

FORAMINIFERAL PALEOECOLOGY AND BIOSTRATIGRAPHY OF THE GRUND FORMATION (MOLASSE BASIN, LOWER AUSTRIA)

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Abstract: This study was undertaken to solve the debate about the age of the sediments from the Grund Formation and to propose an environmental interpretation based on benthic and planktonic foraminiferal assemblages from the profiles excavated in 1998 and 1999 in the type locality of the Grund Formation (Lower Austria). In particular, quantitative data of foraminifers from Profile G were statistically treated to unravel the ecological gradients subtending the samples. Planktonic foraminiferal assemblages suggest a warm paleoclimate for this area. Benthic foraminiferal assemblages testify to strong re-deposition processes displacing shallow-water sediments from the inner shelf to outer shelf. Re-deposition may derive from storm events. Oxygenation of bottom waters is difficult to assess on the basis of benthic foraminifers. In particular, it is not possible to identify the dysoxic episodes suggested by the occurrence of chemosymbiotic bivalves living with anaerobic bacteria as in Zuschin et al. (2001). The studied sediments can be attributed to the Lower Lagenidae Zone in the Badenian (Langhian, Middle Miocene) on the basis of the presence of index fossils like *Praeorbulina glomerosa circularis* and *Uvigerina macrocarinata*.

Key words: Badenian, Austria, Grund Formation, ecology, stratigraphy, molasse, foraminifers.

Introduction

In 1998 and 1999, the Institute of Paleontology of the University of Vienna organized excavation campaigns in the type area of the Grund Formation, at Grund, north of Hollabrunn in Lower Austria, north of the Danube (Fig. 1). A total of 9 profiles were excavated and are currently described in detail in Roetzel et al. (1999), Pervesler et al. (1999), Zuschin et al. (2001), Pervesler & Roetzel (2002) and Roetzel & Pervesler (2004).

Sediments from these profiles are dominated by yellowish fine sands and silts with thin intercalation of gray pelitic layers, with evidence of channels filled with molluscs debris, coarser sand and fine gravel (Harzhauser et al. 1999) and bioturbations throughout (Fig. 2; Pervesler et al. 1999). In particular, Zuschin et al. (2001) interpreted the sedimentary succession as an alternation of fining upward sequences of tempestite layers with the base characterized by abundant molluscan fragments. To the west the Grund Formation is replaced by the Gaiendorf Formation, which is described by Roetzel et al.

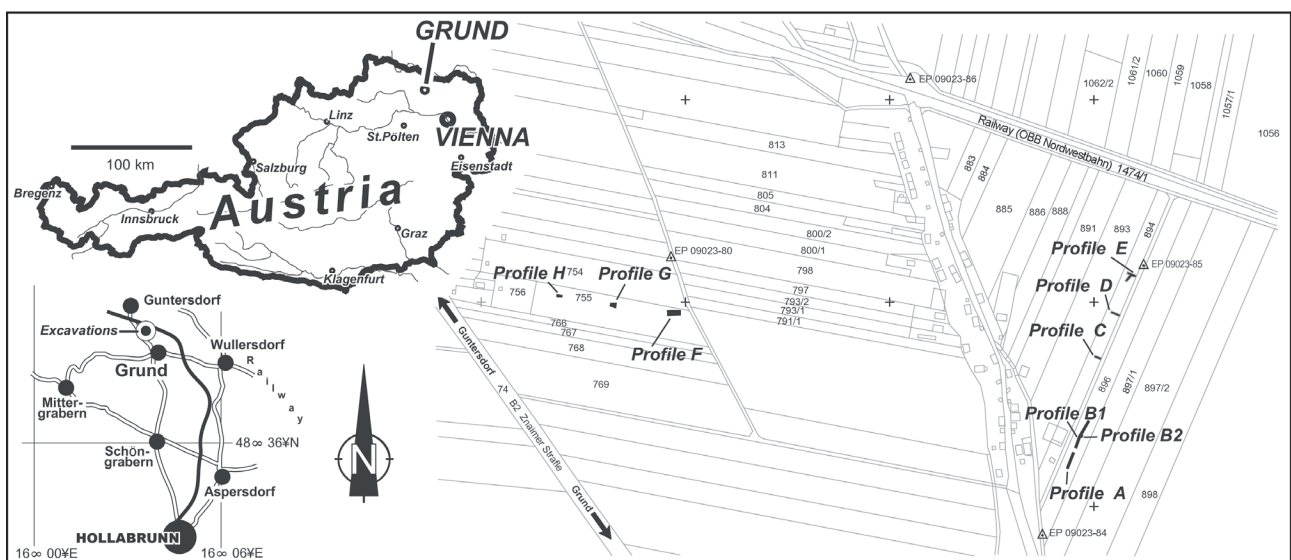


Fig. 1. Locality map showing the position of Profiles A to H (after Roetzel & Pervesler 2004).

