

Foraminiferal paleoecology of a submarine swell – the Lower Badenian (Middle Miocene) of the Mailberg Formation at the Buchberg in the Eastern Alpine Foredeep: initial report

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(With 7 textfigures)

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Abstract

The present paper investigates the depositional setting of the Middle Miocene Mailberg Formation based on benthic and planktonic foraminifera. The studied section is situated in an abandoned quarry at the Buchberg W. Mailberg in Lower Austria. The succession comprises an interbedding of coralline algal limestone with marly intercalations. The sedimentation took place on a submarine paleo-swell that was isolated from any significant siliciclastic influence. Its numerical age ranges between 15.034 and 14.888 Ma and falls into the Lower Badenian. *Cibicidoidea*- and *Cibicidoidea-Elphidium* assemblages indicate fully marine, shallow water, high oxic conditions with oxygen levels ranging from 3.0–6.0 mL/L. Similarity/Dissimilarity Term Analyses, non-metric Multi-Dimensional Scaling and Agglomerative Hierarchical Clustering revealed an assemblage aberrance within a thin marly interlayer. This is defined by an abundance peak of *Melonis pompilioides* and by a minimum level of taxonomic richness and heterogeneity. The abrupt decrease of plankton abundance to 1.6% within the thin marly layer coincides with a short-term eutrophication event. Despite the predominance of oxic indicators in a subsequent recovery phase, the sudden eutrophication apparently resulted not only in a decrease of limestone production but also in the abundance peak of suboxic pioneers inhabiting the bottom sediments before the return of oxic conditions. The plankton abundances ranging between 24.3 and 28.4% indicate upper to middle shelf conditions in an open sea. Based on the macrofauna, the depositional depth for carbonates was maximally 30 m. The foraminiferal assemblages from marls, however, indicate greater depths of about 50 m. Hence, the presence of short-termed, orbitally forced sea level fluctuations is assumed for the section, producing periodical water mass eutrophication and a shut-down of the carbonate factory. The distribution of thermophilic taxa among the plankton indicates a minor sea water cooling in the topmost part of the Mailberg Formation.

Key words: foraminifera, paleoenvironment, water temperature, sea level fluctuations, suboxia, Mailberg Formation, Lower Badenian, Middle Miocene, Austria, Eastern Alpine Foredeep, Central Paratethys

Introduction

The Miocene marine deposition is bound in NE Austria to the Pre-Alpine Molasse Basin and to the adjoining Vienna Basin. The study area belongs to the NE part of the Molasse Basin, representing the westernmost wing of the Alpine-Carpathian Foredeep. The Lower Badenian Mailberg Formation with its well-developed carbonate facies represents an unique occurrence in that mainly siliciclastic basin-fill. Its occurrence can be

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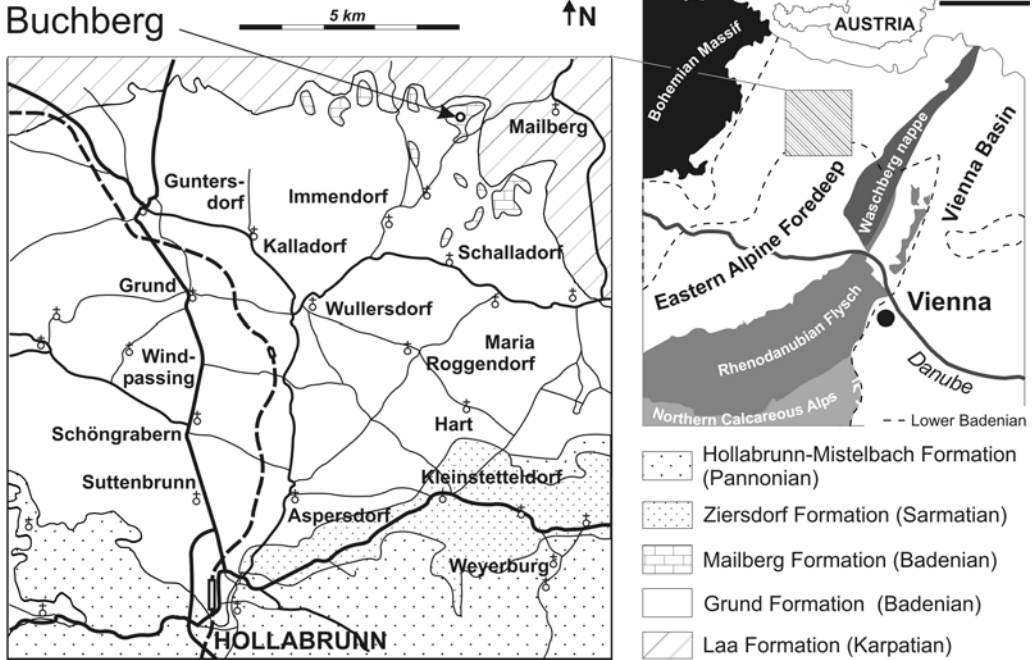
Section
Buchberg

Fig. 1: Geological setting of the studied section. The study area is part of the north-eastern part of the Alpine Molasse Basin. The carbonates and marls of the Mailberg Formation interfinger with the topmost part of the open marine siliciclastics of the Grund Formation. The map on the left combines regional geology and lithostratigraphy of ROETZEL & PERVESLER (2004) with the topography of the Austrian Map 1:200,000 (BEV, Vienna). The map on the right with the geotectonic setting of north-eastern Austria is modified after RÖGL & SPEZZAFERRI (2003); the distribution of Lower Badenian sediments follows PAPP et al. (1978).

best interpreted as reflecting a paleogeographic position on an isolated submarine swell that was separated from siliciclastic discharge. The Mailberg Formation interfingers to the south and to the west with deeper-water sediments of the Grund Formation, although recent paleomagnetic investigations in the classical section near Grund pointed out a slightly older age (CORIC et al. 2002; Fig. 1). These Lower Badenian sediments are the youngest open marine sediments known from the area. Hence, already in the Middle Badenian, alluvial fans transporting vast amounts of debris into the northern Vienna Basin (e.g. Matzen Sands) replaced the marine shelf environment (JIRICEK & SEIFERT 1990) (Fig. 1).

