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Foraminiferal paleoecology and biostratigraphy of the Mühlbach section (Gaindorf Formation, Lower Badenian), Lower Austria

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(With 4 textfigures, 5 tables and 12 plates)

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Abstract

Continental vertebrate faunas are generally very scarce in marine sequences. Therefore, the investigation of the foraminiferal fauna in the Middle Miocene Gaindorf Formation at Mühlbach (Molasse Basin, Lower Austria) was a prerequisite to clarify the sedimentary conditions and the biostratigraphy of these sediments. Statistical methods were used to investigate the paleoecology of the microfauna and to unravel the sedimentary processes which account for the unusual accumulation of vertebrate remains in the basin. Our investigation revealed that muddy sedimentation occurred in water depths ranging from the outer shelf to upper bathyal. The sea-floor was slightly disoxic. A more oxygenated environment apparently occurred in those levels where vertebrate remains are abundant. This observation is consistent with the interpretation involving the transport of coarser material from the land and consequent re-mobilization and oxygenation of the sediments. In the levels without large amounts of vertebrate remains, only the finest fraction of the sediments is displaced.

The benthic foraminiferal fauna at Mühlbach suggests cool bottom waters, whereas the planktonic fauna generally indicates warmer temperature. The highest thermal gradient is inferred for the upper part of the sedimentary sequence, which also contains the best-developed microfauna. The mass occurrence of small, five-chambered globigerinids may reflect an upwelling of cool water currents but can also be explained by enhanced nutrient input from the continent.

The presence of *Praeorbulina glomerosa circularis* transitional to *Orbulina suturalis* indicates that the sediments from the Mühlbach section belong to the top of planktonic foraminiferal Zone M5b/Mt5b. These sediments can also be attributed to the Lower Lagenidae Zone (regional zonal subdivision based on benthic foraminifera) from the Early Badenian-Middle Miocene based on the occurrence of *Uvigerina macrocarinata*. Comparative investigations revealed that the lower part of the Gaindorf Formation lies within Zone M5b based on the occurrence of *Po. glomerosa circularis* s.str. The upper part of the formation containing *O. suturalis* is attributed to Zone M6.

Zusammenfassung

Das Vorkommen von kontinentalen Säugetierfauna in hochmarinen Sedimenten ist äußerst selten. Daher wurde bei der Bearbeitung der Lokalität Mühlbach am Manhartsberg in der niederösterreichischen Molasse der gleichzeitig vorhandenen Foraminiferenfauna genauere Beachtung geschenkt. Die Fundstelle liegt in

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der Gaindorf Formation. Mit Hilfe paläoökologischer, statistischer Methoden wurden die Ablagerungs- und Umweltbedingungen der einzelnen Sedimentschichten analysiert, in deren Verband die Säugetierreste aufgefunden wurden. Weiters wurde mit Hilfe einzelner, biostratigraphisch wichtiger Arten eine genaue stratigraphische Einstufung vorgenommen.

Die Ablagerung erfolgte in größerer Wassertiefe, am äußeren Schelf bis oberen Bathyal, in Schlammfazies. Die Sauerstoffbedingungen am Boden sprechen für schwach dysoxische Verhältnisse, mit besserer Durchlüftung in den Schichten, in denen die Säugetierreste eingelagert sind. Dies spricht für turbulente Bedingungen während des Eintrags von gröberem Sediment, der auch Material vom Kontinent erfaßte. Umlagerungs- und Transportvorgänge in den anderen Schichten betreffen nur Feinmaterial.

Die benthische Foraminiferenfauna weist auf kühles Bodenwasser hin. Im Vergleich mit der planktonischen Vergesellschaftung läßt sich ein deutlicher Temperaturgradient mit warmem Oberflächenwasser erkennen. Der Temperaturunterschied in der Sektion Mühlbach ist am höchsten in den obersten Sedimentschichten mit der reichsten Fauna. Das Massenvorkommen kleiner, meist fünfkammeriger Globigerinen spricht einerseits für up-welling von kühleren Strömungen, kann aber auch in Zusammenhang mit erhöhter Nährstoffzufuhr vom Festland gesehen werden.

