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ROGGENDORF-1 BOREHOLE, A KEY-SECTION FOR LOWER BADENIAN TRANSGRESSIONS AND THE STRATIGRAPHIC POSITION OF THE GRUND FORMATION (MOLASSE BASIN, LOWER AUSTRIA)

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Abstract: Borehole Roggendorf-1 was drilled in the Alpine-Carpathian Foredeep (Molasse Basin) north of the Danube (Lower Austria). Biostratigraphic results and the lithological column revealed until now unrecorded Early Badenian (Middle Miocene) cycles. Calcareous nannoplankton was studied from the upper 800 m of a Neogene sequence and foraminifers were examined from the upper 410 m. The upper 2 m to 255 m fine clastic sediments of the Grund Formation (Lower Badenian, nannoplankton Zone NN5, planktonic foraminiferal Zone Mt6) show a deepening upward, with a maximum depth corresponding to outer shelf. Paleoecological evaluations demonstrate a distinct warming of the surface water. Down-hole, a clastic sequence follows starting with a gravel bed (347–360 m), and ending with a conglomerate bed on top (255–270 m). The latter is probably the transgressive base of the Grund Formation. The boundary of nannoplankton Zones NN 4–NN5 lies within this earlier Badenian cycle, which was deposited on the inner shelf, below 50 m. Limestone and sandstone pebbles originate from the Calcareous Alps and Flysch Unit. The underlying cycle of calcareous silty shales, sands and thin gravel layers belongs to the Laa Formation (Karpatian, nannoplankton Zone NN4; 360–612 m). Deposition occurred, partly under dysoxic bottom conditions on the outer shelf to upper bathyal. Surface waters were distinctly cooler than in the Grund Formation due to strong upwelling with nutrient enrichment. The Karpatian is underlain without a distinct unconformity by the Upper Ottnangian brackish *Rzehakia* (“*Oncophora*”) Beds, fine sands and shales, which are barren of fossils (612–678 m). The lower part of the investigated section belongs to the Ottnangian “*Robulus* Schlier“. Nannoplankton determinations show that this still belongs to nannoplankton Zone NN4. Nannoplankton Zone NN3/4 is recorded on the basis of the occurrence of *Sphenolithus belemnos* only in the lowermost samples (790–800 m).

Key words: Miocene, Alpine-Carpathian Foredeep, Grund Formation, Laa Formation, paleoecology, biostratigraphy, microfossils.

Introduction

Different Miocene formations are exposed in the Austrian Molasse Basin north of the Danube. Miocene sequences in the deep drilling Roggendorf-1 were investigated to determine the stratigraphic extension of the Badenian Grund Formation. Roggendorf-1, drilled by OMV AG in 1962, penetrated 1008 m of Neogene sediments, and terminated in a volcanoclastic complex of the Gresten Formation (Jurassic).

Geological setting

The Austrian Molasse Basin, as part of the Alpine-Carpathian Foredeep, changes direction in the investigated area from a west-east stretching basin to northeast, following the outline of the Bohemian Massif (Fig. 1). Marine sedimentation started north of the Danube in the Egerian (Late Oligocene to Early Miocene). Lower Miocene (Eggenburgian to Ottnangian) marine sediments follow concordantly. The facies changed to brackish *Rzehakia* (“*Oncophora*”) Beds, ending the first Lower Miocene marine cycle. Overthrust of Alpine-Carpathian nappes narrowed the basin strongly, and included the *Rzehakia* Beds in the thrust. The late Early Miocene (Karpatian/Late Burdigalian) Laa Formation transgressed discordantly on older surfaces. At the beginning of the Middle Miocene the Badenian Sea transgressed from the southeast (comp. Jiříček 2001; Jiříček & Seifert 1990; Stráník & Brzobohatý 2000).

The Lower Badenian sediments, developed in northern Austria as sequences of marls, silts, sands, and gravels, belong to the time-equivalent Grund and Gaindorf Formations. The Mailberg Formation consists of corallinacean limestone with some marly intercalations. The submarine fan of the Hollenburg-Karlstetten Formation, coming from the Alps in the southwest, interfingers with the Gaindorf Formation. The geological situation of the study area (Fig. 1) is described in detail by Roetzel et al. (1999) and Roetzel & Pervesler (2004).

The basal Badenian sediments in the foredeep have been dated by calcareous nannoplankton as nannoplankton Zone NN4. Nannoplankton Zone NN5 and, based on the occurrence of *Praeorbulina glomerosa circularis*, planktonic foraminiferal Zone M5b are recorded in the Grund Formation (Rögl et al. 2002; Rögl & Spezzaferri 2003; Spezzaferri 2004). This contrasts with the interpretation of Cicha (1999a), Švábenická & Čtyroká (1999), and Švábenická (2002), who placed the lower

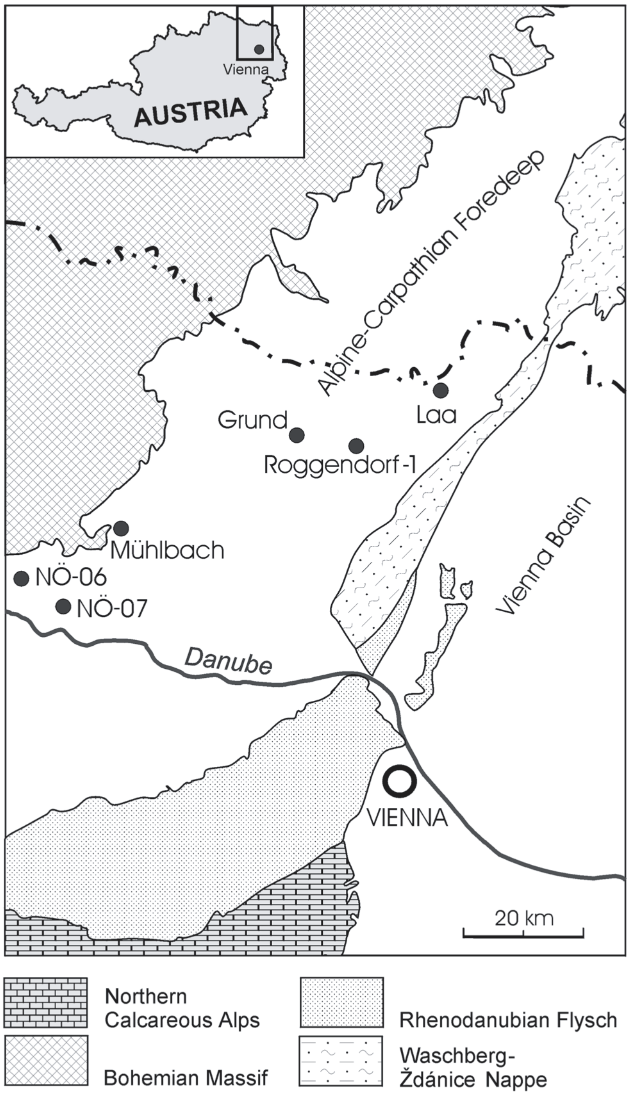


Fig. 1. Geological sketch of the Alpine-Carpathian Foredeep in northeastern Austria, and position of the investigated site Roggendorf-1, together with drill sites NÖ-06 Gneixendorf, 2 and NÖ-07 Diendorf near Hadersdorf am Kamp (redrawn acc. Kreutzer 1993).

part of the Grund Formation in the Early Miocene Karpatian Stage.

Lithology of borehole Roggendorf-1

The lithology is based on an internal report of OMV AG (Schulz 1966), on the resistance log, and on the washed residue of cutting samples (Fig. 2). Samples were available from the upper 10 m, and from 130 m downward. The upper 2 m of the section belong to Quaternary soil and loess.

