7, 11, 12) to strongly corroded (Pl. 1, figs 9, 13, 14). In addition, *B. reticulata*, *B. bireticulata* and *B. moravica* occurring in the same assemblage show a typical marked reticulated pattern even when strongly corroded (Pl. 1, figs 2a–b, 4, 6, 10). This indicates that the wall texture pattern of *B. gneixendorfensis* is real, typical of this species and not due to secondary processes.

Although small and juveniles specimens are generally less markedly ornamented than adult and large specimens (Spiegler & Spezzaferri, 2004), it has been concluded that *B. gneixendorfensis* does not represent a juvenile or small and less ornamented variant in a large population of more strongly reticulate forms (e.g. *B. reticulata* or *B. bireticulata*). In fact the size of most specimens of *B. gneixendorfensis* identified in the material in this study is comparable with the size of well-developed and adult *B. reticulata* (e.g. Pl. 1, fig. 7; Pl. 2, fig. 9) and, therefore, these specimens can be considered as adult.

Most of the specimens in the material possess a double-chambered test. Daniels *et al.* (1981) also observed abundant double-chambered specimens (over 100 specimens) of *B. reticulata* and *B. laevis* from the Reinbekian stage (Nannofossil Zone NN5, Middle Miocene) in a single sample from drill site Wursterheide. These authors observed that the two chambers are slightly elongated and subdivided by a septum with a round opening.

Bolboforma reticulata Daniels & Spiegler, 1974
(Pl. 2, figs 8–10)

1969 *Lagena metzmacheri* Clodius; Langer: 45, pl. 2, figs 1–2.
1974 *Bolboforma reticulata* Daniels & Spiegler: 64, pl. 7, figs 10–11.
1991 *Bolboforma reticulata* Daniels & Spiegler; Spiegler & Daniels: 139, pl. 4, figs 6–11.
1998a *Bolboforma reticulata* Daniels & Spiegler; Spezzaferri & Spiegler: pl. 2, fig. 2.

Diagnosis. Tests are spherical and single-chambered. The wall texture is strongly ornamented with widely spaced reticulations. The aperture is circular, bordered by a thick collar placed in a polygonal depression and surrounded by a smooth area. Often the collar is broken. The encapsulated cysts are single-chambered, ornamented by weaker, but still marked, reticulations corresponding in arrangement to those of the outer test (Pl. 2, fig. 10).