In contrast to the Grund Formation, only little information on the depositional setting and paleoecology of the Mailberg Formation is available. Except for the unpublished thesis by ACHUTHAN (1967) dealing with its foraminifera and calcareous nannoplankton, the other data sources are scattered and "hidden" in geological maps and mapping reports (e.g. GRILL 1968; ROETZEL in SCHNABEL 2002). Therefore, the section in the abandoned quarry W. Mailberg (Fig. 2) was chosen to obtain more detailed information by using the apparently rich benthic and planktonic foraminiferal content of the marls.

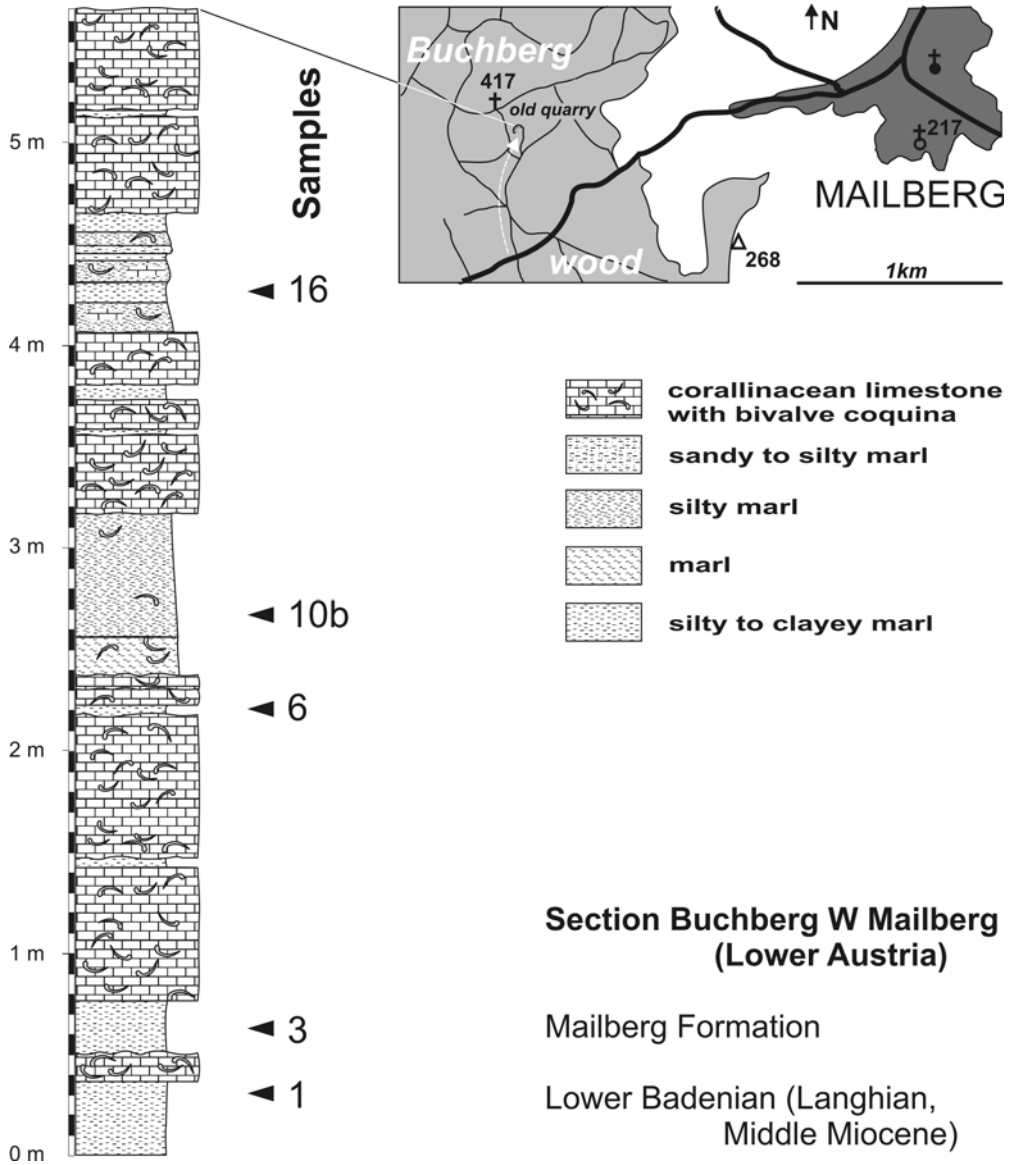


Fig. 2: Sedimentological log of the Buchberg section measured at the northern wall of the abandoned quarry W. Mailberg (logging by Mathias HARZHAUSER, Oleg MANDIC & Martin ZUSCHIN, drawing by M. HARZHAUSER). Note the position of investigated samples. The thin white arrow on the topographic map (Austrian Map 1:50,000, BEV, Vienna) points to the access to the quarry.

The section exposes a 5.5 m thick interbedding of biogenic limestones and marls. The 30 to 70 cm thick coralline-algal-limestone beds, bearing commonly remains of thick-shelled molluscs, are intercalated by 5 to 70 cm thick marly layers (Fig. 2). The locality was used recently as a blasting point for deep geophysical measurements and is well

exposed. Geophysical investigations revealed a thickness of the succession of more than 15 m below the bottom of the quarry (Reinhard ROETZEL, pers. comm.). The present study provides preliminary results. The investigation of wells will provide further data for subsequent investigation.

Methods

The studied samples originate from marly limestone-intercalations (Fig. 2). Sample 6 derives from a 5 cm thick marly layer that interrupts the upper part of a 1.5 m thick, three-fold carbonate package. Other samples are from the thicker marly layers that apparently represent longer crises in carbonate production.

100 g of each sample was sieved under warm running water. The residues of the 125 to 500 μ m fractions were split to bulks with 500 to 800 foraminiferal tests. Their preservation is moderate – recrystallisation and corrosion phenomena, crystal overgrowths, and partial breakages were observed. Apparently due to neighbouring carbonates, the aragonite component is completely leached from the sediment. Moreover, the studied splits were almost free from siliciclastics; beyond bearing foraminifera tests, they also contained minor quantities of mollusc debris, echinoid spines, balanid plates and ostracods. Only sample 16 is characterised by organogenic limestone debris.