2–255 m. Lower Badenian, Grund Formation: Light brown to grey-green, silty to sandy, micaceous marly shales, with intercalated layers of fine to coarse sands and fine gravels. In the fine fraction of the residue, angular quartz and mica dominate, and in the coarse fraction quartz, crystalline and carbonate grains are present. Some pyrite concretions and lignitic plant remains occur. The foraminiferal fauna is abundant in the uppermost part (samples 2–10 m) only.

255–360 m. Lower Badenian, basal clastic sequence:

255–270 m. Conglomerates and sandstones: gravels and pebbles of grey, dark grey and grey-brown limestone and dolomite, light brown biogeneous and oolitic limestones, blue-grey chert, hard sandstones, some quartz and crystalline pebbles, originating mainly from the Calcareous Alps and Flysch Unit. Greenish-grey calcareous sandstones are intercalated, partly also as matrix of the conglomerate.

270–347 m. Fine sands and silty shales: greenish-grey and light grey, silty and sandy, micaceous calcareous shales with interbedded layers of grey fine sand, sometimes coarse sand and small gravels. In the fine residue, mainly angular quartz, in the coarse fraction well-rounded quartz, carbonates, hard sandstone and some crystalline pebbles, lignitic plant remains, and rare pyrite occur. Strong reworking of foraminifers is observed; autochthonous foraminiferal assemblages are scarce.

347–360 m. Basal gravels: commonly quartz, crystalline components rare; grey, dark grey, black, and brownish carbonates, and light brown and grey, biogenous limestones; hard fine-grained sandstones. Carbonates and sandstones originate from the Alps.

360–612 m. Karpatian, Laa Formation: grey and greenish-grey, silty to sandy micaceous calcareous shales, alternating with layers of grey fine sand, and a few horizons with gravels. The fine fraction of the residue consists of quartz and grey carbonates, in the coarse fraction are rounded grains of quartz, crystalline, carbonate, and sandstone. Some pyrite concretions and common lignitic or coal particles occur. The gravels and coarse sands consist of well-rounded quartz, some crystalline, sandstone, and a few carbonates. In cuttings of 370 m the residue consists similarly of quartz and carbonate, and pyritized diatoms are present as in the following samples. Because of the presence of diatoms the upper boundary of the Karpatian has been placed at the base of the gravel bed at 360 m.

612–678 m. Ottnangian, *Rzehakia* (“*Oncophora*”) Beds: grey fine sands with layers of dark grey, well-bedded clay, and a layer of light grey calcareous sandstone at 652 m. The bivalve *Rzehakia* (“*Oncophora*”) was not recorded. The correlation is based on lithology and geophysical measurements.

678–800 m (end of investigation). Ottnangian, “*Robulus* Schlier”:

678–715 m. Dark greenish-grey, silty-sandy shales with thin beds of fine sand, and with fish and molluscan remains, along with some foraminifers.

715–735 m. Greenish-grey, clayey fine sand with layers of dark shales; with some foraminifers, mainly *Lenticulina* (“*Robulus*”).

735–780 m. Greenish-grey sand and grey clayey glauconitic sandstone with pyrite concretions. Some molluscan and echinoid remains, rare foraminifers.

780–793 m. Coarse sand and gravel, well rounded, dominated by quartz; with thin layers of shales. With few molluscan and echinoid remains.

793–800 m. Alternating layers of sand, glauconitic sandstone, and greenish-brownish grey sandy shales. Some fish and molluscan remains, rare foraminifers.

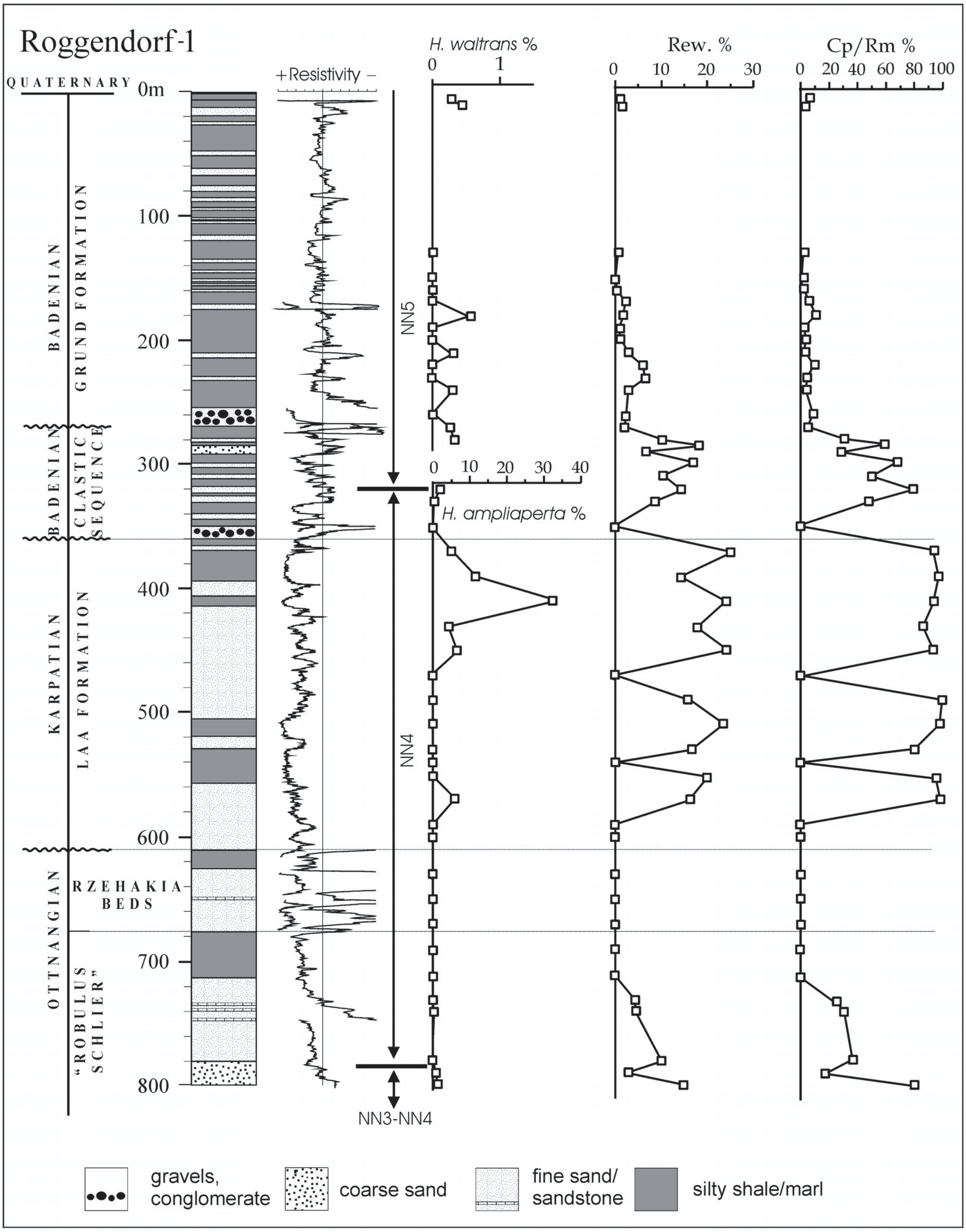


Fig. 2. Borehole Roggendorf-1: stratigraphy, lithology, resistivity, abundance patterns of selected calcareous nannofossils, the percentage of reworked nannoplankton, and variations in *C. pelagicus*/*R. minuta* ratio (Cp/Rm).

Material and methods

The calcareous nannofossil distribution in Roggendorf-1 was studied from the upper 800 m of the section. Samples from the interval 10–130 m were not available. Smear slides were prepared for all samples and analysed using a light microscope (1000× magnification) at normal and crossed nicols to identify calcareous nannofossils. Statistical methods were applied to quantitative data using the Software PRIMER 5 (Clarke & Warwick 1994). This method was already successfully applied for the paleoecological interpretation of the middle Karpatian from Laa an der Thaya, Lower Austria (Spezzaferri & Ćorić 2001). Square-root transformed abundances were used for hierarchical agglomerative clustering (Group Average Linking) based on the Bray-Curtis Similarity coefficient (Fig. 3). Barren samples were not included. Samples are ordered by non-metric MultiDimensional Scaling (nMDS) on the basis of the same similarity matrix as in the clusters, which are investigated through the Similarity and Dissimilarity Term Analysis.