Table 1: Continued

Planktonic foraminifers

Samples	<i>Globigerina praebuloides</i> gr.	<i>Globigerina</i> sp.	<i>Globigerina tarchanensis</i>	<i>Globigerinella obesa</i> group	<i>Globobulimina langhiana</i>	<i>Globobulimina bykova</i>	<i>Paraglobobulimina acrostoma</i>	<i>Paraglobobulimina inaequiconica</i>	<i>Praeorbulina glomerosa</i> circularis	<i>Praeorbulina</i> sp.	<i>Zeaglobigerina woodi</i>	Total Planktonic F.	Reworking	<i>Acarina bulbrooki</i>	<i>Morozovella</i> sp.	<i>Cassigerinella</i> sp.	<i>Globobulimina</i> sp.	<i>Bolivina draco</i>	<i>Bolboforma</i>	Radiolarians	Molluscs
G-14												-									
G-13	2											4									
G-12												-									
G-11												-									
G-10												-									
G-9	6	1				9						16								R	
G-8	8	12	1		12			1				34							C		
G-7	1	1										2								R	
G-6	18	2	8	3		64	2					97		1	1	1				C	
G-5	5				1	1		1	1			9		1							A
G-4	2		1	4								7									A
G-3	3		1			7						11									A
G-2				3						1	4		1				1		R/C		A
G-1	1											1									A

(1999) as characterized by coarser sediments and reduction of pelitic layers.

Cicha & Rudolfský (1996); Cicha (1999) and Švábenická & Čtyroká (1999), have recently attributed the Grund Formation at its type locality to the Karpatian (Burdigalian–Early Miocene). However, their age attribution contrasts with the observations of other authors, such as Weinhandl (1957) and Grill (1958) who documented the occurrence of the planktonic foraminifers *Praeorbulina glomerosa* and *Orbulina suturalis* in the Grund Formation. These microfossils are typical of the Early Badenian (Langhian–Middle Miocene).

The aim of this study is to investigate the age of the Grund Formation and to reconstruct the depositional and paleoenvironmental setting in the area.

Samples from Profiles E to H (Fig. 1) were analysed for their micropaleontological content and for biostratigraphic studies. Ecological investigation was performed on Profile G only (Fig. 2). This profile was found to be the more suitable to reconstruct environmental conditions because it is characterized by more numerous levels representing in-situ sediments, with respect to other profiles. Here after, when mentioning samples, the letter refers to profiles (Fig. 1) and the number to progressive samples taken in each profile from bottom to top.

Material and methods

Samples were taken during the excavation to record the more important sedimentary facies including autochthonous and reworked sediments as shown in Fig. 2. Two hundred grams of sediment for each sample were soaked in hydrogen peroxide for several hours. Samples were then soaked in warm water and washed under running water through >250 µm, >125 µm and >63 µm mesh sieves. Residues from Profile E–H

were analysed qualitatively. Washed residues from Profile G were split, using the splitter described in Rupp (1986) to obtain approximately 500 to 1000 specimens per fraction for each split. Specimens of benthic and planktonic foraminifers were then identified using a binocular microscope and counted.

Multivariate statistics were applied to quantitative data using the Software PRIMER 5 (Plymouth Marine Laboratory). Application of this method to planktonic and benthic foraminifers is extensively discussed in Basso & Spezzaferri (2000) and Spezzaferri & Čorić (2001). Hierarchical agglomerative clustering is based on the Bray–Curtis Similarity (Clifford & Stephenson 1975). Complete linkage was used for benthic foraminifers. On the basis of the same similarity matrix, samples were ordered by non-metric MultiDimensional Scaling — nMDS (Kruskal 1977). Clusters identified both in the dendrograms and nMDS plots, at the same similarity level, were further investigated through the Similarity and Dissimilarity Term Analyses, to highlight the contribution of each species to the total average similarity and dissimilarity within each group and between different groups and thus, to better characterize the assemblages.