The identification of benthic and planktonic foraminifera was carried out at least on the generic level. It was principally based on RÖGL (1969, 1998), PAPP et al. (1978), PAPP & SCHMID (1985), RUPP (1986), CÍCHA et al. (1998), RÖGL et al. (2002) and RÖGL & SPEZZAFERRI (2003). Where needed, the original designations have been checked in ELLIAS & MESSINA (1940); the generic names have been actualised following LOEBLICH & TAPPAN (1987). Identification of *Gavelinopsis praegeri* (HERON-ALLEN & EARLAND, 1913) – a thin-walled, plano-convex species with a typical umbilical knob – is based on specimens described by CIMERMAN & LANGER (1991) from the Recent Mediterranean Sea.

The paleoecological interpretation is based on quantitative data standardised to percentage abundances. Similarities and dissimilarities between samples were analysed for the benthic and for the planktonic foraminifera separately, using the Software Package Primer 5 (Plymouth Marine Laboratory; CLARKE & WARWICK, 1994). The application has been proved to be a powerful tool for relating changes in community structures to changing environmental conditions, both in recent (BASSO & SPEZZAFERRI 2000) and fossil marine environments (SPEZZAFERRI & CORIC 2001, MANDIC et al. 2002, RÖGL & SPEZZAFERRI 2003). Additionally, the present paleoecological interpretations are based on RUPP (1986), MURRAY (1991), YENKE (1993), and RÖGL (1998).

The investigated material is housed in the collection of the Department of Geology and Paleontology at the Museum of Natural History, Vienna (Inv.-Nr. 2003z0091-0095).

Age of the fauna

CORIC et al. (2004) correlated the Mailberg Formation with chron C5Bn.r based on paleomagnetic data which were calibrated with biostratigraphy and lithostratigraphy. This indicates a stratigraphical higher position of the Mailberg Formation compared to the Grund Formation which was correlated with chron C5Bn.2n by CORIC et al. (2004)

(Fig. 1). Calcareous nannoplankton proved the position within Zone NN5, whereas the typical planktonic foraminifera assemblage with *Orbulina suturalis* accompanied with *Praeorbulina glomerata circularis* points to the position within Zone M6. The integration of the paleomagnetic information with the numerical data of BERGGREN et al. (1995) results in an exact age of the (topmost) Mailberg Formation between 15.034 and 14.888 Ma., corresponding to the Langhian of the standard scale. Its position in the Lower Badenian, Lower Lagenid Zone (compare GRILL 1968) is well supported by the presence of *Praeorbulina glomerata circularis*, a subspecies which is absent from the Upper Lagenid Zone deposits (e.g. the Badenian stratotype Baden-Sooss; PAPP et al. 1978).

Paleoecology of benthic foraminifera

In all samples, the assemblage structure of the benthic foraminifera (Fig. 3) shows a predominance of *Cibicidoides* spp., ranging from 17.2% (sample 3) to 35.4% abundance (sample 1). *Cibicidoides* spp. is dominated by thick-walled species of the *Cibicidoides vortex* gr., but other species such as *C. austriacus*, *C. lopjanicus* or *C. ungerianus* are also represented. The second leading species-group is *Elphidium* spp., ranging between 9.7% (sample 1) and 20.9% (sample 6) is dominated by *E. crispum*. The total abundance of both *Cibicidoides* spp. and *Elphidium* spp. ranges from 34% to 52%. Hence, the assemblages of samples 3, 6 and 16 are termed the *Cibicidoides* - *Elphidium* Assemblage. The assemblage of samples 1 and 10b is termed the *Cibicidoides* Assemblage, because *Cibicidoides* is 20% more abundant than *Elphidium*. Such an assemblage structure points out fully marine conditions and well-oxygenated bottom water. According to KAIHO (1994), the high ratio of oxic indicators (e.g. the diverse representatives of *Cibicidoides*) points to normal oxic water conditions with oxygen levels ranging between 3.0 and 6.0 mL/L.

Corresponding assemblages occur in the Lower Miocene siliciclastics and carbonates along the Bohemian Massif in the region of Eggenburg in Lower Austria. JENKO (1989) interpreted them as inhabitants of shallow-water neritic settings with well-developed sea grass meadows. The *Cibicidoides* (referred to as *Cibicides*)-*Elphidium* Assemblage was interpreted to reflect maximal water depths of 30 m. In contrast, the *Cibicidoides* Assemblage, which is found in the transition of the Eggenburg Bay to the open sea, indicates somewhat deeper depositional settings. Due to regional paleotopography, the paleodepths did not exceed 100 m.

All samples from the Buchberg are dominated by small morphs. Only sample 16 contains scattered specimens of larger elphidiids in the fraction >500µm. The food availability was presumably good and is excluded as the limiting factor. Thus, the dwarf phenomenon might be related to temporally limited substrate availability, shortening the growth and reproduction phases. As pointed out by RÖGL (1998), such a substrate is typically provided by algal thalli with seasonal appearance. In contrast, the sea grass substrates, which last for longer periods, produce large-sized assemblages. The absence of sea grass is supported by the rather low percentage of characteristic sea grass inhabitants such as *Lobatula lobata* (e.g. MURRAY 1991).

Similarity and Dissimilarity Term Analysis, Agglomerative Hierarchical Clustering and sample ordination by non-metric Multi-Dimensional Scaling (nMDS) revealed the