The foraminiferal fauna has been qualitatively investigated from cuttings between 2 and 410 m for biostratigraphic and paleoecological indications.

Results

Paleoecology

Calcareous nannoplankton

The autochthonous calcareous nannofossil distribution in Roggendorf-1 borehole is arranged alphabetically and listed in Appendix A.

The data on calcareous nannoplankton were quantitatively analysed using the Bray-Curtis Similarity. Based on agglomerative clustering it is possible to distinguish 6 classes (Appendix C, Figs. 3, 4a).

The Similarity and Dissimilarity Term Analyses of calcareous nannoplankton (Appendix C) suggest that Cluster 2 groups assemblages, which are characterized by a high percentage of *Reticulofenestra minuta*. This species accounts for 89.5 % of the average similarity within this cluster. This cluster includes only samples of Badenian age belonging to the NN5 Zone (Fig. 4b,c). Cluster 6 groups samples, which indicate high nutrients and coastal upwelling, are characterized by *Coccolithus pelagicus* and *Syracosphaera pulchra*. These two species account for 57 % of the average similarity. Clusters 2 to 5 are characterized by the stepwise increase in the ratio of *C. pelagicus* at the expense of *R. minuta*. In Cluster 1 two species (*C. pelagicus* and *R. minuta*) account for 66.7 % of the average similarity. These samples are characterized by a very low abundance of calcareous nannofossils and therefore cannot be satisfactorily interpreted. According to these data it is possible to interpret the first axis of the nMDS as a nutrient (Figs. 4b–c) and surface water temperature gradient (Fig. 4a). Clusters 1, 5 and 6 group samples containing only typical Karpatian sediments from the NN4 Zone. Clusters 3 and 4 include samples from the Ottnangian to Badenian without distinct preference (Fig. 4b,c).

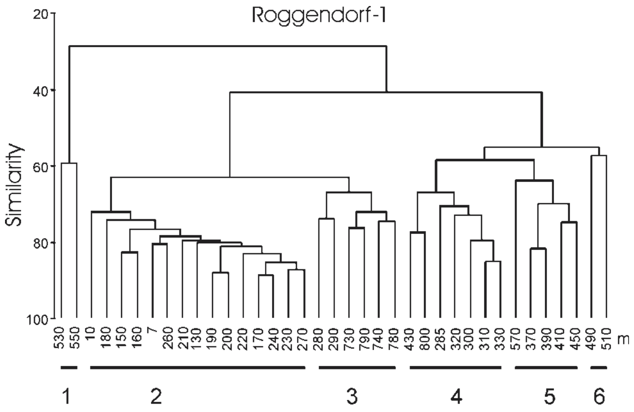
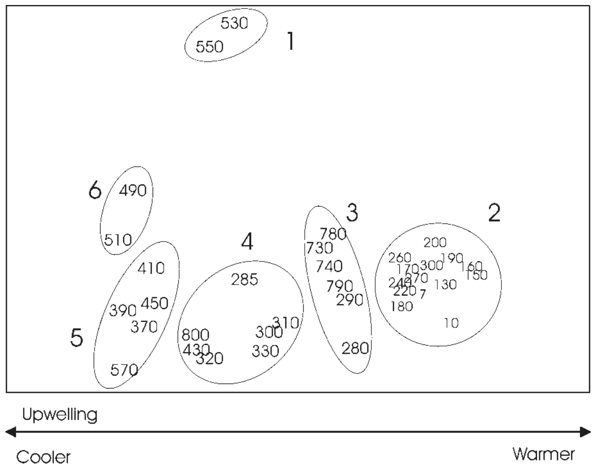


Fig. 3. Hierarchical agglomerative clustering based on the Bray-Curtis Similarity of calcareous nannofossils from Roggendorf-1.

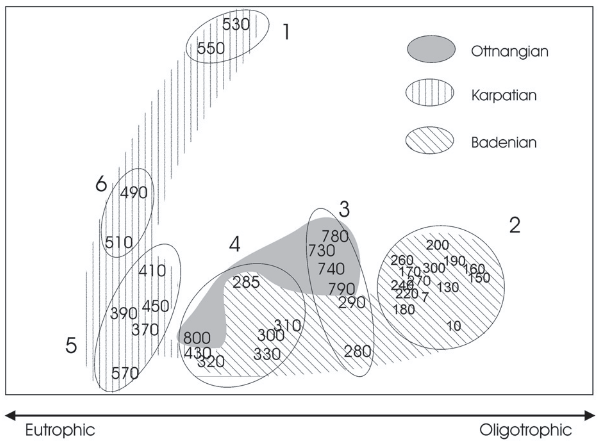
The sample from 510 m contains a calcareous nannofossil assemblage with a high percentage (27.7 %) of *Braarudosphaera bigelowii*. This nannofossil association is characterized by a reduced diversity and contains a relatively high percentage of *Coccolithus pelagicus* and *Syracosphaera pulchra*. *Reticulofenestra minuta*, *Reticulofenestra* sp., *R. gelida*, *Helicosphaera carteri* and *Sphenolithus moriformis* are rare. *Braarudosphaera bigelowii* is very scarce or absent in other samples. Nagymarosy (1991) described a *Braarudosphaera*-bloom from Oligocene sediments and explained it with the partial separation of the Paratethys. Švábenická (1999) reported *Braarudosphaera*-rich sediments in the Turonian of the Bohemian Cretaceous Basin. Bukry (1974) used the high percentage of *Braarudosphaera bigelowii* in Holocene sediments from the Black Sea as an indication of low marine salinity. The enrichment of this cold, nutrient-rich-water-loving species in sediments from Roggendorf-1 suggests a short period of fresh water input and reduced salinity of the surface waters.

Winter et al. (1994) concluded that availability of nutrients, light and temperature are the factors which control phytoplankton productivity. *Coccolithus pelagicus* belongs to the group of so-called r-strategists, which are characteristic of nutrient-rich eutrophic environments. The water movements in upwelling areas lead to enhanced nutrient availability. Such habitats within the euphotic zone were typical for Karpatian sediments within the NN4 Zone. Sparser nutrient supplies during the Badenian (nannoplankton Zone NN5) created oligotrophic conditions within a well-stratified water column and enabled the *R. minuta*-bloom (Fig. 4b,c). Hallock (1987) pointed out that oligotrophic biotas feature small-sized phytoplankton and longer, more complex food chains. Ottnangian sediments from the NN4 Zone recorded in Roggendorf-1 show more oligotrophic paleoceanographic characteristics, whereas the 800 m sample (NN3–NN4) has more eutrophic features.