Biostratigraphisch läßt sich die Sedimentabfolge von Mühlbach durch die Übergangsformen zwischen *Praeorbulina glomerosa circularis* und *Orbulina suturalis* am top der Planktonzone M5b/Mt5b (*Praeorbulina glomerosa* sensu stricto - *Orbulina suturalis* Interval Subzone) einstufen. In der regionalen Gliederung wird die Fundstelle mit Hilfe von *Uvigerina macrocarinata* in die Untere Lageniden-Zone des Unteren Badenium (Mittel Miozän) eingestuft. Vergleichsuntersuchungen zeigen, dass der tiefere Teil der Gaindorf Formation in einem Bereich der M5b liegt, in dem nur *Po. glomerosa circularis* vorkommt. Die jüngeren Anteile der Formation liegen durch den Nachweis von *O. suturalis* s.str. in der Zone M6.

Key words: Foraminifera, paleoenvironment, water temperature, sedimentary conditions, biostratigraphy, Gaindorf Formation, Early Badenian, Middle Miocene, Austria, Central Paratethys

Introduction

The section Mühlbach is located at the western side of the Alpine-Carpathian Foredeep in Lower Austria, north of the Danube (Fig. 1). During the early part of Middle Miocene the Paratethys Sea transgressed northwestward, out of the Vienna Basin into the Alpine-Carpathian Foredeep. The sea extended to the front of the Bohemian Massif, bordered to the south by the rising Alpine chain, and followed the foredeep to the northeast in Moravia and Poland. A detailed description of the geological position of the outcrop is given by ROETZEL 2003 (this volume).

The fossiliferous sediments belong to the Gaindorf Formation, a western equivalent of the Grund Formation. The Gaindorf Formation was described by ROETZEL et al. (1999) as consisting predominantly of sand and gravels with intercalated pelites. The microfauna is characterized by a rich calcareous benthic assemblage and the planktonic index fossils *Praeorbulina glomerosa circularis* and *Orbulina suturalis* (CICHA 1999). Southward the Gaindorf Formation interfingers with the submarine fan of the Hollenburg-Karlstetten Formation.

The main topic of the research at the Mühlbach locality concerned a rich assemblage of microvertebrates occurring in marine sediments. In particular, samples Mü1, Mü2 and to a lesser extent M4 (Fig. 2) contain vertebrate remains together with land gastropods. Foraminiferal investigations were aimed at clarifying the depositional setting and at providing biostratigraphic information about the sediments. Additionally, the excellent preservation of the rich foraminiferal fauna allowed a detailed documentation, which clarified the taxonomic position of some benthic species.