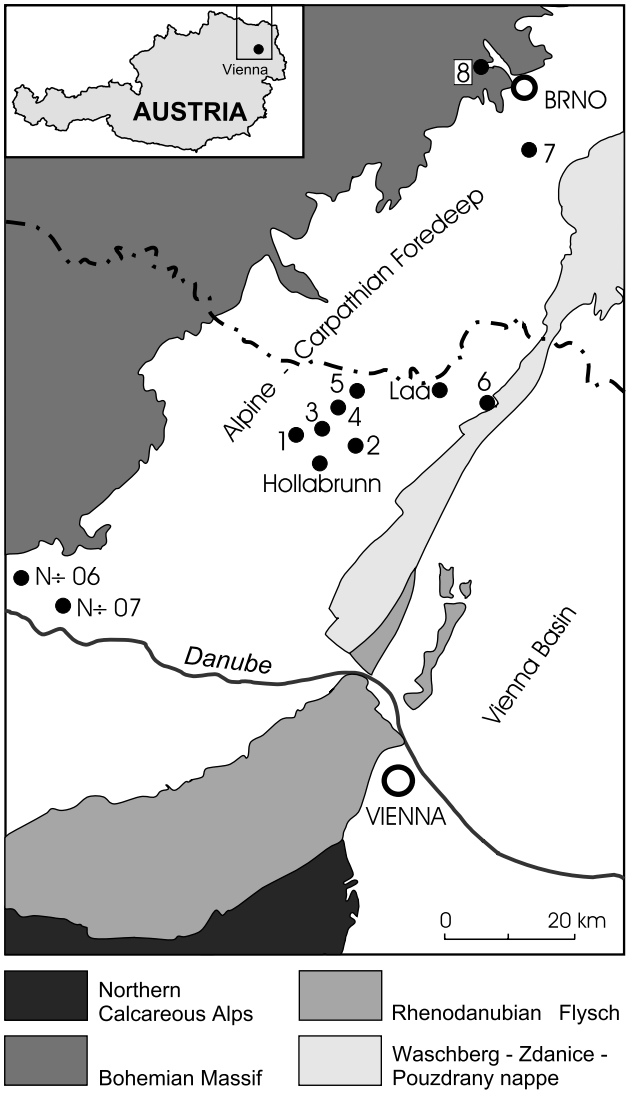


Fig. 2. Tectonic sketch of the Alpine–Carpathian Foredeep and location map showing the localities discussed in the text. 1, Grund; 2, Roggendorf 1; 3, Kalladorf; 4, Locatelliwald; 5, Buchberg near Mailberg; 6, Kautendorf; 7, Zidlochovice; 8, Kralice nad Oslavóu. Dashed line, border between Austria and Czech Republic.

Remarks. This species is relatively well documented in Middle Miocene sediments from the North Atlantic to the Southern Oceans (e.g. Spezzaferri & Spiegler, 1998a; Cooke *et al*., 2002). Its presence in Middle Miocene sediments from the Mediterranean Basin is reported in Spiegler & Daniels (1991) and Spiegler & Rögl (1992). The distribution in the Paratethys and northern Germany is reported in Spiegler & Rögl (1992) and Spiegler (2002) as restricted to the Middle Miocene (Lower to Middle Badenian).

Bolboforma bireticulata Spiegler, 2001
(Pl. 1, figs 1–4)

2001 *Bolboforma bireticulata* Spiegler: pl. 2, figs 7–12.

Diagnosis. Tests are double-chambered and elongated, chambers are spheroidal. The wall texture is strongly ornamented with widely spaced reticulations. The aperture is circular, bordered by a thick collar placed in a polygonal depression and surrounded by a smooth area. Often the collar is broken. Encapsulated cysts are single-chambered, ornamented by weaker but still marked reticulations corresponding in arrangements to those of the outer test.

Remarks. This species differs from *B. reticulata* only in having a double-chambered test and sharper ridges of reticulation.

The specimen in Plate 1 (fig. 1) displays a strongly reticulate texture and evidence of weak corrosion. The specimens of Plate 1 (figs 2a–b, 3) show a well-preserved wall texture with a less marked reticulate texture and very weak corrosion. The specimen in Plate 1 (fig. 4) displays a weakly ornamented texture and heavier corrosion.

Bolboforma moravica Redinger, 1992
(Pl. 1, fig. 10)

1977 *Bolboforma* cf. *clodiusi* Daniels & Spiegler; Bizon, Tagourdeau & Wright: 143, pl. 1 fig. 3.
1987 *Bolboforma badenensis* Szczechura; Poag & Karowe: 43, pl. 3, figs 1–4.
1992 *Bolboforma moravica* Redinger: 19, pl. 2, figs 9–16.
1992 *Bolboforma moravica* Redinger; Spiegler & Rögl: 83, pl. 3, figs 10–12.

Diagnosis. Tests may be single- or double-chambered. The wall texture is strongly ornamented by reticulations. The edges of the reticulations bear a little spine-like projection not present in *B. reticulata*. The aperture is circular, sometimes bordered by a thick collar situated in a polygonal depression.

Remarks. This species is documented from the Central Paratethys as well as in the North Atlantic (Voering Plateau) and North America (Spiegler & Rögl, 1992).

Its distribution spans the Badenian–Middle Miocene (Nannofossil Zones NN5 and NN6).