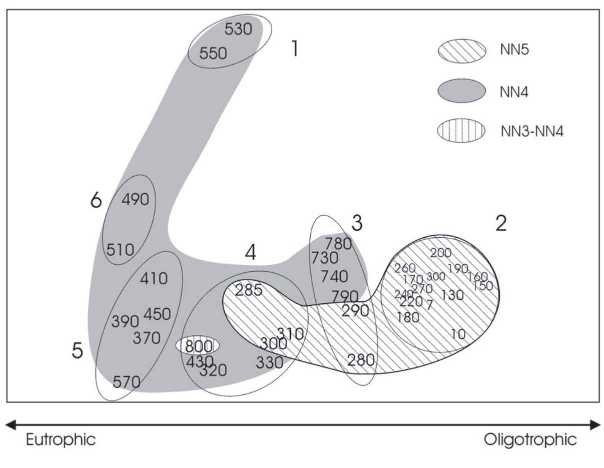
The paleoecological interpretation of the calcareous nannofossil assemblages is based on variations in the abundances of *C. pelagicus* and *R. minuta. Coccolithus pelagicus* is already well known as an important paleoclimatic marker. This species is normally used as a paleotemperature proxy for cooler waters. It is abundant at water temperatures between −1.5 and +15 °C, with optimum growth from 2 to 12 °C (Okada & McIntyre 1979; Winter et al. 1994). The enrichment of *C. pelagicus* in sediments indicates high nutrient levels in surface water and upwelling paleoconditions. Beaufort & Aubry (1992) studied abundance variations of *C. pelagicus* at the Kerguelen Plateau (Southern Indian Ocean) within the Ocean Drilling Program (ODP) Site 747A. They computed the percentage of *C. pelagicus* vs. *Reticulofenestra* spp. and compared their results with paleoceanographic events revealed by stable isotope studies.



4a. Arrangement of clusters shows the increase from cooler to warmer conditions.



4b. Changes in trophic conditions. Eutrophic surface waters dominate in the Karpatian; during the Badenian a progressive decrease of nutrient supply occurs, whereas the Ottnangian shows intermediate trophic conditions.



4c. Changes in trophic conditions in nannoplankton Zones NN3–NN5.

Fig. 4. Non-metric MultiDimensionalScaling (nMDS) of calcareous nannofossils from Roggendorf-1.

According to the Cp/Rm ratio (*C. pelagicus*/(number of *R. minuta* + *C. pelagicus*)) the following subdivision of the borehole Roggendorf-1 is proposed (Fig. 2):

1. The interval from 2 m to 270 m with very low values of Cp/Rm % (up to 20 %), which generally corresponds to sediments of the Grund Formation. Low percentages of *Coccolithus pelagicus* and the bloom of *Reticulofenestra minuta* characterize this interval. It is interpreted as showing the influence of warm waters without upwelling conditions. Discoasterids have a rare and sporadic occurrence in the upper part of this interval only.
2. The interval from 270 m to 360 m shows a stepwise increase of this value from about 10 % at 270 m to about 80 % at 320 m. This clastic part of the section is characterized by a continuous increase in abundance of *C. pelagicus*, and can be regarded as the transitional horizon between the Laa and Grund Formations. It indicates a gradual change in paleoecological conditions.
3. The interval from 360 m to 570 m is characterized by very high abundances of *C. pelagicus* (up to more than 90 %). Such an increase corresponds to strong upwelling conditions.
4. The interval from 570 m to 730 m is barren of calcareous nannofossils and includes the lowest part of the Laa Formation, *Rzehakia* Beds, and the upper part of the "*Robulus* Schlier".
5. The interval from 730 m down to 800 m shows a repeated increase of *C. pelagicus* in thanatocoenoses.

Changes in the paleoenvironment are clearly expressed by the distribution of samples in the non-metric MultiDimensional Scaling plots (Fig. 4b,c). There is a clear distinction between eutrophic and oligotrophic patterns within time. The lowermost Ottnangian sample (800 m) belonging to the nannoplankton Zone NN3/NN4 shows eutrophic conditions. Intermediate surface water masses existed in the later Ottnangian (Fig. 4b,c). An upwelling system with eutrophic conditions dominated during the Karpatian, while in the Badenian a gradual change to warmer and more oligotrophic conditions in surface waters occurred. The most oligotrophic conditions existed in the warm period of the Grund Formation.

Note also that reworked nannofossil species are significantly more abundant in the Karpatian and lowermost Badenian, which is caused by strong erosion and turbulent water masses. Abundance changes of reworked species are presented in Fig. 2. The correspondence of this abundance pattern to the Cp/Rm ratio is obvious. Strong reworking of mostly Cretaceous species is observed, e.g. *Watznaueria barnesae, Micula decussata, Arkhangelskiella cymbiformis, Eiffellithus gorkae, Eiffellithus turriseiffelli, Cribrosphaerella ehrenbergii.* Reworked Paleogene species are represented by: *Chiasmolithus altus, Reticulofenestra bisecta, R. stavensis, R. umbilica, R. hillae*, *Ericsonia* spp., *Toweius* spp. etc.

Foraminifers

In the Grund Formation (2–255 m), the uppermost 10 m of the section contain the richest foraminiferal assemblages, decreasing in abundance down-section. The distribution of species is given in Appendix B. 'Lagenids' are common, whereas agglutinated foraminifers and miliolids are scarce. The planktonic assemblage is dominated by small globigerinas; *Globigerinoides* occurs regularly, orbulinids are very scarce, while small globorotalias (*G. bykovae*) are abundant. The occurrence of *Globigerinoides* and *Globorotalia* indicates warm surface waters. The benthic assemblage is characteristic for the outer shelf. The reduction of diversity and the increase of *Ammonia* in the lower part point to shallower conditions, than in the upper part and thus a deepening upward of the section. Higher numbers of *Valvulineria complanata* in some layers indicate a reduced oxygen content in the bottom sediments. A gradual enrichment of the assemblages towards the top of the formation is shown by Cicha (1999b).

Clastic Sequence (255–360 m): The gravels and conglomerates at 255–270 m are barren. In the finer clastics, autochthonous foraminifers are mainly small globigerinas and small benthics. Richer assemblages at 320–330 m with *Amphimorphina, Caucasina, Hanzawaia, Heterolepa, Mylostomella,* and *Pseudoparrella* indicate deeper water, at least below 50 m, and the accompanying *Ammonia, Elphidium,* and *Porosononion* may be transported from shallow regions. The high content of reworked specimens from the Upper Cretaceous and Paleogene in the clastic sequence is remarkable. The basal gravels are barren.

Laa Formation (360–612 m): A distinct faunal change is observed at 370 m, with an increase of small, five-chambered globigerinas and some deep-water agglutinated forms (*Bathysiphon, Haplophragmoides*). This indicates water depth of outer shelf to upper bathyal and cooler surface waters for the upper part of the Karpatian section. The foraminiferal fauna is scarce or samples are barren, with the increase of sand downsection. From the lower part some *Ammonia beccarii* are reported, which indicate shallower water. Pyritized foraminifers and the common occurrence of pyritized diatoms indicate dysoxic bottom conditions. Some reworking of Upper Cretaceous foraminifers and recrystallized radiolarians is observed.

According to internal reports (Schulz 1966; Fuchs 1963) the *Rzehakia* Beds are barren, and the upper part of the "*Robulus* Schlier" (678–715 m) contains commonly fish remains and foraminifers (*Cyclammina, Lenticulina,* lagenids, cibicids). In the sandy part of the section some molluscan and echinoid detritus occurs with a scarce foraminiferal assemblage (*Cyclammina*?, *Haplophragmoides*, lagenids, *Lenticulina, Bulimina aculeata, Siphonina, Heterolepa dutemplei, Nonion, Elphidium*). This indicates greater water depth (outer shelf) with a transport from shallow areas.