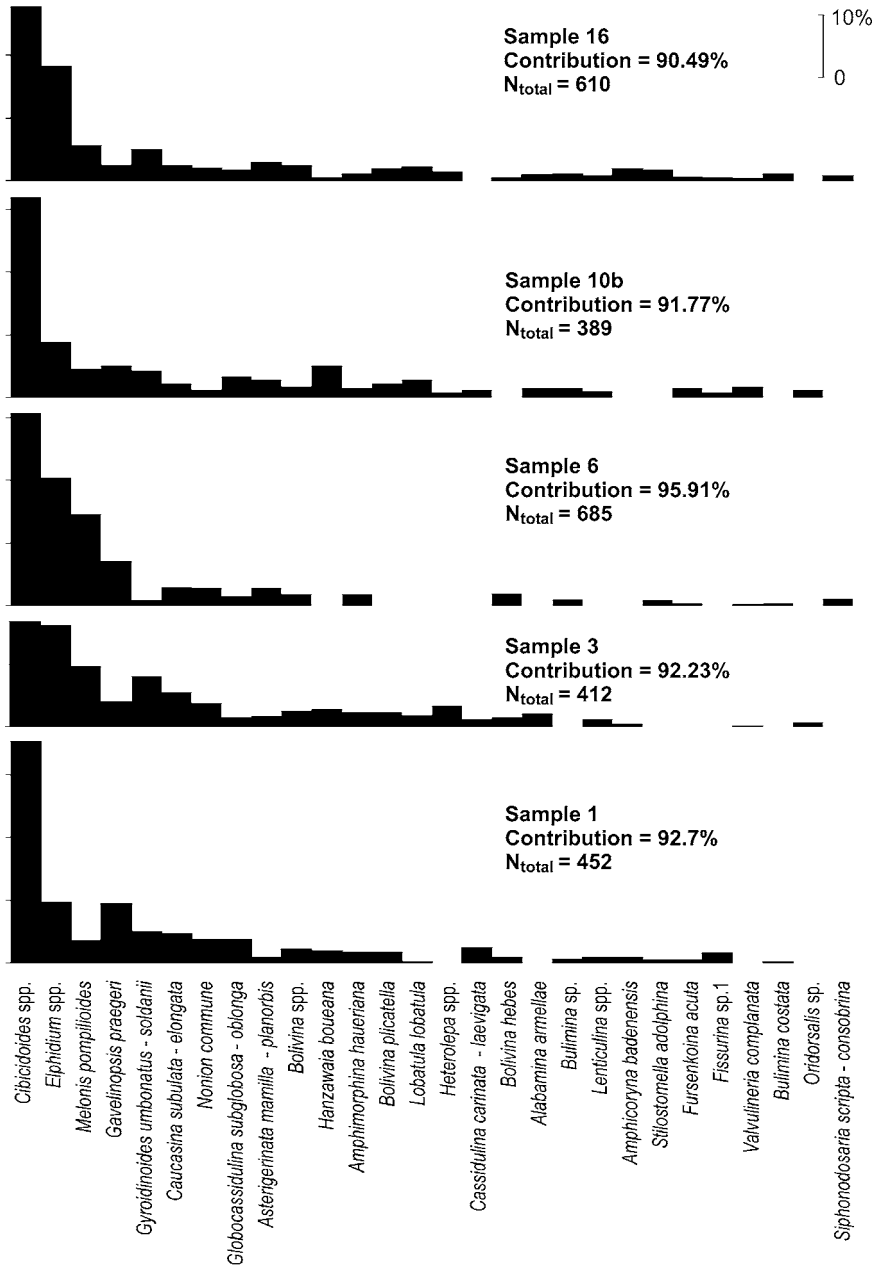


Fig. 3: The taxonomic structure of the benthic foraminifera assemblages is characterised by the vigorous dominance of *Cibicides* spp.; in sample 3, however, *Elphidium* spp. is only slightly less abundant. Each of 28 plotted taxa contributes at least in one sample to 1% of its abundance. Note that they compose more than 90% of each total sample content. Included taxa are species and supraspecies units resulting from the data reduction prior to statistical treatment following MURRAY (1991) and CLARKE & WARWICK (1994). Information on the number of counted benthic foraminifera individuals per sample is provided by the N_{total} value.

existence of 2 paleoecological units among the investigated samples (Fig. 4). These units reflect differences of percentage abundances and taxonomic content of the contributing taxa. Whereas the Agglomerative Hierarchical Clustering revealed a high-level similarity between all samples, the nMDS showed the aberrance of sample 6. This coincides well with the method characterisations by CLARKE & WARWICK (1994). Sample 6 is characterised by a significantly lower diversity, although it had the highest number of individuals (Figs. 3 and 5). The heterogeneity value (MURRAY 1991) also reached its absolute minimum in this sample.

The thin marly layer from which sample 6 was taken divides a massive carbonate package into two parts. Its position in the succession can be best interpreted as a short-term crisis in carbonate production. Such a crisis might have resulted from a suboxic event, coupled with an episode of increased primary productivity. An increased nutrient input into the basin by river runoffs would trigger water eutrophication and terminate the carbonate production.

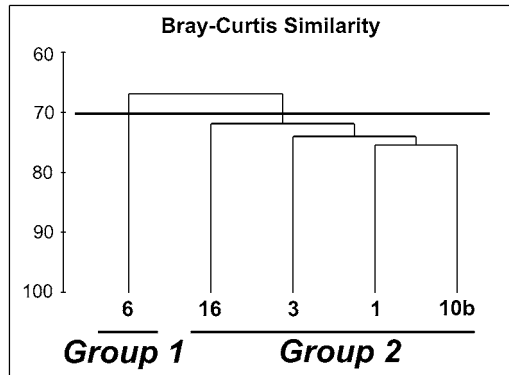
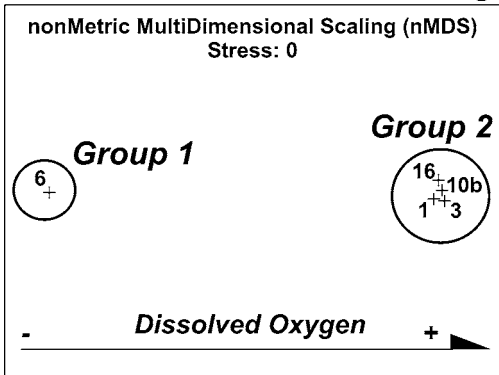
The Similarity and Dissimilarity Term Analyses showed that the peak abundance of *Melonis pompilioides* is the most important feature within the succession (Fig. 4). This species belongs to the group of the most abundant species in the samples. It is always more abundant than 3.5% (Fig. 5). *Melonis pompilioides* is a deep water species (MURRAY 1991). In the Lower Miocene Eggenburg Bay it characterised paleodepths exceeding the 30 m mark (JENKE 1998). Moreover, *Melonis* belongs to the group of suboxic indicators B of KAIHO (1994) and is a typical indicator of high organic matter supply and high primary production (RÖGL & SPEZZAFERRI 2003). Thus, its enhanced presence in sample 6 points to eutrophication as cause for the crisis in carbonate production. After this short-termed event, the *Cibicidoides-Elphidium* Assemblage rapidly re-established. Thus, still in the same layer *Cibicidoides* spp. and *Elphidium* spp. reached the highest total abundance (52%), indicating a re-establishment of strongly oxic conditions. Consequently, in the next step the carbonate production recovered as well.