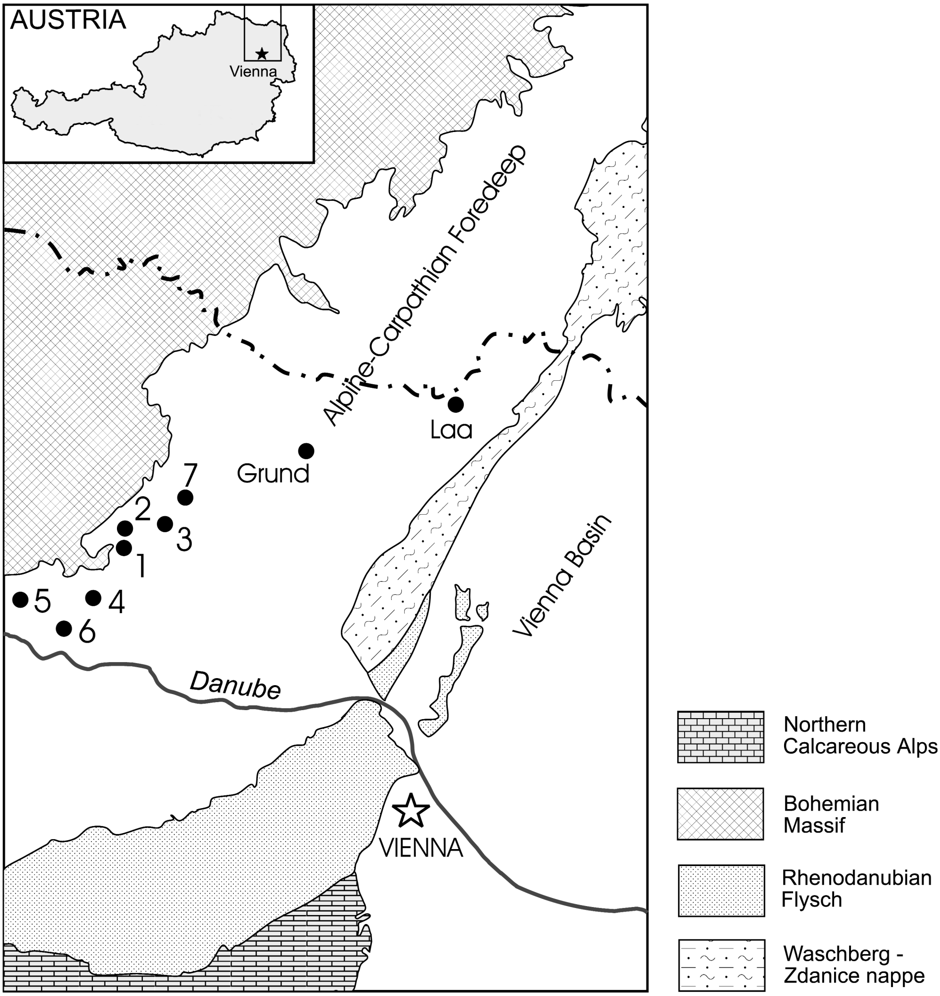


Fig. 1: Geological sketch of the Alpine-Carpathian Foredeep in northeastern Austria, and position of investigated sites (redrawn acc. KREUTZER 1993). Locations: 1 Mühlbach am Manhartsberg, 2 Zemling, 3 Pfaffstetten, 4 Grubgraben near Strass, 5 drill site NÖ-06 Gneixendorf, 6 drill site NÖ-07 Diendorf near Hadersdorf am Kamp, 7 Gaindorf.

Methods and Sample Description

The Mühlbach section is a small construction site for a water supply station. The sedimentary succession is tectonically disturbed and faulted. Samples were taken by R. ROETZEL from the opposite east and west walls of the excavation (Fig. 2 acc. to ROETZEL 2003) and correlated by the occurrence of distinct horizons with calcareous concretions.

The lowermost part of the section consists of blue-grey to light-grey silty, non-calcareous clay (samples Mühlbach M3, M7, M8). The residue consists of fine angular quartz, mica, some crystalline grains, and partly of a larger amount of black pyrite concretions.

Rare fish remains, some organic walled spheres, and very few sponge spicules form the autochthonous microfossil content. Very scarcely reworked foraminifera and few recrystallized radiolarians probably originate from the Alpine-Carpathian Flysch units. One specimen of *Globigerinoides trilobus* seems to be a contaminant.

The following sequence of samples comes from blue-grey, calcareous clayey and sandy silts and fine sands, which follow concordantly on top of the non-calcareous clays. Below sample Mühlbach M6 the bed contains a layer with *Mytilus* shells and plant debris. The residue of the sample consists of angular, rarely rounded quartz, mica, crystalline grains, mollusc and bone fragments, few echinoid spines, and a fairly rich foraminiferal fauna. The next higher bed has a distinct layer of carbonate concretions on top, and the sandy sample Mühlbach M5 within this layer yields some mollusc and vertebrate fragments. The microfauna is fairly rich, with large lenticulinas and a high number of *Nonion*. Rare bolboformas, ostracods, and some echinoid spines occur. The vertebrate horizon (sample Mühlbach Mü2) lies in a bed between two concretion layers, south of a distinct fault. From this vertebrate horizon, micro-sample Mühlbach M4 was collected. The microfauna of vertebrate sample Mü2 is similar to that of M4. The vertebrate sample Mü1 comes from the opposite, western wall of the outcrop and is correlated with bed Mü2 by the lower layer of calcareous concretions. The foraminifera in this sample show transport and reworking, partly by brown encrustations and whitish recrystallized preservation, and by stronger corrosion of tests. The assemblage is generally similar to Mü2.

Directly above the concretion horizon of the west wall, follows sample Mühlbach M2. The residue consists of angular quartz, mica, crystalline grains, and carbonate sand. Debris of molluscs, serpulids, and echinoid spines are common. The foraminiferal assemblage is dominated by lenticulinas and small globigerinas. The highest sample in the section represents Mühlbach M1 with a sandy residue of quartz, crystalline particles and mica, and a very rich benthic foraminiferal fauna.