Biostratigraphy

Calcareous nannoplankton

Miocene sediments from Roggendorf-1 generally contain well-preserved calcareous nannofossil assemblages. Samples 350, 470 and 540 m and the interval from 590 m to 710 m are barren of nannofossils. The biostratigraphically important species *Sphenolithus heteromorphus* is very scarce but present in the whole section. The absence of *Helicosphaera ampliaperta* and the scarce presence of *S. heteromorphus* in the upper part of the section Roggendorf-1 (from 7 to 320 m) indicate the *Sphenolithus heteromorphus* Zone (nannoplankton Zone NN5). The accompanying assemblage is characterized by the presence of small helicoliths (*H. walbersdorfensis* and *H. vedderi*), *H. carteri*, *H. waltrans*, *Coccolithus pelagicus*, *Coronocyclus nitescens*, *Cyclicargolithus floridanus*, *Discoaster formosus, D. musicus*, *D. variabilis*, *Reticulofenestra daviesii*, *R. gelida*, *R. haqii*, *R. minuta*, *Sphenolithus moriformis*, *Syracosphaera pulchra*, *Thoracosphaera* spp., and *Umbilicosphaera jafarii.*

Investigations of calcareous nannofossils from the Mühlbach Beds, Gaindorf Formation, Lower Badenian (Ćorić 2003) and the Karpatian-Badenian transition in the Styrian Basin showed that *H. waltrans* occurs only in nannoplankton Zone NN5. This corresponds to the distribution pattern in Miocene sediments of the Mediterranean region (Fornaciari et al. 1996). They confirmed that *Helicosphaera waltrans* occurs in the middle part of the *Sphenolithus heteromorphus* Partial-range Nannoplankton Zone MNN5, which corresponds to nannoplankton Zone NN5 of Martini (1971).

Helicosphaera ampliaperta occurs in sediments from 320 m down to 800 m. Therefore, based on the co-occurrence with *S. heteromorphus*, this part of Roggendorf-1 can be attributed to the *Helicosphaera ampliaperta* Zone (nannoplankton Zone NN4). The accompanying taxa are *Braarudosphaera bigelowii*, *Coccolithus pelagicus*, *Coronocyclus nitescens*, *Cyclicargolithus floridanus*, *Helicosphaera carteri*, *H. euphratis*, *H. scissura*, *Reticulofenestra daviesii*, *R. gelida*, *R. haqii*, *R. minuta*, *Sphenolithus moriformis*, *Syracosphaera pulchra*, *Thoracosphaera* spp., *Triquetrorhabdulus milowii*, *Umbilicosphaera jafarii.*

The sediments from 590 m down to 710 m are barren of calcareous nannofossils. Most of this interval belongs to the regressive brackish facies of the *Rzehakia* Beds. In the lowermost part of the section (samples 790 m and 800 m), very scarce *Sphenolithus belemnos*, a marker species of nannoplankton Zone NN3, was found. The co-occurring *S. heteromorphus* can be contaminated from the upper part of the section. The accompanying assemblage contains *Helicosphaera ampliaperta, H. carteri*, *H. mediterranea, H. scissura, Coccolithus pelagicus*, *Coronocyclus nitescens*, *Cyclicargolithus floridanus*, *Reticulofenestra daviesii*, *R. gelida*, *R. haqii*, *R. minuta*, *Syracosphaera pulchra*, and *Thoracosphaera* spp.

Foraminifers

The biostratigraphic correlation of the Grund Formation by means of foraminifers is based primarily on the occurrence of orbulinas. *Orbulina suturalis* and *Praeorbulina glomerosa circularis* occur together in samples from 2–10 m. This corresponds to a short interval in the lower part of Middle Miocene, Langhian, in plankton Zone Mt6, from 15.1 Ma (FAD of *O. suturalis*) to around 14.8 Ma (LAD of *Po. glomerosa*; comp. Berggren et al. 1995 and Rögl et al. 2002). The common occurrence of *Globorotalia bykovae* together with *Paragloborotalia*? *mayeri* seems to be characteristic for the Lower Badenian. Within the local stratigraphy, uvigerinas are important, but rare in the section. Only one specimen of *Uvigerina macrocarinata*, the index fossil of the Lower Lagenidae Zone (Papp & Turnovský 1953), was found, whereas *U. grilli* occurs rather continuously. The species *U. graciliformis* defines the base of the Karpatian, but ranges up into the Lower Badenian Grund Formation.

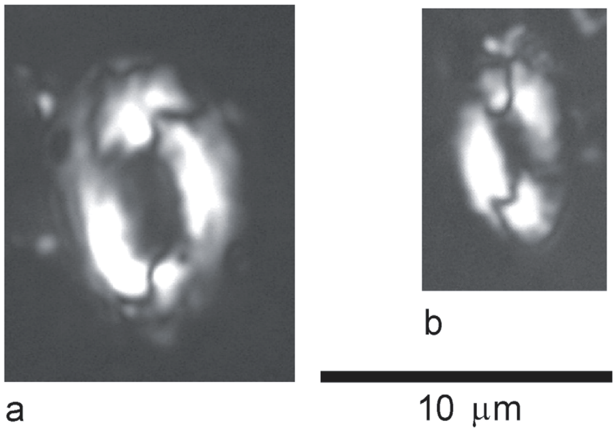


Fig. 5. Size variations of *Helicosphaera ampliaperta* in the samples 400 m (**a**) and 800 m (**b**).

In the Lower Badenian clastic sequence and in the Karpatian Laa Formation, index foraminifers are absent. Planktonic assemblages are dominated by small *Globigerina ottnangiensis.* The benthic foraminiferal fauna is similarly uncharacteristic in the investigated part of the section (to 410 m).

Helicosphaera ampliaperta — *taxonomic note*

The last occurrence of *Helicosphaera ampliaperta* is widely used to define the upper boundary of nannoplankton Zone NN4 (Martini 1971). This stratigraphically very important species was described for the first time by Bramlette & Wilcoxon (1967) from middle Tertiary sediments from the Cipero section (Trinidad). Originally they described this taxa as ”... nearly oval in outline, normally showing little of the terminal flare of the larger (distal) shield, and with no bridge in the large oval central opening ...” and gave a length between 7 and 12 µm. The lower part of the investigated section (740–780 m) contains two clearly different types of this species. The long axis of the smaller type is about 6–9 µm (Fig. 5a). The second type encompasses specimens, whose long axis is larger than 10 µm (Fig. 5b). This type occurs in the whole part of the section identified as the NN4 Zone. Our investigation shows that these two size-defined types can be very useful for the stratigraphy of Lower Miocene sediments.

Conclusions

The lowermost investigated part (“*Robulus* Schlier”) containing *Sphenolithus belemnos* — a marker of nannoplankton Zone NN3 — is correlated to nannoplankton Zone NN3/4 by the co-occurrence of *S. heteromorphus*. The microflora is indicative for more eutrophic conditions (Fig. 4c). The uppermost part of the “*Robulus* Schlier” consists of layered, partly non-calcareous shales and fine sands with fish remains. This shows some similarities with fish shales of the Zellerndorf Formation (Ottnangian), and with non-calcareous parts of the so-called “*Robulus* Schlier” south of the Danube (e.g. in prospection drill site NÖ-03, Schaubing). The nannoplankton indicates a biostratigraphic position within nannoplankton Zone NN4. During the Late Ottnangian, paleoecological conditions were intermediate between eutrophic and oligotrophic conditions (Fig. 4b,c).

The sandy sedimentation of the *Rzehakia* Beds is barren of nannofossils and foraminifers. The lower boundary is based on the lithology and additionally up-section by the appearance of a new foraminiferal assemblage at 678 m. A similar sequence was observed in the Goggendorf U1 drill site (Cicha 1999b).

The Karpatian Laa Formation (360–612 m) is correlated to nannoplankton Zone NN4, but the assemblages of the hanging wall and the underlying Ottnangian are distinctly different (Fig. 2, Appendix A). The basal samples are barren. Therefore, the lower boundary is based on a change in lithology at 612 m. Benthic assemblages point to a deepening upward and partly dysoxic bottom conditions. The nannoflora, with an increase of *C. pelagicus* of more than 90 %, the interpretation of the nMDS plots (Fig. 4a–c) and small globigerinas indicate cooler surface water, upwelling conditions and increasing nutrient supply. The 250 m of Karpatian sediments in Roggendorf-1 represent only a small part of the normal thickness in the Molasse Basin, e.g. about 1000 m of incomplete thickness in the water drill site Laa Thermal Süd 1. There, poor planktonic foraminiferal assemblages and pyritized diatoms similarly characterize the lower part of the Laa Formation, showing an up-section increase of agglutinated foraminifers (Cicha 1997).