Paleoecology of planktonic foraminifera

The analysis of planktonic foraminifera reveals a high similarity of all samples. However, three distinct groups can be depicted (Fig. 6). Sample 6 is not considered because of its drastically lowered plankton content (Fig. 7). Samples 10b and 16, positioned in the upper part of the section, group together (Fig. 6). This similarity is based on a low abundance of *Globorotalia* gr. and an increased abundance of *Globigerina praebulloides* gr. Therefore, a somewhat cooler seawater temperature can be inferred for that part of the section.

The interpretation of paleotemperature requirements for planktonic foraminifera follows RÖGL & SPEZZAFERRI (2003). Accordingly, the taxonomic units which result from data reduction prior to analysis are split into thermophilic taxa (*Globorotalia* gr., *Paragloborotalia* gr., *Globigerinoides* gr., *Praeorbulina - Orbulina* gr.) and psychrotrophic taxa (*Tenuitellinata* gr., *Globigerinita* gr., *Turborotalita* gr., *Globigerina praebulloides* gr., *Globigerina tarchanensis* gr., *Globoturborotalita connecta*). High abundances of the small, five-chambered globigerinids (*Globigerina tarchanensis* gr.) are considered to indicate phases of enhanced primary productivity.

Section Buchberg - Benthic Foraminifera



Average similarity: 71.32

| Species | Group 2 | | | | |
|--|----------|--------|--------|----------|-------|
| | Av.Abund | Av.Sim | Sim/SD | Contrib% | Cum.% |
| <i>Cibicides</i> spp. | 28.41 | 23.51 | 3.33 | 32.97 | 32.97 |
| <i>Elphidium</i> spp. | 13.48 | 10.49 | 3.54 | 14.71 | 47.68 |
| <i>Gyroidinoides umbonatus</i> (Silvestri) - <i>soldanii</i> (d'Orbigny) gr. | 5.7 | 4.73 | 12.09 | 6.63 | 54.31 |
| <i>Melonis pompilioides</i> (Fichtel & Moll) | 5.96 | 4.27 | 4.77 | 5.99 | 60.29 |
| <i>Gavelinopsis praegeri</i> (Heron-Allen & Earland) | 5.31 | 3.46 | 2.99 | 4.85 | 65.15 |
| <i>Caucasina subulata</i> (Cushman & Parker) - <i>elongata</i> (d'Orbigny) | 3.75 | 2.75 | 2.95 | 3.86 | 69.01 |
| <i>Bolivina</i> spp. | 2.29 | 2.05 | 7.16 | 2.87 | 71.88 |
| <i>Nonion commune</i> (d'Orbigny) | 2.77 | 1.98 | 2.05 | 2.78 | 74.65 |
| <i>Bolivina plicatella</i> Cushman | 2.12 | 1.93 | 9.05 | 2.7 | 77.35 |
| <i>Globocassidulina subglobosa</i> (Brady) - <i>oblonga</i> (Reuss) | 2.59 | 1.89 | 2.57 | 2.64 | 80 |
| <i>Asterigerinata mamilla</i> (Williamson) - <i>planorbis</i> (d'Orbigny) | 2.09 | 1.48 | 1.92 | 2.08 | 82.07 |
| <i>Hanzawaia boueana</i> (d'Orbigny) | 2.63 | 1.4 | 1.33 | 1.96 | 84.03 |
| <i>Amphimorphina haueriana</i> Neugeboren | 1.72 | 1.38 | 5.11 | 1.94 | 85.97 |
| <i>Lobatula lobatula</i> (Walker & Jacob) | 1.82 | 1.14 | 1.12 | 1.6 | 87.57 |
| <i>Lenticulina</i> spp. | 0.99 | 0.88 | 10.81 | 1.23 | 88.8 |
| <i>Cassidulina carinata</i> Silvestri - <i>laevigata</i> d'Orbigny | 1.27 | 0.7 | 1.19 | 0.98 | 89.78 |
| <i>Alabamina armellae</i> Popescu | 1.18 | 0.58 | 0.87 | 0.82 | 90.6 |