Family **Calciodinelloidea?** Deflandre, 1947
Genus *Bachmayerella* Rögl & Franz, 1979

Rögl & Franz (1979) discussed the possibility that these organisms are Tintinnidae or reproduction stages of some marine metazoans. These authors documented a multi-layered wall for the Miocene forms. Successively, the Plio-Pleistocene specimens from ODP Leg 160 were attributed to the group of calcareous cyst of dinoflagellates (Calciodinelloidea) by Spezzaferri & Spiegler (1998b) based on a single-layered wall consisting of elongated calcite microcrystals orientated perpendicular to the surface of the cyst. In contrast to Calciodinelloidea, the wall consists of small polygonal plates. A more precise taxonomic position is still to be clarified.

Bachmayerella tenuis Rögl & Franz, 1979
(Pl. 2, fig. 6)

1979 *Bachmayerella tenuis* Rögl & Franz: 90, pl. 1 figs 9–14; pl. 4, figs 35–38; pl. 5, figs 39–46.
1986 *Bachmayerella tenuis* Rögl & Franz; Szczechura: 225, pl. 22, figs 3–4; pl. 27, figs 1–2, 4–8.

Samples	*Bolboforma reticulata*	*Bolboforma moravica*	*Bolboforma bireticulata*	*Bolboforma* cf. *badenensis*	*Bolboforma spinosa*	*Bolboforma* sp. C	*Bolboforma gneixendorfensis*	Cyst	*Bachmayerella tenuis*	*Bachmayerella laqueata*	*Bachmayerella* sp.	Various Calc-dinocyst
Grund F., Profile G-10												R
Grund F., Profile G-3		VR										R
Grund F., Profile G-6	R											
Grund F., Profile G-8	C	cf										
Grund F., Profile G-10												R
Grund F., Profile E-2	R	R										
Grund F., Windmühlberg, W1	c											
Grund F., Windmühlberg, W2	R	R										
Grund F., Windmühlberg, W3	R/C	R	R	VR								
Grund F., Windmühlberg, W4	R	R			cf							
Grund F., Roggendorf-1, 2–7 m	R	R										
Grund F., Roggendorf-1, 7–10 m	R					R		VR	R	cf		
Grund F., Roggendorf-1, 180 m	VR							VR				
Kautendorf, Rö 9/94	R											
Kalladorf, Rö-Kal-1	R/C											
Locatelliwald-Stü 11/87									C		R	
Locatelliwald-Stü 10/87									R/C			
Frättingsdorf, Rö 7/76										R		
Kralice bad Oslavou, 4B										R/C		
Zidlochovice, Schultz 82									R/C	R		
Hadersdorf, Nö-07, 41.6–41.7										R		
Hadersdorf, Nö-07, 85.20–85.30									VR	R		
Hadersdorf, Nö-07 176.7–176.8								VR				
Hadersdorf, Nö-07 214.5–214.6										cf		
Gneixendorf, Nö-06, 89.4–89.5									R			
Gneixendorf, Nö-06, 104.7–104.8	C	C	R/C			R	C/A	C	R	VR		
Buchberg/Mailberg. Ro 80/77									C		R	

Bolboforma badenensis sensu Spezzaferri & Spiegler (1998a)

Table 1. Distribution of *Bolboforma* and Calciodinelloidea in the studied sections/samples.

1997 *Bachmayerella tenuis* Rögl & Franz; Poignant: 94, pl. 5, fig. 23.

1998b *Bachmayerella tenuis* Rögl & Franz; Spezzaferri & Spiegler: 128, pl. 1, figs 4–9.

Diagnosis. The calcareous test is sub-spherical with a typical circular archaeophyle of 25–35 μm in diameter. The wall texture is covered by a regular pattern of reticulations. Distinct pores are visible in well-preserved material, irregularly distributed and present on the intersections of the ridges forming the reticulations. A spine-like protruding tube is present in an aboral position.

Remarks. These forms are rare in the Lower Badenian (Langhian, Zone NN5) of the Central Paratethys, but common in some horizons of the Middle to Upper Badenian (Lower Serravallian, Zone NN6). They are also relatively common in the Pliocene and Pleistocene (Spezzaferri & Spiegler, 1998b) and rarer in Miocene (Spezzaferri *et al.*, 2001) sediments from the eastern Mediterranean. Poignant (1997) reports the species from the Burdigalian and Langhian of the Aquitaine Basin.