Within the clastic sequence (270–347 m) a biostratigraphic dating as Badenian was possible based on nannoplankton only. The boundary between nannoplankton Zones NN4 and NN5 was observed at 320 m. In the Styrian Basin, nannoplankton Zone NN4 was documented in the Lower Badenian also (Rögl et al. 2002). The basal gravels (347–360 m) are regarded as the transgressive base of the Badenian in the Molasse Basin north of the Danube. In the interval from 350 m to 270 m a stepwise decrease of the Cp/Rm % value from 80 % to 10 %, as well as the nMDS plot, demonstrate a gradual change to warmer conditions accompanying the transition from the Laa to the Grund Formations.

The fine clastic sediments of the Grund Formation (2–255 m) belong to nannoplankton Zone NN5, and are dated at the top by planktonic foraminifers as the lower part of plankton Zone Mt6 (*Orbulina suturalis/Globorotalia peripheroronda* Concurrent Range Zone of Berggren et al. 1995). The level with *G. bykovae* and *P. mayeri,* recorded in the lower part of the Grund Formation in Roggendorf-1, corresponds to the lower part of the Grund Formation in Cicha (1999a) and Švábenická & Čtyroká (1999), attributed there to the Karpatian. Paleoecologically, the Grund Formation in Roggendorf-1 shows a deepening upward sequence to water depths of the outer shelf. The surface waters were warm, as indicated by the low percentages of *Coccolithus pelagicus* (low value of Cp/Rm %, Fig. 2) and a relatively high number of the planktonic foraminifer *Globigerinoides.* This is clearly expressed by the nMDS plots (Fig. 4a–c). The conglomerates at 255–270 m are considered to be the coarse basal transgression level of the Grund Formation because the nannoplankton paleoecology is in good agreement with the overlying fine clastics (Fig. 2).

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Appendix A: Distribution of calcareous nannoplankton in the borehole Roggendorf-1.

m	*Braarudosphaera bigelowii*	*Calcidiscus leptoporus*	*Coccolithus miopelagicus*	*Coccolithus pelagicus*	*Coronocyclus nitescens*	*Cyclicargolithus floridanus*	*Discoaster formosus*	*Discoaster musicus*	*Discoater variabilis*	*Discoaster* sp.	*Geminilithella rotula*	*Helicosphaera ampliaperta*	*Helicosphaera ampliaperta* (<10)	*Helicosphaera carteri*	*Helicosphaera euphratis*	*Helicosphaera granulata*	*Helicosphaera mediterranea*	*Helicosphaera obliqua*	*Helicosphaera scissura*	*Helicosphaera vedderi*	*Helicosphaera waltrans*	*Helicosphaera walbersdorfensis*	*Helicosphaera* sp.	*Holodiscolithus macroporus*	*Micrantholithus vesper*	*Pontosphaera multipora*	*Pontosphaera* sp.	*Reticulofenestra daviesii*	*Reticulofenestra gelida*	*Reticulofenestra haqii*	*Reticulofenestra minuta*	*Reticulofenestra pseudoumbilica*	*Reticulofenestra* sp.	*Rhabdosphaera sicca*	*Sphenolithus belemnos*	*Sphenolithus conicus*	*Sphenolithus dissbelemnos*	*Sphenolithus heteromorphus*	*Sphenolithus moriformis*	*Sphenolithus* sp.	*Syracosphaera histrica*	*Syracosphaera pulchra*	*Thoracosphaera heimii*	*Thoracosphaera saxea*	*Thoracosphaera* sp.	*Triquetrorhabdulus milowii*	*Triquetrorhabdulus* sp.	*Umbilicosphaera jafarii*
2–7 m				18	1									8						3	1	3		1		1			1	20	321		1									1			1			4
7–10 m				10	1	1	1		1		1			11			1			3	2	2	1		1				2	54	375	1		1				p										5
130				5	1	1								1								2					1		1	21	320	2																
150				2										2								5								14	352							p										25
160				1													1			3		1								15	350	1		1				p				1						6
170				17										2												1			3	16	300	1	3							1								5
180			1	38				1						5							2	3				1		2	2	9	295					1			1									1
190				7	2																									17	325									1								12
200				12																									1	7	306									1								3
210				7	3																1	2				1			2	5	310	3						1	3	1		1						5
220				32		1								1						1		1				1	1	1	2	10	310	2												1				4
230				13										1						1									4	10	320	1						1				1						5
240				10		2								3							1					1		1	4	22	309	1	1							1		3						7
260				22	1															3		1			1				2	19	243	4	1									3						12
270				15										2							1	1							1	15	313	1										5						14
280				69		2								7							1	1				1		1		27	158	1						1	2		2		5	16				4
285	1			73	1															2								1	2	4	48	4	3						1	1	9	33						1
290				74							1			3						2								1		12	182	1							1			5						5
300				140		1								13		1											2	1	4	19	68	6	3					3	5		3	38						6
310				99										9									1					1	3	78	97	1	2					1	1	1	2	38						3
320	1	1		135								6		1					1									1	1	57	34		1						4		1	80		1				
330	1			83								1		14		1										1			2	112	88	2	2				1		3	1	3	42		1				
350																																																
370	7			165	3	3						13							11									2	2	6	11		1				1		2			34		2				
390	6			117		4				1		21							7							1		2		5	4		1				1					12		1				
410				61		1						46		1	3				4									1		5	4	1	3						1	1		9					1	
430	1			177	2	7					1	14		4					7							1		2	1	15	28	1	3					1	5	2	1	63	1		1			
450				65	1	4						9			1				6				1					1	1	4	5	1	1						3	1	1	33		2				
470																																																
490			1	120						1							1													3	1		1						1			13		1		1		
510	93			181										1															1	1	4		8						1	1		45						1
530				12																									1		3		1						1				1					
540																																																
550				18																										1	1		1									1				1		
570	5			240		1					1	18							20				1							12	4	3	1			2		2	3	2	1	7	5	5	1	3		
590																																																
600																																																
630																																																
650																																																
670																																																
690																																																
710																																																
730			1	70		1								1					4										2	1	210		3						2	1	2		1					
740				92		1						1	1	1		1							2				1			3	212		5							1		3						2
780				95									1					1	5				2						4	7	170	3								1						1		1
790				57								2		1			1		2									2	1	10	253	1	5		1						2	2			1			
800	1			160	2	2				2		4	2	8		1	1		7										2	5	39		5		1			3				47	1					

Appendix B: Distribution of benthic and planktonic foraminifers in the borehole Roggendorf-1.