Average dissimilarity = 30.52

| Species | Group 2 | | Group 1 | | Contrib% | Cum.% |
|--|----------|----------|---------|---------|----------|-------|
| | Av.Abund | Av.Abund | Av.Diss | Diss/SD | | |
| <i>Melonis pompilioides</i> (Fichtel & Moll) | 5.96 | 14.89 | 4.46 | 3.18 | 14.62 | 14.62 |
| <i>Elphidium</i> spp. | 13.48 | 20.88 | 3.7 | 1.53 | 12.11 | 26.74 |
| <i>Cibicides</i> spp. | 28.41 | 31.39 | 2.81 | 0.97 | 9.2 | 35.93 |
| <i>Gyroidinoides umbonatus</i> (Silvestri) - <i>soldanii</i> (d'Orbigny) gr. | 5.7 | 0.88 | 2.41 | 2.78 | 7.9 | 43.83 |
| <i>Gavelinopsis praegeri</i> (Heron-Allen & Earland) | 5.31 | 7.3 | 1.55 | 2.47 | 5.07 | 48.9 |
| <i>Hanzawaia boueana</i> (d'Orbigny) | 2.63 | 0 | 1.32 | 1.35 | 4.32 | 53.22 |
| <i>Bolivina plicatella</i> Cushman | 2.12 | 0 | 1.06 | 6.97 | 3.47 | 56.69 |
| <i>Lobatula lobatula</i> (Walker & Jacob) | 1.82 | 0 | 0.91 | 1.62 | 2.98 | 59.67 |
| <i>Heterolepa</i> spp. | 1.41 | 0 | 0.71 | 0.97 | 2.31 | 61.99 |
| <i>Caucasina subulata</i> (Cushman & Parker) - <i>elongata</i> (d'Orbigny) | 3.75 | 3.07 | 0.68 | 1.55 | 2.23 | 64.22 |
| <i>Bolivina hebes</i> Mactadyen | 0.71 | 2.04 | 0.67 | 2.17 | 2.19 | 66.41 |
| <i>Alabamina armellae</i> Popescu | 1.18 | 0 | 0.59 | 1.27 | 1.93 | 68.34 |
| <i>Globocassidulina subglobosa</i> (Brady) - <i>oblonga</i> (Reuss) | 2.59 | 1.46 | 0.57 | 1 | 1.86 | 70.19 |
| <i>Cassidulina carinata</i> Silvestri - <i>laevigata</i> d'Orbigny | 1.27 | 0.15 | 0.56 | 1.22 | 1.85 | 72.04 |
| <i>Nonion commune</i> (d'Orbigny) | 2.77 | 2.92 | 0.53 | 2.7 | 1.73 | 73.77 |
| <i>Lenticulina</i> spp. | 0.99 | 0 | 0.49 | 5.65 | 1.62 | 75.39 |
| <i>Siphonodosaria scripta</i> (d'Orbigny) - <i>consobrina</i> (d'Orbigny) | 0.2 | 1.17 | 0.48 | 2.35 | 1.58 | 76.97 |
| <i>Amphicoryna badenensis</i> (d'Orbigny) | 0.96 | 0 | 0.48 | 1.39 | 1.58 | 78.54 |
| <i>Asterigerinata mamilla</i> (Williamson) - <i>planorbis</i> (d'Orbigny) | 2.09 | 2.92 | 0.42 | 0.88 | 1.38 | 79.93 |
| <i>Stilostomella adolphina</i> (d'Orbigny) | 0.63 | 0.88 | 0.36 | 3.1 | 1.17 | 81.1 |
| <i>Fissurina</i> sp.1 | 0.7 | 0 | 0.35 | 1.09 | 1.15 | 82.25 |
| <i>Oridorsalis</i> sp. | 0.54 | 0 | 0.27 | 0.93 | 0.89 | 83.14 |
| <i>Pullenia bulloides</i> (d'Orbigny) | 0.34 | 0.88 | 0.27 | 2.05 | 0.87 | 84.01 |
| <i>Stilostomella advena</i> (Cushman & Laiming) | 0.65 | 0.15 | 0.25 | 1.61 | 0.83 | 84.85 |
| <i>Bulimina</i> sp. | 0.84 | 1.02 | 0.25 | 1.33 | 0.83 | 85.68 |
| <i>Uvigerina grilli</i> Schmid | 0.49 | 0 | 0.24 | 1.12 | 0.8 | 86.47 |
| <i>Valvulineria complanata</i> (d'Orbigny) | 0.59 | 0.29 | 0.24 | 0.67 | 0.77 | 87.25 |
| <i>Plectofrondicularia medelingensis</i> (Karrer) | 0.12 | 0.58 | 0.23 | 3.34 | 0.76 | 88.01 |
| <i>Fursenkoina acuta</i> (d'Orbigny) | 0.66 | 0.44 | 0.22 | 0.93 | 0.72 | 88.73 |
| <i>Amphimorphina haueriana</i> Neugeboren | 1.72 | 1.9 | 0.22 | 1.67 | 0.72 | 89.45 |
| <i>Bolivina</i> spp. | 2.29 | 1.9 | 0.22 | 1.49 | 0.72 | 90.17 |

Additionally to sample 6, such a phase can be recognised in sample 1, which shows an increased abundance of *Globigerina tarchanensis* gr. (Fig. 7). Warm water conditions are reflected by the abundance of *Globorotalia* gr. and the decrease of *G. praebulloides* gr. As benthic foraminifera did not indicate such conditions, the event was probably short. In contrast, the increasing abundance of both *Globigerina tarchanensis* gr. and *G. praebulloides* gr., along with the decreasing *Globorotalia* gr., in the topmost sample can be explained by seawater cooling. This interpretation is well supported by the abundance distribution of thermophilic and psychrotrophic taxa shown in Fig. 7.

Finally, the total abundances of planktonic foraminifera in the samples (Fig. 7) allow a reconstruction of an inner shelf (<20%), middle shelf (10-60%) and outer shelf (>40%) environment (according to MURRAY 1976). These values highly depend on the regional paleocirculation patterns and the distance to the open water mass. Hence, the values derived from the thick marly layers (24.3% - 28.4%) indicate upper middle shelf conditions of less than 100 m depth (compare also SPEZZAFERRI & CORIC 2001 and MANDIC et al. 2002). Inner to middle shelf conditions are also supported by the predominantly small-sized planktonic foraminifera (MURRAY 1976).

In contrast, the minimal plankton abundance (1.5%) of sample 6 points to inner shelf conditions. Based on the evidence from benthic foraminifera, this is improbable. In fact, marine areas in marginal positions, such as the Badenian Alpine Molasse Basin, have restricted water circulation and are susceptible to recurring eutrophication events. Such events can be recognised by depleted planktonic fauna, while the benthic fauna - characterised by the abundance peaks of suboxic indicators - points to deeper water conditions (e.g. Styrian Basin suboxia of RÖGL et al. 2002).

Conclusions

The studied samples represent four thick marly layers and one thin intercalation within the carbonate package dominating the lower part of the succession. The latter intercalation is characterised by a dramatically decreased plankton abundance, by a decreased

Fig. 4: Ordination of benthic foraminifera samples by non-metric Multi-Dimensional Scaling (nMDS) and the Hierarchical Agglomerative Clustering; relations between and within inferred groups (1 and 2) are analysed below. Note the distance of sample 6 ("Group" 1) from the remaining samples ordered homogeneously within Group 2. As argued in the text, the horizontal axis can be best interpreted as the function of dissolved oxygen (compare Figs. 5 and 7). The stress value of nMDS represents the distortion involved in compressing the data from a multidimensional space into a smaller number of dimensions. The nMDS ordination (applying the maximal available value of 9999 restarts) and the hierarchical clustering (applying the group average cluster mode) are based on the similarity matrix produced by the Bray-Curtis similarity measure of the square root transformed sample data. The latter transformation was made in order to highlight the contribution of less abundant species following the recommendation by CLARKE & WARWICK (1994). Similarity and Dissimilarity Term Analyses of inferred groups use the Bray-Curtis similarity and dissimilarity measure of square root transformed data as well. The species are ordered in decreasing contribution, whereas the list cut-offs are placed at 90%. Abbreviations: **Avg.Ab.** - average abundance of single species in the groups of samples analysed; **Avg.Sim.** - average similarity; **Avg.Dis.** - average dissimilarity; **Contrib.%** - percentage contribution of the single species to the total similarity; **Cum%** - summary of the percentage contribution of the single species.