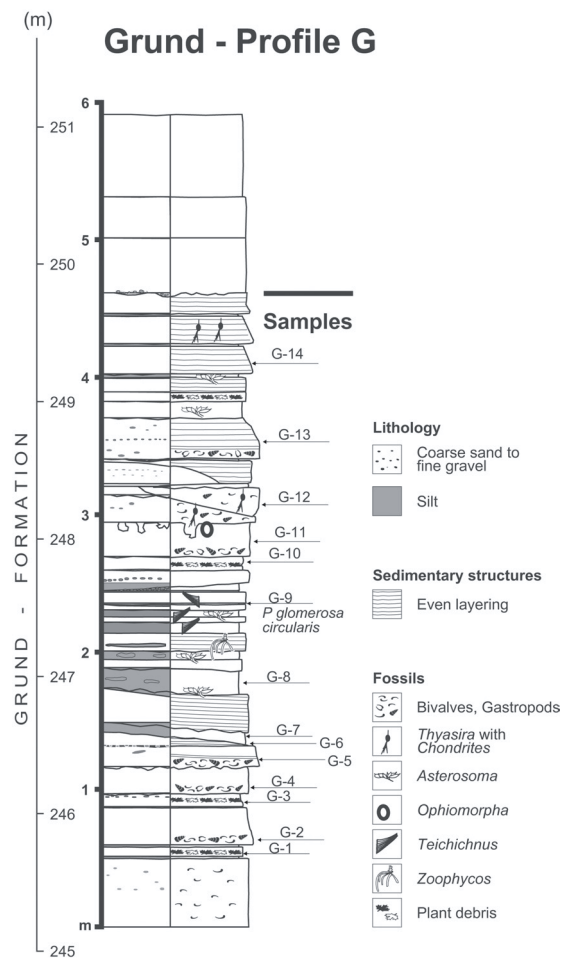


Fig. 2. Lithological section of Profile G (after Roetzel & Pervesler 2004). Indicated is also the level where *Praeorbulina glomerosa circularis* occurs.

Results

Micropaleontology and biostratigraphy

Benthic foraminifers are generally abundant in all samples. The abundance and presence of planktonic foraminifers varies from sample to sample from absent to common (Table 1). The quantitative study performed on benthic foraminiferal assemblages from Profile G revealed that the levels characterized by coarser lithology contain high abundance of the *Ammonia*, *Elphidium* and *Asterigerinata* groups, whereas, *Amphistegina* sp., *Reussella* spp., and *Glabratellina* sp. are rarer. These forms are generally corroded and often broken. The accompanying assemblages include common to abundant *Pappina* spp., *Bolivina* spp., *Bulimina* spp., *Caucasina* spp., *Heterolepa* spp., *Lenticulina* spp., *Uvigerina graciliformis* and

Nonion commune. Specimens from the *Globobulimina pyru-la-pupoides* group, *Cassidulina* sp., *Baggina arenaria*, *Virgulopsis tuberculatus* and *Valvulineria complanata* are rare. *Uvigerina macrocarinata* was found in Sample F-10. Deformed shells of benthic foraminifers and, in particular, *Ammonia* spp. are observed in several samples.

Planktonic foraminifers are generally small-sized and include specimens from the *Globigerina praebuloides* group, *Globigerinella obesa*, *Globorotalia bykovae*, *Paragloborotalia* sp. *Praeorbulina glomerata circularis* occurs in Samples G-9 and F-6. Clearly reworked species include rare *Acarinina* sp. (Eocene), *Globotruncana* sp. (Cretaceous) and *Cassigerinella* sp. (Oligocene). Table 1 shows the distribution and abundance of benthic and planktonic foraminifers in Profile G together with the distribution of molluscan fragments and radiolarians.

Table 2: Bray-Curtis Similarity and Dissimilarity of benthic foraminifers. *Lentic.* — *Lenticulina* group; *Saracen.* — *Saracenaria* sp.; Avg. Ab. — average abundance; Avg. Dis. — average dissimilarity; Contrib. — contribution, Cum — cumulative.