Appendix B/1

Appendix B/1 ROGGENDORF-1 Foraminifers	2–7 m	7–10 m	130 m	150 m	160 m	170 m	180 m	210 m	220 m	240 m	260 m	270 m	280 m	285 m	290 m	295 m	300 m	320 m	330 m	350 m	370 m	380 m	390 m	400 m	410 m
Bathysiphon filiformis M. Sars																					x	x			
Budashevaella wilsoni (Smith)														x											
Haplophragmoides vasiceki vasiceki Cicha et Zapl.																					x	x	x		
Karrerotextularia sp.			x				x																		
Martinotiella communis (d'Orbigny)		x	x	x	x	x	x																		
Martinotiella karreri (Cushman)	x						x	x																	
Semivulvulina deperdita (d'Orbigny)	x	x		x	x																				
Siphotextularia concava (Karrer)	x	x		x																					
Siphotextularia sp.			x																						
Spirorutilus carinatus (d'Orbig+A45ny)	x	x	x	x			x																		
Textularia laevigata d'Orbigny	x	x	x	x																					
Textularia mariae d'Orbigny				x																					
Cycloforina sp.					x														x						
Lachlanella incrassata (Karrer)							x																		
Nodobaculariella sp.							x																		
Pyrgo simplex (d'Orbigny)	x																								
Quinqueloculina akneriana d'Orbigny							x																		
Quinqueloculina buchiana d'Orbigny		x	x	x	x		x																		
Quinqueloculina seminulina (Linné)					x																				
Sigmoilinita tenuis (Czjzek)	x	x	x	x	x		x																		
Sigmoilopsis celata (Costa)	x	x	x	x			x																		
Sinuloculina cyclostoma (Reuss)	x																								
Spiroloculina excavata d'Orbigny			x	x	x																				
Spirillina vivipara Ehrenberg		x																							
Alabamina armellae Popescu		x																							
Ammonia pseudobeccarii (Putrja)	x			x	x	x	x	x	x	x						x	x	x							
Ammonia tepida (Cushman)					x	x	x																		
Ammonia viennensis (d'Orbigny)	x		x	x			x		x					x	x			x							x
Amphicoryna badenensis (d'Orbigny)	x	x	x	x	x	x	x	x	x																
Amphicoryna hispida (d'Orbigny)	x	x	x	x			x																		
Amphimorphina haueriana Neugeboren	x	x	x	x	x		x												x		x				
Angulogerina angulosa (Williamson)	x	x	x	x		x	x	x	x										x						
Asterigerinata mamilla (Williamson)					x																				
Asterigerinata planorbis (d'Orbigny)			x		x		x	x																	
Aubignyna brixi Rögl									x												x				
Aubignyna sp.						x	x																		
Biapertorbis biaperturata Pokorný	x																								
Bolivina antiqua d'Orbigny				x																	x				
Bolivina antiquaeformis Cicha et Zapletalová	x																								
Bolivina dilatata brevis Cicha et Zapletalová	x		x	x				x													x				
Bolivina dilatata dilatata Reuss	x	x		x	x		x	x		x					x				x		x	x			
Bolivina hebes Macfadyen	x	x	x	x	x		x	x									x		x			x	x		
Bolivina aff. *iriensis* Tedeschi		x																							
Bolivina cf. *lowmani* Phleger et Parker	x		x																						
Bolivina plicatella Cushman	x	x	x	x																					
Bolivina pokornyi Cicha et Zapletalová	x																								
Bolivina pseudoplicata Heron-Allen et Earland					x																				
Bolivina scalprata retiformis Cushman	x	x	x		x																				
Bolivina sp. (aff. simplex Phleg. et Park. acc. C.&Z.)	x		x	x	x	x				x													x		x
Buccella granulata (Di Napoli)				x																					
Bulimina buchiana d'Orbigny	x	x		x																					
Bulimina striata mexicana Cushman		x	x	x	x		x	x													x				
Bulimina striata striata d'Orbigny	x	x	x	x	x	x	x		x																
Buliminella elegantissima d'Orbigny		x																							
Cassidulina carinata Silvestri	x			x			x	x																	
Cassidulina laevigata d'Orbigny		x		x		x																			
Cassidulina margareta Karrer			x	x														x	x						

Appendix B/2

Appendix B/2 ROGGENDORF-1 Foraminifers	2–7 m	7–10 m	130 m	150 m	160 m	170 m	180 m	210 m	220 m	240 m	260 m	270 m	280 m	285 m	290 m	295 m	300 m	320 m	330 m	350m	370 m	380 m	390 m	400 m	410 m
Caucasina cylindrica Zapletalová							x		x														x		
Caucasina elongata (d'Orbigny)		x	x	x																					
Caucasina schischkinskayae Samoylova		x	x	x			x	x	x										x		x				
Caucasina subulata (Cushman et Parker)	x	x	x	x	x	x	x		x	x								x	x						
Ceratobulimina contraria (Reuss)	x																								
Ceratocancris haueri (d'Orbigny)	x		x	x			x	x																	
Chilostomella ovoidea Reuss																									x
Cibicides refulgens Montfort			x																						
Cibicidoides spp.	x		x	x	x	x	x	x	x					x	x		x						x		
Cibicidoides lopjanicus (Myatlyuk)		x			x										x						x				
Cibicidoides ungerianus (d'Orbigny)	x	x	x	x	x	x																			
Dentalina beyrichana Neugeboren					x																				
Dimorphina akneriana (Neugeboren)	x	x																							
Discorbinoides patelliformis (Brady)			x																						
Elphidiella dollfusi (Cushman)	x																								
Elphidiella subnodosa (Reuss)																		x							
Elphidium cf. *angulatum* (Egger)				x	x													x							
Elphidium flexuosum (d'Orbigny)		x			x																				
Elphidium praeforme Papp				x																					
Elphidium reussi Marks					x																				
Elphidium ungeri (Reuss)							x																		
"*Eponides*" *pusillus* Parr	x	x	x	x	x																x				
Favulina hexagona (Williamson)	x																								
Fissurina aperta Seguenza	x																								
Fissurina solida Seguenza	x																								
Fissurina? *aequabilis* (Matthes)	x																								
Fursenkoina acuta (d'Orbigny)		x	x																x						
Gavelinopsis praegeri (Heron-Allen et Earland)		x																							
Glabratellina sp.		x																							
Glandulina laevigata d'Orbigny				x																					
Globocassidulina oblonga (Reuss)		x	x		x													x							
Globocassidulina subglobosa (Brady)	x	x		x	x		x			x						x									
Globobulimina pupoides (d'Orbigny) s.l.	x				x		x												x						
Globobulimina pyrula (d'Orbigny)			x																						
Globulina gibba d'Orbigny	x		x																						
Globulina punctata d'Orbigny	x																								
Grigelis? *mariae* (d'Orbigny)	x	x																							
Guttulina austriaca d'Orbigny	x		x	x	x																				
Guttulina communis d'Orbigny		x																							
Gyroidinoides octocameratus (Cushman)	x	x	x	x	x		x									x			x						
Gyroidinoides soldanii (d'Orbigny)		x	x	x	x														x						
Gyroidinoides umbonatus (Silvestri)	x	x	x	x	x		x	x		x															
Hanzawaia boueana (d'Orbigny)								x		x									x						
Hemirobulina glabra (d'Orbigny)		x		x																					
Hemirobulina spp.	x			x															x						
Heterolepa praecincta (Karrer)	x	x	x			x	x	x	x							x			x						
Heterolepa dutemplei (d'Orbigny)	x			x		x	x																		
Hoeglundina elegans (d'Orbigny)	x	x	x	x	x		x																		
Hyalinonetrion elongatum (Ehrenberg)					x																				
Laevidentalina badenensis (d'Orbigny)					x																				
Laevidentalina spp.	x																								
Lagena haidingeri (Czjzek)	x				x																				
Lagnea sp.	x																								
Lapugyina schmidi Popescu			x	x	x	x	x							x											
Lenticulina americana (Cushman)	x	x		x																					
Lenticulina austriaca (d'Orbigny)	x	x	x	x	x												x					x			
Lenticulina calcar (Linné)		x																							