Comparative samples (Fig. 1) come from the Gaindorf Formation of surrounding areas, e.g., from the water supply line, north of the village Mühlbach. The assemblage is dominated by *Globobulimina* and *Nonion commune*; small globigerinas are common, *Globigerinoides trilobus, Globorotalia bykovae*, and *Tenuitella selleyi* occur. Locality Zemling is about 1.5 km north of Mühlbach and is dominated by *Lenticulina* and *N. commune; Amphicoryna badenensis, Myllostomella*, and *Siphonodosaria* are common; only few small globigerinas with *G. bykovae* are present. Basinward, samples from Pfaffstetten are similar, with a dominance of *Globobulimina*, common bolivinas, *Caucasina, N. commune, A. badenensis, Amphimorphina haueriana, Heterolepa praecincta*, and *Spirorutilus carinatus*. Small globigerinas, *G. bykovae, Paragloborotalia mayeri, P. inaequiconica, T. selleyi*, and *Turborotalita quinqueloba* occur. From more to the south comes sample Grubgraben NW Strass. Dominant are *N. commune, Globobulimina*, caucasinas and bolivinas; the plankton is similar to the above samples. Also here, as in the other samples, orbulinas are missing.

Some prospection wells in the Krems embayment, in the south to southwest, encountered the Badenian transgression. In well NÖ-07 (Diendorf, near Hadersdorf am Kamp) coarse marine gravels, probably Hollenburg-Karlstetten Formation, cover Oligocene limnofluvial lignite formations at 281.20m drill depth. Intercalated pelitic layers contain