Bachmayerella laqueata Rögl & Franz, 1979
(Pl. 2, fig. 6)

1979 *Bachmayerella laqueata* Rögl & Franz: 87, pl. 1 figs 1–8; pl. 2, figs 15–22; pl. 3, figs 2–30; pl. 12, figs 31–34.

1986 *Bachmayerella laqueata* Rögl & Franz; Szczechura: 224, pl. 22, figs 5–9 (not 1–2, 10); pl. 25, fig. 6.

1992 *Bachmayerella laqueata* Rögl & Franz; Poignant: 1155, figs 1–6.

Diagnosis. The calcareous test is sub-spherical with a typical circular archaeophyle with diameter sometimes exceeding 50 μm. The wall texture is covered by an irregular pattern of reticulations. Distinct pores are visible in well-preserved material, irregularly distributed and present on the intersections of the ridges forming the reticulations. A small spine-like protruding tube may be present in an aboral position.

Remarks. This species differs from *B. tenuis* in being generally larger in size and having a more irregular pattern of its strong reticulations. In the Central Paratethys this species has the same stratigraphic distribution as *B. tenuis* within the Badenian. The only record outside the Paratethys, is from the Upper

Burdigalian and Langhian of the Aquitaine Basin (Poignant, 1997).

Other Calciodinelloidea. By comparison with the species documented in Keupp (1979a) the specimens in Plate 2 (figs 1a–b, 2a–b, 4) have been tentatively attributed to the Family Calciodinelloidea Deflandre (1947) and Genus *Alasphaera* Keupp (1979b). The presence of individuals of the same species with or without apertures indicates their cyst nature (Keupp, 1979b); however, their taxonomic position remains uncertain.

Alasphaera sp. 1
(Pl. 2, figs 1a–b)

The tests are calcareous, rounded, the wall texture is smooth and covered by smooth and regularly distributed pustule-like structures. These specimens differ from *Alasphaera caudata* Keupp (1979b) in having less pronounced, smaller but more numerous pustules without thickened terminations, and from *Alasphaera verrucosa* Keupp (1979b) for the smaller, more numerous and smoother pustules. Both *A. caudata* and *A. verrucosa* occur in Lower Cretaceous sediments from NW Germany.

Alasphaera sp. 2
(Pl. 2, fig. 5)

This form also resembles *Alasphaera* sp., but differs in having more pronounced pustule-like structures that are more irregularly distributed. Although the specimen is relatively poorly preserved, the pustule terminations seem to be thickened, resembling those of *A. caudata*, although pustules are less numerous in the latter species.

Incertae Sedis/radiolarian?
(Pl. 2, figs 2a–b)

1976 *Bolboforma* aff. *B. rotunda* Daniels & Spiegler; Odrzywolska-Bienkowa: 555, pl. 2, figs 2A–B.

These specimens are similar to *Alasphaera* sp. 1, but differ in having a polygonal pattern all over the wall covered with pustule-like structures. The specimen figured by Odrzywolska-Bienkowa (1976) shows the same fine reticulation covering the entire wall.

Similar wall texture and reticulations can also be seen in some radiolarians such as, *Conocaryomma universa* Pessagno or *Praeconocaryomma* spp. (Gregory pers. comm.) with the test diagenetically replaced by calcite. Subsequently, the specimen in Plate 2 (figs 2a–b) was sectioned. It displays calcite infilling and, therefore, may be a re-crystallized radiolarian (Rögl, pers. obs.). This specimen demonstrates how difficult it is to distinguish real calcareous cysts of dinoflagellates from *incertae sedis* and re-crystallized radiolarians.

Odrzywolska-Bienkowa's specimen is described from the locality Kikov, Poland, from the Miocene. The presence of *B. reticulata* (described as *B. metzmacheri*) in the same locality indicates a possible Badenian age.

Incertae Sedis
(Pl. 2, figs 3a–b)

1986 *Bachmayerella laqueata* Rögl & Franz; Szczechura: 222, pl. 22, figs 1–2 (not pl. 22, figs 5–10, pl. 25, fig. 6).