Appendix B/3

Appendix B/3 ROGGENDORF-1 Foraminifers	2–7 m	7–10 m	130 m	150 m	160 m	170 m	180 m	210 m	220 m	240 m	260 m	270 m	280 m	285 m	290 m	295 m	300 m	320 m	330 m	350 m	370 m	380 m	390 m	400 m	410 m
Lenticulina inornata (d'Orbigny)	x	x	x																						
Lenticulina melvilli (Cushman et Renz)					x																				
Lenticulina orbicularis (d'Orbigny)	x		x																						
Lenticulina spinosa (Cushman)			x																						
Lenticulina spp.	x	x	x	x	x	x	x	x	x																x
Lobatula lobatula (Walker et Jacob)		x	x	x																					
Marginulina hirsuta d'Orbigny		x																							
Melonis pompilioides (Fichtel et Moll)	x	x	x	x	x		x	x																	
Myllostomella advena (Cushman et Laiming)	x	x	x	x	x	x	x	x									x		x		x	x	x		
Myllostomella recta (Palmer et Bermudez)	x	x		x	x				x																
Neoconorbina terquemi (Rzehak)			x																						
Neugeborina irregularis (d'Orbigny)	x	x																							
Neugeborina longiscata (d'Orbigny)	x	x																							x
Nonion commune (d'Orbigny)	x	x	x	x	x	x	x	x	x										x		x				
Nonionella turgida (Williamson)	x																								x
Nonionoides? *exesa* (Langer)	x	x																							
Nonionoides karaganicus (Krasheninnikov)	x	x	x	x	x		x																		
Nonionoides ventragranosus (Krasheninnikov)							x																		
Nuttallides convexus (Parker)	x	x																							
Oridorsalis umbonatus (Reuss)		x	x	x	x																				
Orthomorphina ambigua (Neugeboren)	x																								
Orthomorphina sp.	x	x																							
Pappina primiformis (Papp et Turnovský)						x																			
Pappina breviformis (Papp et Turnovský)								x	x																x
Planularia moravica (Karrer)								x																	
Plectofrondicularia digitalis (Neugeboren)		x																							
Plectofrondicularia medelingensis (Karrer)	x	x																							
Porosononion granosum (d'Orbigny)					x				x										x						
Pseudoparrella exigua (Brady)	x	x		x															x		x		x		
Pseudosolenia lateralis carinata (Buchner)	x																								
Pullenia bulloides (d'Orbigny)	x	x	x	x	x	x	x	x								x	x								
Pullenia quinqueloba (Reuss)						x																			
Reussella laevigata Cushman					x														x						
Siphonodosaria consobrina (d'Orbigny)	x		x	x					x																
Siphonodosaria nuttalli gracillima (Cush. et Jarvis)	x	x	x	x																					
Siphonodosaria scabra (Reuss)	x	x							x																
Siphonodosaria scripta (d'Orbigny)					x																				
Sphaeroidina bulloides d'Orbigny			x	x	x		x		x																
Spiroloxostoma czechoviczi (Kantorova)																					x	x			
Stilostomella adolphina (d'Orbigny)	x	x	x	x	x																				
Stilostomella? sp.		x																							
Trochulina patella (Reuss)			x																						
Uvigerina acuminata Hosius	x		x				x																		
Uvigerina graciliformis Papp et Turnovský				x	x	x		x																	
Uvigerina grilli Schmid	x	cf.	x	x		x																			
Uvigerina cf. *laviculata* Coryell et Rivero			x																						
Uvigerina macrocarinata Papp et Turnovský		cf.																							
Uvigerina saprophila Daniels et Spiegler	x						x																		
Uvigerina semiornata d'Orbigny	x	x		x	x																				
Valvulineria complanata (d'Orbigny)	x	x	x	x	x	x	x	x	x							x					x		x	x	x
Valvulineria? *minuta* (Schubert)				x																					
Virgulopsis tuberculatus (Egger)						x	x																		

Appendix B/4

Appendix B/4 ROGGENDORF-1 Foraminifers	2–7 m	7–1 0m	130 m	150 m	160 m	170 m	180 m	210 m	220 m	240 m	260 m	270 m	280 m	285 m	290 m	295 m	300 m	320 m	330 m	350 m	370 m	380 m	390 m	400 m	410 m
Globigerina cf. *bollii* Cita et Premoli-Silva	x	x	x		x		x																		
Globigerina bulloides d'Orbigny	x	x	x	x	x	x	x										x	x			x				
Globigerina concinna Reuss	x	x	x		x		x																		
Globigerina diplostoma Reuss	x	x	x	x																					
Globigerina dubia Egger																			x						
Globigerina cf. *falconensis* Blow	x	x		x	x	x	x	x																	
Globigerina ottnangiensis Rögl		x	x	x	x		x	x								x	x	x	x		x	x	x	x	x
Globigerina praebulloides Blow	x	x	x	x	x	x	x	x	x							x	x		x		x	x			
Globigerina tarchanensis Subbotina et Chutzieva	x			x	x			x	x												x	x			
Globigerinella regularis (d'Orbigny)	x	x	x	x	x	x	x																		
Globigerinoides bisphericus Todd				x	x																				
Globigerinoides quadrilobatus (d'Orbigny)	x	x	x	x	x	x	x		x																
Globigerinoides trilobus (Reuss)			x	x	x	x	x																		
Orbulina suturalis Brönnimann	x	x																							
Praeorbulina glomerosa circularis (Blow)	x	x																							
Globoturborotalita connecta (Jenkins)														x											
Globoturborotalita druryi (Akers)					x	x	x		x																
Globoquadrina cf. *altispira* (Cushman et Jarvis)			x		x																				
Globorotalia bykovae (Aisenstadt)	x	x	x	x	x	x	x	x	x	x															
Paragloborotalia? *acrostoma* (Wezel)	x		x		x																				
Paragloborotalia? cf. *continuosa* (Blow)			x	x	x				x																
Paragloborotalia? *inaequiconica* (Subbotina)	x	x	x	x	x		x		x																
Paragloborotalia? *mayeri* (Cushman et Ellisor)	x	x	x	x	x	x		x	x																
Globigerinita glutinata (Egger)	x	x	x	x	x	x	x	x		x					x						x	x			
Globigerinita uvula (Ehrenberg)	x	x	x	x	x	x	x	x	x																
Tenuitella cf. *clemenciae* (Bermudez)		x																				x	x		
Tenuitellinata angustiumbilicata (Bolli)						x								x	x				x		x			x	x
Tenuitellinata selleyi Li, Radford et Banner	x	x	x	x		x		x	x					x	x			x			x	x	x	x	x
Turborotalita neominutissima (Bermudez et Bolli)		x		x	x	x	x		x									x	x		x		x		
Turborotalita quinqueloba (Natland)	x	x	x	x	x	x	x			x				x	x	x	x		x		x	x	x	x	x
Turborotalita sp. 1	x	x		x	x		x																		
Turborotalita sp. 2 (*clarkei*-group)				x	x																				
Cassigerinella globulosa (Egger)		x													x										
Cassigerinella spinata Rögl	x	x																							
Cassigerinella boudecensis Pokorný	x	x	x	x	x	x	x	x	x	x								x						x	

Appendix C: Bray-Curtis Similarity of calcareous nannofossils; dissimilarity values are available upon request (C pel — *Coccolithus pelagicus*, Hel am — *Helicosphaera ampliaperta*, Hel sc — *Helicosphaera scissura*, Ret ha — *Reticulofenestra haqii*, Ret min — *Reticulofenestra minuta*, Sy pu — *Syracosphaera pulchra*).

Group 1					
Average similarity: 66.67					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
C pel	15.00	57.14	#######	85.71	85.71
Ret min	2.00	4.76	#######	7.14	92.86
Group 2					
Average similarity: 89.46					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Ret min	316.60	81.91	13.94	91.56	91.56
Group 3					
Average similarity: 82.89					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Ret min	197.50	57.49	10.70	69.35	69.35
C pel	76.17	22.06	6.16	26.61	95.97
Group 4					
Average similarity: 68.66					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
C pel	123.86	32.51	3.92	47.35	47.35
Ret min	57.43	13.53	2.70	19.71	67.06
Sy pu	48.71	12.82	7.12	18.67	85.73
Ret ha	41.43	5.20	0.87	7.58	93.31
Group 5					
Average similarity: 61.82					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
C pel	129.60	38.86	3.80	62.87	62.87
Hel am	21.40	6.41	2.48	10.38	73.24
Sy pu	19.00	5.64	1.36	9.13	82.37
Hel sc	9.60	2.77	4.21	4.47	86.84
Ret ha	6.40	2.28	5.22	3.68	90.53
Group 6					
Average similarity: 56.96					
Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
C pel	150.50	49.90	#######	87.59	87.59
Sy pu	29.00	5.41	#######	9.49	97.08