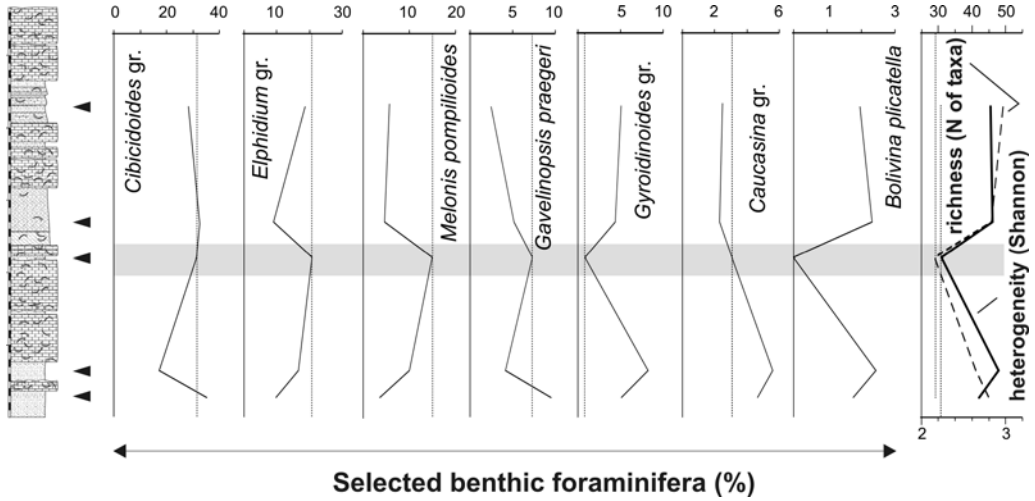


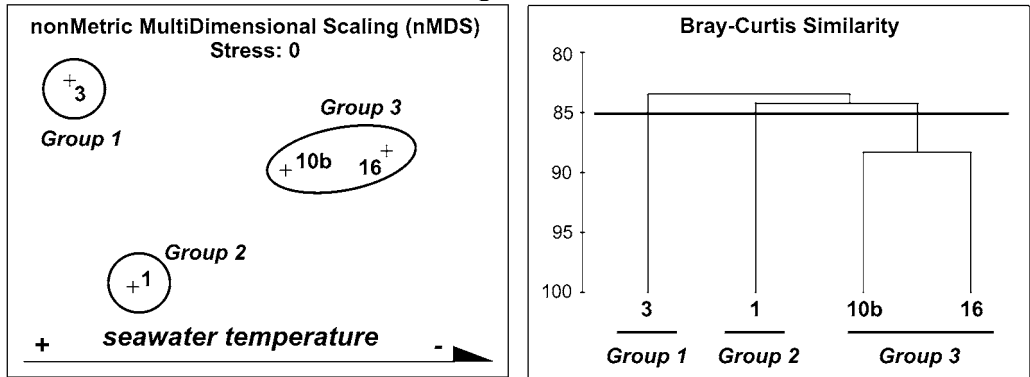
Fig. 5: Abundance curves of selected benthic foraminifera followed by plots of up-section changes in taxonomic diversity (expressed by number of taxa represented per sample) and heterogeneity (using the Shannon-Weaver formulation) in studied samples. Gray field marks the position of sample 6. Among other ecologically significant factors, the maximum abundance of *Melonis pompilioides* and the minimum values for sample richness and sample heterogeneity point to suboxia within the depositional environment (compare Figs. 4 and 7).

richness and heterogeneity of benthic foraminifera and by the absolute dominance of *Cibicidoides* spp. and *Elphidium* spp. (together 52%). The trigger for the interruption of the carbonate production was a short-termed enhanced primary productivity and the resulting increase of organic matter in the water column. This is reflected by the peak abundance of the opportunistic species *Melonis pompilioides*.

The thicker marly layers are characterised by an enhanced richness and heterogeneity of benthic foraminifera, along with abundant planktonic foraminifera, indicating open sea conditions of the upper middle shelf. The long-termed decrease in carbonate production might be linked to fluctuations of the relative sea level. Hence, the abundance of *Elphidium*, which is an inner shelf indicator, and the common presence of deeper-water taxa such as *Globocassidulina* and *Cassidulina* imply an average paleodepth of about 50 m.

Fig. 6: Ordination of planktonic foraminifera samples by non-metric Multi-Dimensional Scaling (nMDS) and Hierarchical Agglomerative Clustering; relations between and within inferred groups (1 and 2) are analysed below. Sample 6, with drastically reduced planktonic foraminifera content, is excluded from the analyses. The existence of three units based on similarities within groups and dissimilarities between groups is revealed; samples 10b and 16, positioned in the upper part of the section, are grouped together. The decreased abundance of *Globorotalia* gr. and increased abundance of *Globigerina praebulloides* gr. suggest a somewhat cooler sea water temperature for that part of the section. Applied statistical parameters and abbreviations correspond to those of Fig. 3.