Cluster 1	Average similarity = 55.52				Average dissimilarity = 58.71					
	Avg. Ab.	Avg. Sim.	Contrib.%	Cum%	Group 2	Group 1	Avg. Ab.	Avg. Dis.	Contrib.%	Cum%
<i>Caucasina</i> gr.	30.33	10.21	18.40	18.40						
<i>A. viennesis</i>	47.67	8.36	15.05	33.45	<i>A. viennesis</i>		169.80	47.67	16.65	28.37
<i>A. parkinsoniana</i>	19.67	4.28	7.71	41.16	<i>Elphidium</i> gr.		84.60	19.67	9.13	15.55
<i>Cibicidoides</i> gr.	12.33	2.99	5.38	46.55	<i>Lentic.-Saracen.</i> gr.		42.80	6.33	5.05	8.59
<i>A. perlucida</i>	8.67	2.58	4.66	51.20	<i>H. dutemplei</i>		39.60	12.33	3.96	6.74
<i>Elphidium</i> gr.	19.67	2.58	4.65	55.85	<i>Caucasina</i> gr.		5.40	30.33	3.47	5.90
<i>N. commune</i>	12.33	2.25	4.06	59.91	<i>A. parkinsoniana</i>		39.40	19.67	2.96	5.04
<i>H. dutemplei</i>	12.33	2.18	3.92	63.83	<i>Bolivina</i> gr.		1.20	10.33	1.44	2.46
<i>Pappina</i> gr.	10.67	2.12	3.82	67.65	<i>Asterigerinata</i> gr.		15.00	11.67	1.26	2.15
<i>Asterigerinata</i> gr.	11.67	2.10	3.79	71.44	<i>Pappina</i> gr.		1.80	10.67	1.17	1.99
<i>P. granosum</i>	6.67	1.82	3.29	74.73	<i>B. elongata</i> group		0.60	8.00	1.08	1.84
<i>H. boueana</i>	7.67	1.69	3.04	77.77	<i>A. perlucida</i>		1.20	8.67	1.03	1.76
<i>A. tepida</i>	9.67	1.58	2.85	80.62						
					Average dissimilarity = 31.90					
Cluster 2	Average similarity = 75.28				Group 2	Group 3	Avg. Ab.	Avg. Dis.	Contrib.%	Cum%
<i>A. viennesis</i>	169.80	25.69	34.13	34.13	<i>A. viennesis</i>		169.80	282.40	10.90	34.17
<i>Elphidium</i> gr.	84.60	15.34	20.38	54.51	<i>Elphidium</i> gr.		84.60	124.80	4.06	12.72
<i>H. dutemplei</i>	39.60	7.82	10.39	64.90	<i>A. parkinsoniana</i>		39.40	66.20	2.36	7.41
<i>A. parkinsoniana</i>	39.40	7.75	10.29	75.19	<i>N. commune</i>		8.40	31.80	1.72	5.40
<i>Lentic.-Saracen.</i> gr.	42.80	7.64	10.15	85.34	<i>H. dutemplei</i>		39.60	56.80	1.32	4.14
					<i>Lentic.-Saracen.</i> gr.		42.80	49.60	1.29	4.03
Cluster 3	Average similarity = 73.22				<i>Cibicidoides</i> gr.		5.60	18.20	1.10	3.44
<i>A. viennesis</i>	282.40	26.78	36.57	36.57	<i>Asterigerinata</i> gr.		15.00	28.20	1.07	3.35
<i>Elphidium</i> gr.	124.80	10.84	14.81	51.38	<i>Caucasina</i> gr.		5.40	18.40	1.00	3.13
<i>A. parkinsoniana</i>	66.20	7.77	10.61	61.99	<i>Pappina</i> gr.		1.80	10.00	0.65	2.04
<i>H. dutemplei</i>	56.80	6.34	8.65	70.64	<i>P. granosum</i>		2.20	9.40	0.60	1.87
<i>Lentic.-Saracen.</i> gr.	49.60	5.25	7.17	77.82	<i>A. tepida</i>		3.20	11.20	0.59	1.86
<i>Asterigerinata</i> gr.	28.20	2.98	4.07	81.89	<i>Amphistegina</i> spp.		4.00	8.40	0.58	1.81
					Average dissimilarity = 61.60					
					Group 1	Group 3	Avg. Ab.	Avg. Dis.	Contrib.%	Cum%
					<i>A. viennesis</i>		47.67	282.40	21.85	35.47
					<i>Elphidium</i> gr.		19.67	124.80	9.54	15.49
					<i>A. parkinsoniana</i>		19.67	66.20	4.85	7.87
					<i>Lentic.-Saracen.</i> gr.		6.33	49.60	4.29	6.97
					<i>H. dutemplei</i>		12.33	56.80	4.27	6.94
					<i>N. commune</i>		12.33	31.80	1.73	2.82
					<i>Asterigerinata</i> gr.		11.67	28.20	1.73	2.81
					<i>Caucasina</i> gr.		30.33	18.40	1.39	2.26

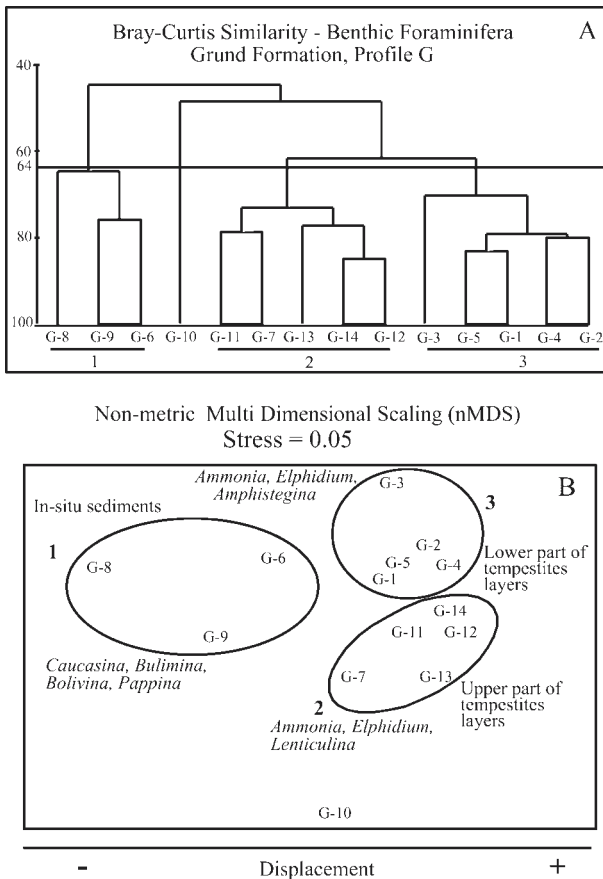


Fig. 3. **A** — Hierarchical agglomerative clustering based on the Bray-Curtis Similarity, and **B** — non-metric MultiDimensional Scaling (nMDS) plot of benthic foraminifers from Profile G.