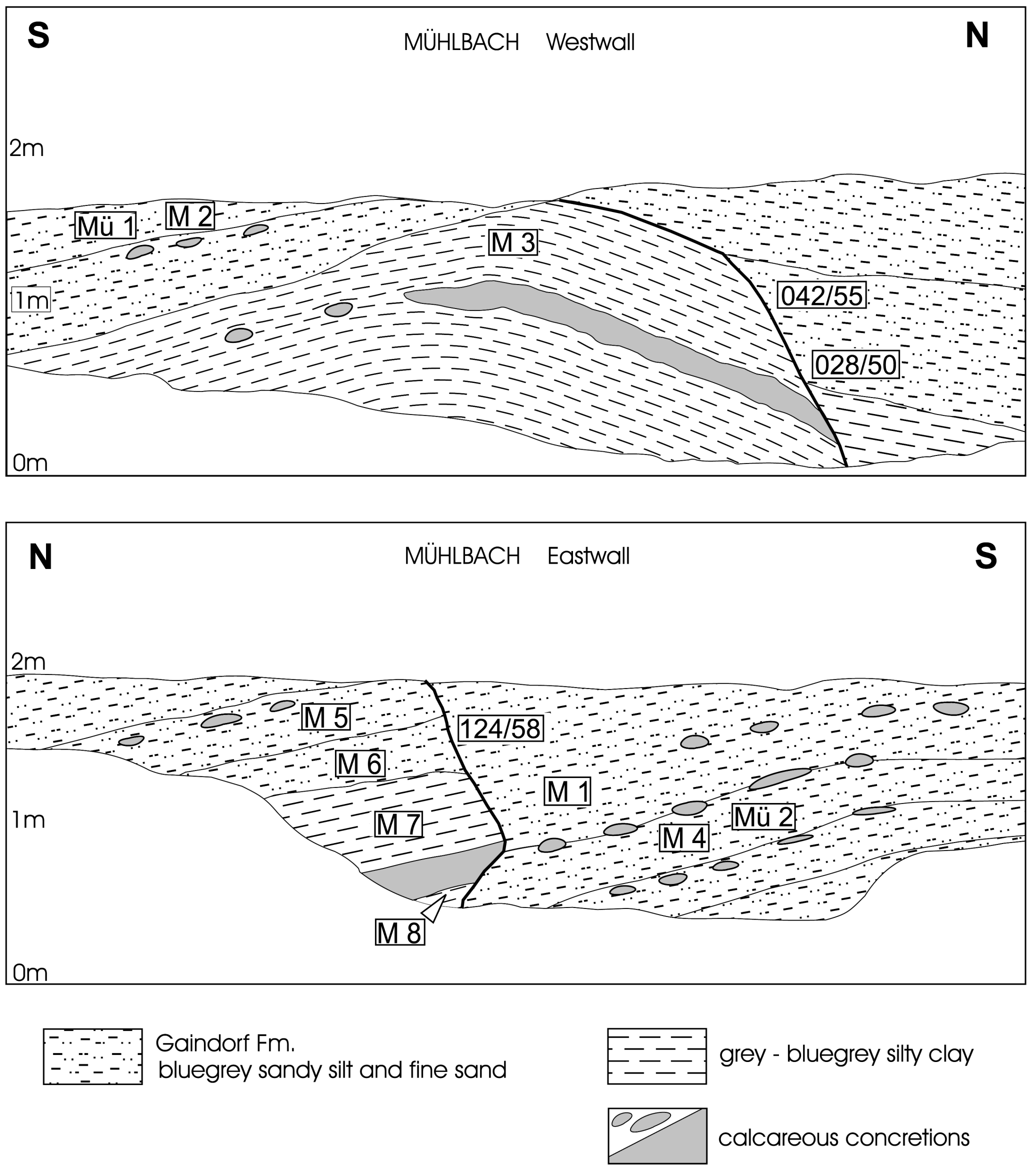


Fig. 2: Sketch of outcrop Mühlbach am Manhartsberg, with location of samples (according to field book of R. ROETZEL, Austrian Geological Survey, Vienna).

Globigerinoides quadrilobatus, Globoquadrina cf. *altispira, G. bykovae*, and *Uvigerina grilli*. In well NÖ-06 (Gneixendorf) the transgressive gravel bed lies on crystalline basement at 126.80m. The lowermost investigated sample from silty marls at 104.80m contains *Praeorbulina glomerosa circularis, Gs. quadrilobatus, Gq.* cf. *altispira,* and *G. bykovae*.

Micropaleontological analyses were carried out on the samples of the Mühlbach section to clarify the depositional setting. Samples were washed through a 63 µm mesh sieve. Benthic and planktonic foraminifera were counted from a split of the obtained residue. The remaining part of the residues was investigated for rare species. The lithology and other microfossil groups have been studied for correlation of samples.

Micropaleontological Investigation

Benthic and planktonic foraminiferal assemblages from the Mühlbach section are abundant, rich and well preserved throughout. Only samples M3, M7 and M8 yield depleted assemblages. A total of about 135 benthic and 37 planktonic species have been identified. Additionally, the excellent preservation of the rich fauna provides the opportunity to discuss taxonomic problems of some species. Some taxonomic comments are given in Appendix 1.

Table 1 shows the distribution of benthic foraminifera at Mühlbach. Remarkable is the benthic foraminiferal assemblage observed in sample M1. It consists of abundant *Sphaeroidina bulloides*, which is generally absent in the remaining samples. *Amphicoryna* spp., bolivinids, *Cibicidoides ungerianus, Heterolepa praecincta,* and *Lenticulina* spp. are rarer in the remaining samples. Rare, clearly reworked benthic specimens include *Ammodiscus* cf. *cretaceous, Hyperammina* sp., and *Psammosphaera fusca*.

Table 2 shows the distribution of planktonic foraminifera at Mühlbach. Remarkable also here is the planktonic foraminiferal assemblage observed in sample M1. It includes more abundant warm-water taxa like *Globigerinoides, Praeorbulina, Globorotalia,* and *Globoquadrina* cf. *altispira* than do the remaining samples. Sample M2 contains the highest abundance of the cool-water taxon *Globigerina ottnangiensis*. Rare reworked planktonic specimens include the Oligocene-Early Miocene species *Cassigerinella globulosa*, the Paleocene species *Igorina pusilla,* and the Cretaceous *Pseudotextularia* sp. and *Hedbergella* sp.

Biostratigraphic Results

In the section Mühlbach, sample M1contains only scarce orbulinids. The evolutionary stage of *Praeorbulina glomerosa circularis* is at the transition to *Orbulina suturalis*. The sutural apertures still form half-circular openings with a distinct lip, but on the surface of the encircling final chamber the first few additional apertures appear. This transition has been observed in other Early Badenian localities of the Central Paratethys, e.g. Styrian Basin or Lapugiu de Sus (Lapugy) in the Transylvanian Basin, where species attribution to *O. suturalis* can be difficult. Comparing the ranges of the *Orbulina* lineage (Berggren et al. 1995), this level falls into the top of Zone M5b, as the base of M6 is defined by the first appearance of *O. suturalis* s.str.