Section Buchberg - Planktonic Foraminifera



Average similarity: 87.83

| Species | Group 3 | | Sim/SD | Contrib% | Cum.% |
|--------------------------------------|----------|--------|--------|----------|-------|
| | Av.Abund | Av.Sim | | | |
| <i>Globorotalia</i> gr. | 52.33 | 48.29 | # | 54.98 | 54.98 |
| <i>Globigerina praebulloides</i> gr. | 24.57 | 23.49 | # | 26.74 | 81.73 |
| <i>Globigerina tarchanensis</i> gr. | 12.15 | 8.05 | # | 9.17 | 90.9 |

Average dissimilarity = 16.97

| Species | Group 2 | Group 1 | | Diss/SD | Contrib% | Cum.% |
|--------------------------------------|----------|----------|---------|---------|----------|-------|
| | Av.Abund | Av.Abund | Av.Diss | | | |
| <i>Globigerina tarchanensis</i> gr. | 17.88 | 6.06 | 5.91 | # | 34.82 | 34.82 |
| <i>Globorotalia</i> gr. | 62.01 | 71.21 | 4.6 | # | 27.11 | 61.94 |
| <i>Globigerina praebulloides</i> gr. | 9.5 | 14.39 | 2.45 | # | 14.43 | 76.37 |
| <i>Paragloborotalia</i> gr. | 5.59 | 1.52 | 2.04 | # | 12 | 88.36 |
| <i>Turborotalita</i> gr. | 1.12 | 2.27 | 0.58 | # | 3.4 | 91.77 |

Average dissimilarity = 18.83

| Species | Group 2 | Group 3 | | Diss/SD | Contrib% | Cum.% |
|--------------------------------------|----------|----------|---------|---------|----------|-------|
| | Av.Abund | Av.Abund | Av.Diss | | | |
| <i>Globigerina praebulloides</i> gr. | 9.5 | 24.57 | 7.53 | 9.91 | 40.01 | 40.01 |
| <i>Globorotalia</i> gr. | 62.01 | 52.33 | 4.84 | 1.69 | 25.7 | 65.71 |
| <i>Globigerina tarchanensis</i> gr. | 17.88 | 12.15 | 2.87 | 0.99 | 15.22 | 80.93 |
| <i>Globigerinita</i> gr. | 3.35 | 1.74 | 0.81 | 2.87 | 4.28 | 85.21 |
| <i>Paragloborotalia</i> gr. | 5.59 | 4.06 | 0.76 | 1.69 | 4.06 | 89.27 |
| <i>Turborotalita</i> gr. | 1.12 | 2.62 | 0.75 | 17.69 | 4 | 93.27 |

Average dissimilarity = 20.93

| Species | Group 1 | Group 3 | | Diss/SD | Contrib% | Cum.% |
|--------------------------------------|----------|----------|---------|---------|----------|-------|
| | Av.Abund | Av.Abund | Av.Diss | | | |
| <i>Globorotalia</i> gr. | 71.21 | 52.33 | 9.44 | 3.3 | 45.11 | 45.11 |
| <i>Globigerina praebulloides</i> gr. | 14.39 | 24.57 | 5.09 | 6.69 | 24.3 | 69.41 |
| <i>Globigerina tarchanensis</i> gr. | 6.06 | 12.15 | 3.04 | 1.05 | 14.54 | 83.95 |
| <i>Paragloborotalia</i> gr. | 1.52 | 4.06 | 1.27 | 2.81 | 6.08 | 90.03 |

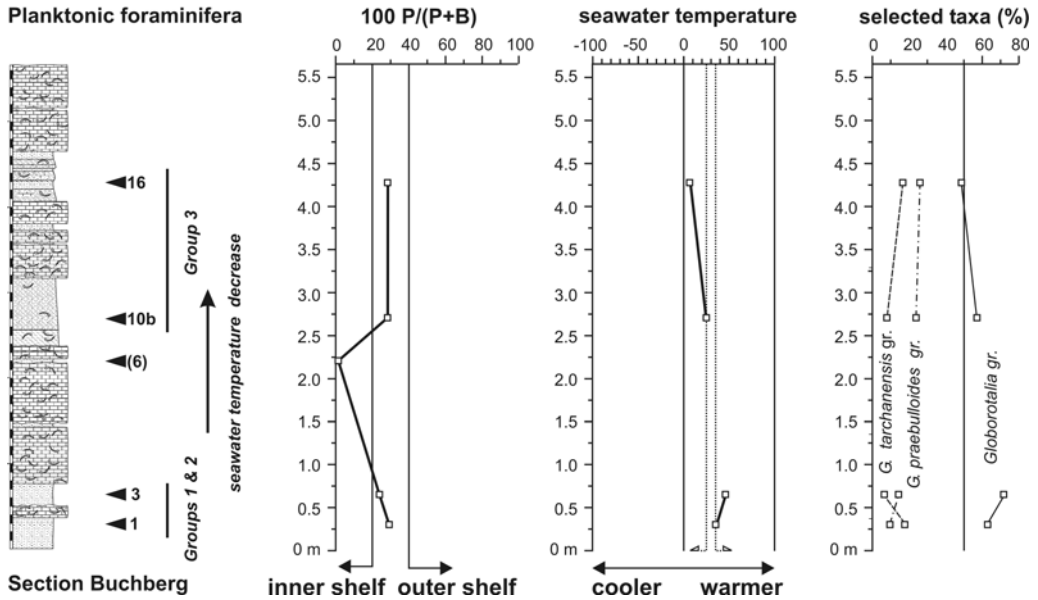


Fig. 7: Interpretation of Similarity/Disimilarity Term Analyses for planktonic foraminifera plotted along with the plankton/benthos ratio (100P/P+B) curve. Note the minimum value for sample 6. Additionally plotted is the record of the relative sea water temperature change based on subtraction of psychrotrophic and thermophilic plankton abundances following RÖGL & SPEZZAFERRI (2003). Note the correspondence with the interpretation of the nMDS ordination. Finally, the abundance curves for the three most common taxa are added. The upward increase of the *Globigerina tarchanensis* group in the lower part of the section might reflect increasing productivity. The statistically insignificant record of sample 6 is excluded from both latter plots.

The occurrence of thick-shelled molluscs within the organogenic limestone, however, implies shallower depths down to 30 m. This indicates that the limestone production and its interruption by marl phases were probably controlled by sea level fluctuations. Hence, orbital forcing producing smaller-scale sea level fluctuations (acc. to BASSANT 1999 - 3-6 m within a 13-20ka period) would significantly influence the organic matter influx into marginal basins such as the Eastern Alpine Foredeep. That would explain the recorded plankton fluctuations and the extreme abundance of oxic indicators following the benthic ecosystem recovery.

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