Formation based on benthic foraminiferal assemblages is very difficult. The presence of stilostomellids (including the genus *Siphonodosaria*) together with *Pullenia bulloides*, *Melonis pompilioides*, and costate uvigerinids (*U. graciliformis* and *U. macrocarinata*) indicate a relatively deep-water of about 100 meters corresponding to the outer shelf. This depth attribution disagrees with the interpretation of Zuschin et al. (2001), who inferred a water depth of much less than 100 meters based on molluscan assemblages and shell-beds geometry suggesting proximal tempestites. The presence throughout Profile G of shallow-water species like the *Ammonia* group, *Aubignyna perlucida*, *Porosonion granosum*, *Asterigerinata* and *Amphistegina* groups may indicate shallow water depth. However, tests of these taxa appear always broken and/or corroded with respect to the well preserved deeper-water species. Therefore, mixing of shallow-water benthic foraminifers and deeper-water species indeed, indicates re-deposition processes displacing the upper shelf sediments into the deeper part of the sedimentary basin.

Statistical treatment

As demonstrated in Rögl & Spezzaferrri (2003) the distribution in space and time of benthic and planktonic foraminifers

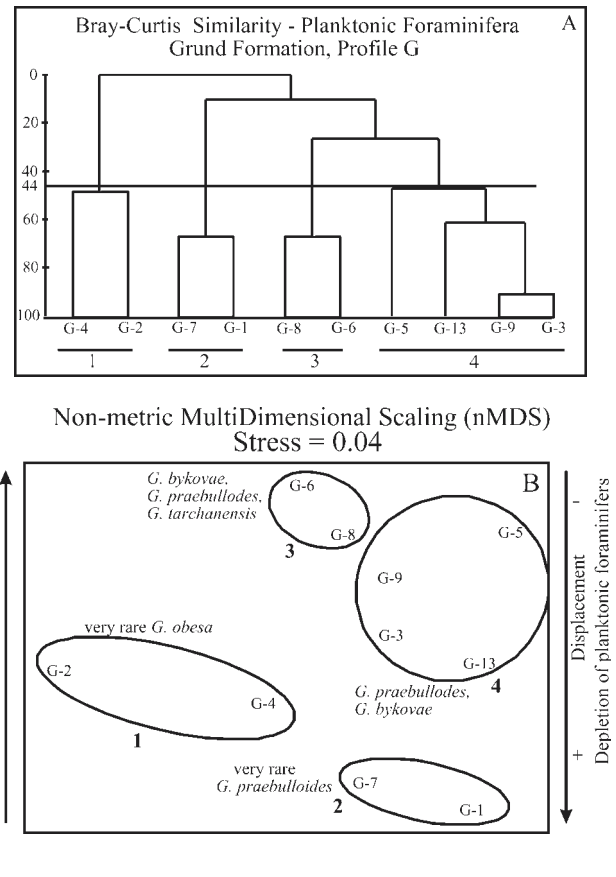


Fig. 4. **A** — Hierarchical agglomerative clustering based on the Bray-Curtis Similarity, and **B** — non-metric MultiDimensional Scaling (nMDS) plot of planktonic foraminifers from Profile G.

and their ecology can provide important information to characterize the sediments in term of displacement and reworking.

Combining the ecological data reported in the literature and partially summarized in Rögl & Spezzaferrri (2003), with the distribution patterns of benthic and planktonic foraminifers (Table 1) and the statistical parameters (Tables 2–3), allows us to reconstruct the paleoenvironments in which the sediments from Profile G (Grund Formation) were deposited.

Benthic foraminifers

Cluster 1 includes Samples G-6, G-8 and G-9 collected from the thin pelitic layers and is characterized by infaunal elements consisting of *Caucasina*, *Pappina*, *Bolivina* and *Bulimina* (Tables 1, 2) which are very rare in the other clusters. The *Uvigerina* group is also present in this cluster but not abundant (Table 1). Kaiho (1994) considers *Uvigerina* spp. and *Lenticulina* spp. as suboxic indicators of Group B (between the extremes of oxic and dysoxic) and *Bulimina* as suboxic indicators of Group C (between group B and dysoxic indicators). Since the genus *Caucasina* is morphologically and phylogenetically related to the *Bulimina* group, specimens belonging to this genus are here retained as suboxic indicators of Group C. On the contrary Kaiho (1994) includes bolivinids in

the dysoxic indicators group. Oxidic indicators such as *Cibicides* and *Hanzawaia boueana* are scarce in this cluster (Average abundance = 12.33 % and 7.67 % respectively). Almost all the taxa identified in this cluster are mud-preferring species (Rögl & Spezzaferri 2003). Therefore, this cluster represents the autochthonous sediments deposited on a suboxic to dysoxic sea floor with oxygen-depletion down to the first centimeters of the sediments.