The taxonomic position of these specimens is unclear. Their morphology resembles that of *Bachmayerella*, but their wall texture is irregular, rough, with interspaced spine-like heavy pustules. A subdivision of the wall into polygonal plates is absent. The specimen in Plate 2 (figs 3a–b) shows an irregularly rounded archaeophyle. Similar forms are figured by Szczechura (1986) from the Badenian of Poland.

Pithonella sp.
(Pl. 2, figs 4a–b)

This form displays a rounded test with a moderately wide archaeophyle. The genus *Pithonella* is generally described from Mesozoic and Danian sediments (Bolli, 1974; Rögl, 1976). However, the form documented in Plate 2 (figs 4a–b) and found in Middle Miocene sediments, is tentatively attributed to the Genus *Pithonella* (Lorenz) based on morphological similarity, a double-layered wall and the nature of the outer layer composed of crystallites. Such forms were also observed in Middle Miocene sediments of the eastern Mediterranean, DSDP Leg 42 (Müller pers. obs.). *Pithonella* is included here in the Family Calciodinelloidea Deflandre following Keupp (1979a) who demonstrated a systematic relationship between *Pithonella* and the calcareous cyst of dinoflagellates.

DISCUSSION

Bolboforma is generally not abundant in outcropping sediments in European sections (see Spezzaferri *et al*., 2001 and Spiegler, 2002 for a review). It has been demonstrated that *Bachmayerella* spp. is stratigraphically useful in the Pliocene and Pleistocene of the eastern Mediterranean (Spezzaferri & Spiegler, 1998b) although their distribution and ecological preferences are still poorly known. In particular, although, their upper range is well documented (Spezzaferri & Spiegler, 1998b), their first occurrence is still uncertain. The older sediments in which they are found are attributed to the Late Burdigalian from the Aquitaine Basin (Poignant, 1997).

In the Central Paratethys, these organisms are common only in distinct horizons, although the literature available is poor (e.g. Spiegler & Rögl, 1992; Szczechura, 1986, 1997). No descriptions are available for other Miocene calcareous cysts of dinoflagellates. Although complete information about their distribution is still missing, this research contributes important data to improve their stratigraphic value.

Spiegler (2002) correlated the marine Miocene *Bolboforma* standard zonation that was calibrated with the Nannoplankton zonation of Martini (1971) and the chronostratigraphy of Berggren *et al.* (1995) with the regional zonation based on uvigerinids in northern Germany (Fig. 1). Spiegler (2002) reports the presence of *B. reticulata* in sediments spanning 14.5 Ma to 15.6 Ma, and the range of *B. bireticulata* from 14.5 Ma to 15.0 Ma. In particular, she recognizes a Lower *B. reticulata* Zone (14.5–15.6 Ma) and an Upper *B. reticulata* Zone (12.7–14.5 Ma). The Lower *B. reticulata* Subzone (Total Range