Cluster 2 (Samples G-7, G-11, G-12, G-13 and G-14) is characterized by high abundance of shallow-water elements like the *Ammonia* and *Elphidium* groups. Their contribution to the total average similarity is up to 64.7 %. *Amphistegina* spp. (also shallow-water species) is present and displays an average similarity of 4 %. *Lenticulina* spp. (Suboxic species B) is relatively abundant and contributes 10.15 % of the average similarity within this cluster. *Caucasina*, *Bulimina* and *Bolivina* belonging to the Suboxic Group C are very rare (Table 2). This cluster includes samples collected from coarse sediments with high abundance of probably transported shallow-water species. The absence of molluscs in these layers may indicate deposition during the terminal phase of storm events.

Cluster 3 (Samples G-1, G-2, G-3, G-4, and G-5) is very similar to Cluster 2 and is characterized by the highest abundance of shallow-water elements such as *Ammonia*, *Elphidium*, *Asterigerinata* groups. Their contribution to the total average similarity is 66.04 %. *Amphistegina* spp. is present and displays an average similarity of 8.4 %. *Lenticulina* spp. contribute 7.17 % of the average similarity within this cluster (Table 2). The difference between Clusters 2 and 3 is the highest abundance in Cluster 3 of *Caucasina*, *Bulimina* and *Bolivina* belonging to the Suboxic Group C. This Cluster includes samples from the levels containing high abundances of molluscs and plants (Table 1, Fig. 1) and possibly represents molluscan and plant debris at the base of the tempestites layers.

These observations allow us to interpret the non-metrical MultiDimensional Scaling (nMDS) plot and to identify the displacement gradient subtending the samples (Fig. 3B). The gradient representing the bottom water oxygenation could not be clearly identified as a result of secondary oxygenation due to remobilization of sediments during storm events. Sample G-12 (Cluster 2) roughly corresponds to a level where the bivalve *Thyasira michelottii* was found in life position (Fig. 2). This species is currently interpreted as having a chemosymbiotic mode of life by comparison with the ecology of modern thyasirid bivalves (Tyson & Pearson 1991). Zuschin et al. (2001) interpreted the sediments from Profiles C–E as a dysaerobic biofacies on the basis of the occurrence of a monospecific macrofauna consisting of *Thyasira michelottii* in life position within bioturbated clay-silt sediments. On the basis of these data, Sample G-12, but also the other samples from Cluster 2 collected near the thyasirid horizon, should include high abundance of dysoxic indicators. However, in these samples, benthic foraminifers do not show evidence of strong oxygen depletion. On the contrary low oxygen-preferring species are less abundant in Cluster 2 (and in Sample G-12) than in Clusters 1 and 3. To explain this paradox, three interpretations are suggested: (1) bottom waters were only slightly suboxic. *Thyasira michelottii* was searching through the sedi-

ments for short-life pockets of sulphide material which is unstable in the presence of oxygen. This search explains the conspicuous tunnel-burrow-system which could be extended up to 300 mm into the sediments (Zuschin et al. 2001). The bivalve monospecific assemblage was due to currently unknown environmental conditions preferred by thyasirid but unsuitable for other molluscan taxa. (2) Dysoxic condition dominated the sea floor but dysoxic benthic foraminiferal indicators were removed or diluted by other processes (e.g. bioturbation and/or storm events). Occurrence of infaunal dysoxic indicators like bolivinids and buliminids in Clusters 1 and 3 together with the occurrence of deformed specimens of *Ammonia* spp., throughout the section (Fig. 5), may support the interpretation of dysoxia also in shallower water. In fact, in the presence of environmental stress like anoxia benthic foraminifers may produce abnormal and deformed shells in foraminifers (e.g. Yanko et al. 1994). (3) The dysoxic layer in which the thyasirid bivalves proliferated was very thin and is not represented in the studied samples.

Planktonic foraminifers

Clusters 1 and 2 (Samples G-2 and G-4; and G-1 and G-7) are characterized by the *Globigerinella obesa* (temperate-water indicator) and *Globigerina praebulloides* groups (cool-water indicators) respectively. Their contribution of up to 100 % to the average similarity is an artifact due to the scarcity of planktonic foraminifers in the samples. Cluster 3 (Samples G-6 and G-8) is characterized by *Globorotalia bykova*, *G. praebulloides* groups and *Globigerina tarchanensis*. *Globorotalia bykova* is considered a warm-temperate indicator. Its contribution to the average similarity within this Cluster is 41.38 %. *Globigerina praebulloides* and *G. tarchanensis* may indicate increased nutrient input (e.g. Rögl & Spezzaferri 2003).

Cluster 4 (Samples G-3, G-5, G-9 and G-13) is characterized by *G. praebulloides* group with contribution to the average similarity of 54.91 %. *Globorotalia bykova* is also abundant.

Due to the scarcity of planktonic foraminifers in the samples from Profile G the identification of the paleoclimate is only tentatively done (left side of Fig. 4B). The relatively warmer paleoclimate apparently occurred in Grund in the interval from Sample G-3 to G-13. The displacement and depletion of planktonic foraminifers gradients are more clearly identified as at the right side of Fig. 4B. However, the absence of planktonic foraminifers in samples G-10, G-11, G-12 and G-14 prevents a fully reliable interpretation of the data set.

Biostratigraphy

The biostratigraphy of the studied portion of the Grund Formation is based on the standard zonation for the Paratethys (see e.g. Rögl et al. 2002 for a synthesis). Although planktonic foraminifers are scarce in the analysed samples, the presence of *Praeorbulina glomerata circularis* in Samples F-6 (Profile F) and G-9 (Profile G) from the pelitic layers (Fig. 5), enable the correlation with the Early Badenian (Langhian–Middle Miocene). The occurrence of *Uvigerina macrocarina*-

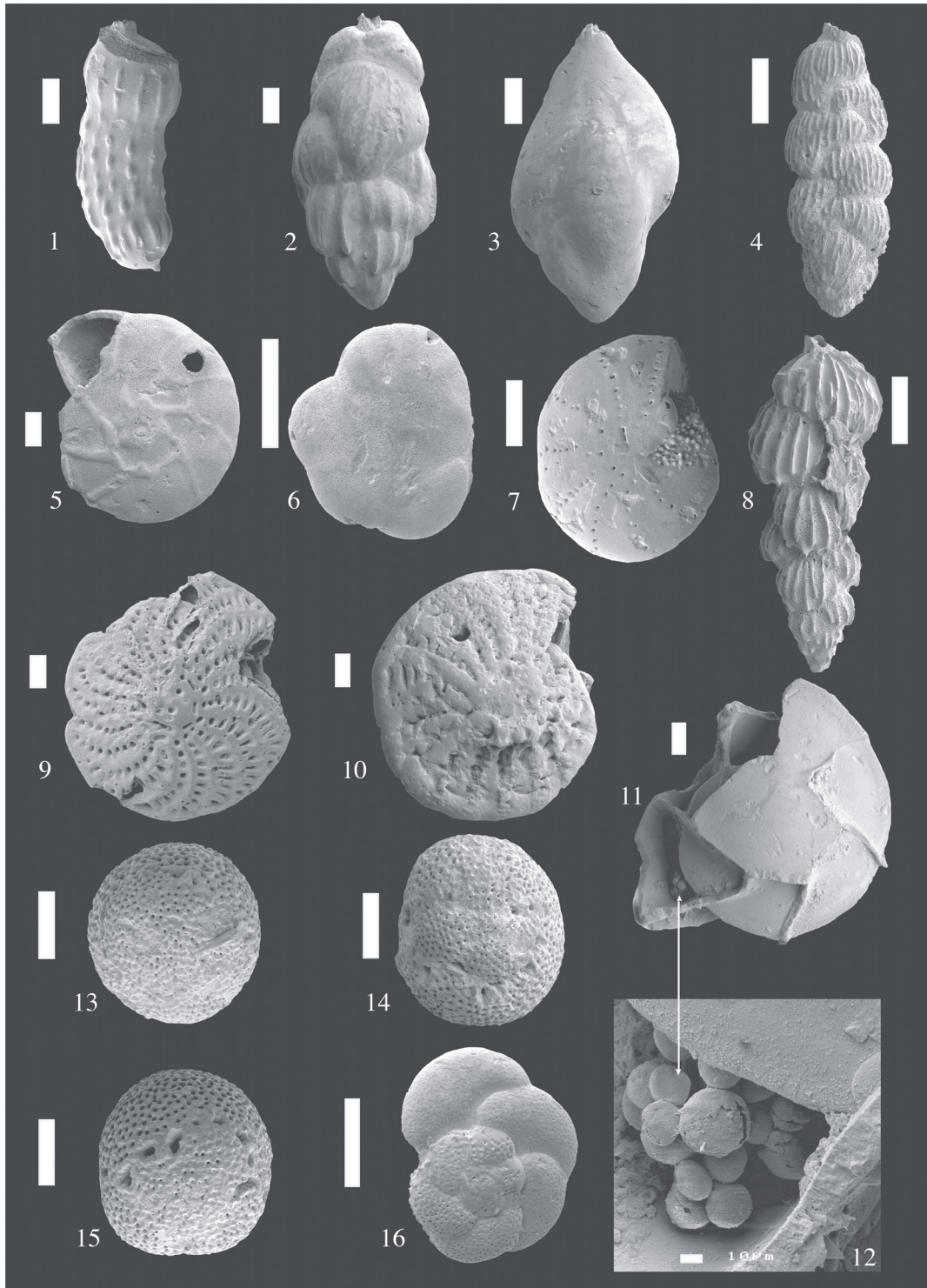


Fig. 5. 1 — *Marginulina hirsuta* d'Orbigny. Sample G-1. Magnification $\times 100$. 2. — *Uvigerina macrocarinata* Papp et Turnovský. Sample F-10. Magnification $\times 100$. 3 — *Guttulina austriaca* d'Orbigny. Sample F-10. Magnification $\times 100$. 4 — *Pappina primiformis* (Papp et Turnovský). Sample F-10. Magnification $\times 150$. 5 — *Ammonia viennensis* (d'Orbigny). Sample G-11. Magnification $\times 70$. Broken specimen. 6 — *Ammonia tepida* (Cushman). Sample G-9. Magnification $\times 250$. Deformed specimen. 7 — *Elphidiella minuta* (Reuss). Sample G-1. Magnification $\times 150$. 8 — *Uvigerina graciliformis* Papp et Turnovský. Sample G-9. Magnification $\times 150$. 9 — *Elphidium crispum* (Linné). Sample G-11. Magnification $\times 70$. Broken specimen. 10 — *Elphidium flexuosum* (d'Orbigny). Sample G-13. Magnification $\times 70$. Broken specimen. 11 — *Lenticulina inornata* (d'Orbigny). Sample G-11. Magnification $\times 70$. Broken specimen. 12 — *Lenticulina inornata* (d'Orbigny). Sample G-11. Magnification $\times 600$. Particular of a broken chamber. Visible are rounded elements that resemble gametes. 13 — *Praeorbulina glomerosa circularis* (Blow). Sample F-6. Magnification $\times 150$. 14 — *Praeorbulina glomerosa circularis* (Blow). Sample F-6. Magnification $\times 150$. 15 — *Praeorbulina glomerosa circularis* (Blow). Sample G-9. Magnification $\times 150$. 16 — *Globorotalia bykovae* (Aisenstat). Sample G-6. Magnification $\times 200$. Scale bars = 100 μm .