Locality	Foraminifera	*Bolboforma* and calcareous cysts of dinoflagellates	Nannofossil zonation	*Bolboforma*/*Uvigerina* zonation	Ages (Ma)	References
Grund, sections	*Po. glomerosa circularis*, *Gr. bykovae*, *U. graciliformis*, *U. macrocarinata*	*B. reticulata*, *B. moravica*	NN5	Lower *B. reticulata* Zone–*U. macrocarinata* Subzone	Approximately 14.8–15.1	Spezzaferri (2004); Coric & Svabenicka (2004); this study
Grund, Windmühlberg	*Gr. bykovae*, *Gr. transsylvanica*, *U. graciliformis*	*B. reticulata*, *B. bireticulata*, *B. moravica*		Lower *B. reticulata* Zone–*U. macrocarinata* to *U. brunnensis* Subzones	Approximately 14.5–15.1	unpublished data and this study
Roggendorf 1, 7–10 m	*Po.glomerosa circularis*, *Orbulina suturalis*	*B. reticulata*, *B. moravica*, *Bachmayerella*	NN5			Coric & Rögl (2004); this study
NÖ-07, Diendorf near Hadersdorf, 240.0–260.4 m	*Pgr. mayeri*, *Gr. bykovae*	*Bachmayerella* group	NN4			Coric *et al.* (2004); this study
NÖ-06, Gneixendorf, 79.1–97.0 m	Upper Lagenid Z.: *Orbulina suturalis*, *Gr. bykovae*, *U. grilli*	*Bachmayerella tenuis*	NN5			Coric *et al.* (2004); this study
NÖ-06, Gneixendorf, 97.0–104.8 m	Lower Lagenid Z.: *Po. glomerosa*, *Gr. bykovae*	*B. reticulata*, *B. moravica* *B. bireticulata*, *B. gneixendorfensis*, *Bachmayerella* group	NN4	Lower *B. reticulata* Zone–*U. macrocarinata* to *U. brunnensis* Subzones	Approximately 14.8–15.1	Coric *et al.* (2004); this study
Kautendorf near Staatz	*Po.glomerosa circularis*, *Orbulina suturalis*, *Gr. bykovae*, *Gr. transsylvanica*, *U. macrocarinata*	*B. reticulata*		*B. reticulata* Zone	14.5–15.1	Coric *et al.* (2004); this study
Buchberg near Mailberg, Mailberg Fm.	*Po.glomerosa circularis*, *Orbulina suturalis*, *Gr. bykovae*, *U. macrocarinata*	*Bachmayerella* group				Spiegler & Rögl (1992); Ctyroky (1997); Coric & Rögl (2004)
Locatelliwald near Immendorf, Mailberg Fm.	*Po. glomerosa*, *O. suturalis*, *Gr. bykovae*	*Bachmayerella* group				Spiegler & Rögl (1992); Ctyroky (1996)
Kalladorf near Hollabrunn, Grund Fm.	*Po.glomerosa circularis*, *Orbulina suturalis*, *Gr. bykovae*	*B. reticulata*		*B. reticulata* Zone	14.5–15.1	Coric & Rögl (2004); this study
Zidlochovice, CZ (Badenian para-stratotype)	*Po.glomerosa circularis*, *O. suturalis*, *U. grilli*, *U. macrocarinata*	*Bachmayerella* group				Cicha (1978) in Papp *et al.* (1978)
Kralice and Oslavou, W of Brno	*U.macrocarinata*, *O. suturalis*	*Bachmayerella* group				Hamrsmid (1984); Redinger (1992)

The reference list refers to foraminifera and calcareous nannofossils only, with the exception of Spiegler & Rögl (1992) reporting a preliminary study of *Bolboforma*. Nannofossils zones follow Martini (1971).

Table 2. Biostratigraphic summary of the studied sections, zonations and ages of *Bolboforma*.

Zone of *B. reticulata*) is identified between the first occurrence (FO) of *B. reticulata* and the FO of *B. platyreticulata* and contains common *B. reticulata sensu strictu*, the Upper *B. reticulata* Subzone does not contain *B. reticulata sensu strictu* and is identified between the FO of *B. platyreticulata* and the FO of *B. danielsi*. Within the Lower *B. reticulata* Zone, four subzones are recognized based on the distribution of uvigerinids (*U. tenuipustulata*, *U. acuminata*, *U. macrocarinata* and *U. brunnensis*).