ta, index species of the Lower Lagenidae Zone (Papp & Turnovský 1953) in Sample F-10 (Profile F) support this age attribution (Fig. 5). An Early Badenian age is also indicated by the presence of *Bolboforma reticulata* (protophyta incertae sedis) in Sample G-8 (Spezzaferri & Rögl in print). This event is calibrated with the time scale of Berggren et al. (1995) and equated to Zone NN5 of Martini (1971) by Spiegler & Gürs (1996).

Nannofossil assemblages indicate a Badenian age (Zone NN5) for the excavated sections based on the presence of *Helicosphaera waltrans*, as also in Cicha (1999) and Švábenická & Čtyroká (1999).

Summary and conclusion

— This study contributes to solving the debate about the age of the Grund Formation. Foraminiferal analyses suggest a Badenian age (Langhian–Middle Miocene), for the sediments recovered from profiles excavated by the Institute of Paleontology, University Vienna. In particular, the presence of *P. glomerata circularis* and *U. macrocarinata* enable the correlation with the Lower Lagenidae Zone.

— Massive re-deposition processed possibly due to stormy events displaced shallower-water sediments into the deeper parts of the basin as indicated by mixing of abundant and generally broken shallow-water species like *Ammonia*, *Elphidium*, *Asterigerinata* groups, and *Amphistegina* spp. with better preserved deeper-water species. The high abundance of broken shallow-water specimens (Fig. 5) testifies to the intense re-deposition.

— Different phases in the storm events can be identified combining micro- and macrofauna. Coarse bioclasts (dominantly molluscs) dominate at the base of the tempestites layers indicating the strongest pulse of the stormy event. Finer elements like foraminifers dominate in the middle part and at the top, indicating decreased intensity.

— Paleodepth estimation based on benthic foraminiferal assemblages indicates that the sediments from Profile G were deposited in the outer shelf.

— A relatively warm paleoclimate characterized the interval of the deposition of the sediments from Profile G at least from Sample G-3 to G-13 based on the presence of warm-water indicators such as *Globorotalia bykova* and *P. glomerata circularis*. The scarcity of planktonic foraminifers, however, prevents a more reliable and detailed interpretation of data.

— The oxygenation of the bottom waters is difficult to assess. Dysoxic episodes in sediments with chemosymbiotic bivalves living with anaerobic bacteria are not identified based on benthic foraminiferal assemblages.

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