A good example of how *Bolboforma* can be used in the Paratethys to confirm and improve the stratigraphic resolution based on other microfossil groups and magnetostratigraphy is within the framework of the studies on the Grund Formation. Weinhandl (1957) and Grill (1958) identified in these sediments the typical Early Badenian (Langhian–Middle Miocene) planktonic foraminiferal assemblage consisting of *Praeorbulina glomerosa* and *Orbulina suturalis*. In more recent years the lower part of this formation has been dated as Karpatian (Burdigalian–Early Miocene) by Cicha & Rudolsky (1996) and Cicha (1999). The combined effort of different projects focused on the Austrian Miocene contributed new information and insight into this issue. In particular, it was improved by the study of eight profiles (Profiles A–I) previously excavated by the Institute of Paleontology of the University of Vienna in the Grund Formation type locality. The documentation of three specimens of *P. glomerosa circularis*, in one sample from Profile G, a few specimens of *U. macrocarinata* identified in Profile F adjacent to Profile G (Spezzaferri, 2004) and *Helicosphaera waltrans* (Coric *et al*., 2004; Coric & Rögl, 2004) enable the correlation of the lower part of the Grund Formation with the Early Badenian (nannofossil Zone NN5 and foraminiferal Zones M5b). The magnetostratigraphy, displaying normal polarity in the Grund type locality, could also be interpreted using biostratigraphic data of calcareous nannofossils and planktonic foraminifera and is tentatively attributed to Chron C5Bn.2n (from 15.034 to 15.155 Ma) as in Coric *et al.* (2004). The co-occurrence of *B. reticulata* and *Uvigerina macrocarinata*, allow the correlation of the investigated sediments with the Lower *B. reticulata* Zone (14.5–15.6 Ma) and with the *U. macrocarinata* Subzone (approximately 14.8–15.1 Ma, by comparison with the correlation of Spiegler, 2002). This age is consistent with the age of Chron C5Bn.2n and confirms the age of the sediments of the lower part of the Grund Formation.

Spezzaferri (2004) demonstrated that the sediments at the type locality of the Grund Formation can be dated using planktonic foraminifera such as *Praeorbulina* and *Orbulina* spp. Although these species are generally very rare and confined in the thin and rare marly layers, their finding in the Grund Formation represents the framework for future studies. However, many outcrops (including some profiles adjacent to Profile G and F, where these specimens were found) do not contain planktonic foraminifera. This formation is characterized by different facies (Harzhauser *et al*., 1999; Zuschin *et al*., 2001), which represent environmental conditions such as shallow waters, storm layers and/or coarse sediments, where planktonic foraminifera are absent. Since *Bolboforma* can also be found in relatively shallow water (neritic) and coarser sediments (such as wackestone and packstone (Spezzaferri *et al*., 2001), in many cases it remains an important biomarker to identify the Early Badenian (Middle Miocene Nannofossil Zone NN5) in the Grund Formation.

Table 2 summarizes the occurrences of planktonic foraminifera, *Bolboforma* and calcareous cysts of dinoflagellates, compared with the calcareous nannofossil, *Bolboforma* and *Uvigerina* zonations. Ages are derived by comparison of foraminifera and *Bolboforma* bioevents.

CONCLUSIONS

The distribution of *Bolboforma* and *Bachmayerella* and, for the first time, the presence of some calcareous cysts of dinoflagellates, such as *Alasphaera* and *Pithonella*, are reported here from Badenian (Langhian–Middle Miocene) sediments in Austrian and Moravian localities.

Alasphaera and *Pithonella* have been previously described in Cretaceous and Palaeocene, but never in Miocene, sediments. Therefore, these new discoveries, allow their range to be extended into the Paratethyan Middle Miocene.

Additionally, the biostratigraphy of the Grund Formation has been investigated in eight profiles excavated at the type locality. Results indicate that, at this site, planktonic foraminifera can be used for biostratigraphy, but are very rare. In particular, three specimens of *Praeorbulina glomerosa circularis* and a few specimens of the benthic *Uvigerina marocarinata* have been found in Profiles G and F. Sediments from adjacent profiles and other Middle Miocene sections in Austria and Moravia are barren of planktonic foraminifera, or contain only non-age diagnostic species. In these cases, *B. reticulata* is an important correlative biomarker, which enables the identification of the Middle Miocene Zone M5b (planktonic foraminifera) and Zone NN5 (calcareous nannoplankton). Therefore, this study demonstrates how the use of *Bolboforma* may improve stratigraphic resolution in the absence of more precise dating.

Finally, the new species *Bolboforma gneixendorfensis* is described. This species is similar in size and shape to *B. reticulata*, *B. bireticulata* and *B. moravica*, but differs from them in having a very weakly ornamented wall texture.

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