Other components of the planktonic assemblage are also typical for Early Badenian: *Globigerinoides quadrilobatus, Globoquadrina* cf. *altispira, Paragloborotalia mayeri, Globorotalia bykovae*. The mass occurrence of *Globigerina ottnangiensis* is characteristic of the Early Miocene, but has been observed in the Early Badenian of the Styrian Basin (Rögl et al. 2002).

In the local ecostratigraphy and benthic foraminiferal zonation, uvigerinas are important tools. Species of this genus are extremely rare in the studied samples. Most important for a definition of the Lower Lagenidae Zone (PAPP & TURNOVSKY 1953, PAPP 1963) is the first occurrence of *Uvigerina macrocarinata*, which has been found in sample M5. The range of *Uvigerina graciliformis* was formerly considered to be Karpatian only, but has now been verified to continue upward into the Early Badenian. This also concerns Grund, the type locality of this species which already lies in nannoplankton zone NN5 (RÖGL et al. 2002). Similarly, also *Pappina breviformis* and *P. primiformis* were once considered more indicative for the Karpatian. Otherwise, already PAPP & TURNOVSKY (1953) believed in a longer range of these species. Typical Lower Lagenidae Zone species such as *Vaginulina legumen, Planularia lanceolata,* or *Lenticulina echinata* are missing in Mühldorf, probably due to the ecological conditions.

Ecology of planktonic foraminifera

The ecological preferences of Paratethyan planktonic foraminifera are herein retained following SPEZZAFERRI (1995) and SPEZZAFERRI & CORIC (2001). The *Globigerinoides, Globoquadrina* cf. *altispira, Praeorbulina-Orbulina, Paragloborotalia,* and *Globorotalia* groups are considered to be warm-water indicators. *Globigerina, Globoturborotalita, Tenuitellinata, Tenuitella, Globigerinita*, and *Turborotalita* groups are considered to be cool-water indicators. *Globigerina concinna-G. diplostoma* and *Globigerinella regularis* groups are considered herein to be temperate-water indicators. Following SPEZZAFERRI et al. (subm.) we also consider the small, five-chambered globigerinids such as the *G. tarchanensis-G. ottnangiensis* group to be species that prefer high productivity.

Ecology of benthic foraminifera

The ecology of benthic foraminifera is herein retained following MURRAY (1991), KAIHO (1994), JONES (1994), BASSO & SPEZZAFERRI (2000), and SPEZZAFERRI & CORIC (2001, see for further information) among others. A summary of the paleoecological preferences of the most relevant benthic foraminifera from the Mühlbach Section is shown in Tab 3.

Statistical Treatment

To identify the biological relationship between the samples from the Mühlbach section in the temporal framework of sediment deposition, we have treated the data statistically. Statistical testing in this context enables identification and characterization of changes in community structures through time and permits them to be related to changing environmental conditions (CLARKE & WARWICK 1994).

Species with phylogenetic affinities and similar environmental significance were grouped to better interpret the distribution patterns. Multivariate statistics was applied to quantitative data using the Software PRIMER 5 (Plymouth Marine laboratory). Application of this method on planktonic and benthic foraminifera is extensively discussed in BASSO & SPEZZAFERRI (2000), SPEZZAFERRI & CORIC (2001), and SPEZZAFERRI

Tab. 1: Distribution and abundances of benthic foraminifera in the Mühlbach Section.

	M1	M2	Mü1	Mü2	M4	M5	M6	M3	M7	M8	Rew.
Ammodiscus cf. cretaceus (Reuss)										1	r
Hyperammina sp.								1			r
Martinottiella communis (d'Orbigny)	7										
Psammosphaera fusca Schultze						1					r
Semivulvulina pectinata (Reuss)		3	7	2	1						
Siphotextularia sp.	1										
Textularia spp.	1		1	1							
Sigmoilopsis celata (Costa)			2		1		1				
Quinqueloculina sp.				1							
Allomorphina trigona Reuss	1		1	1							
Ammonia cf. beccarii (Linne)	10			1	1	6					
Ammonia pseudobeccarii (Putrja)	9	3	10	14		17	9				
Ammonia tepida (Cushman)	9	5	8	5	4		11				
Ammonia viennensis (d'Orbigny)	21	8	13	9	7	20	11				
Amphicoryna badenensis (d'Orbigny)	29	4	3	8	8	5	4				
Amphicoryna hispida (d'Orbigny)	17		1								
Amphimorphina haueriana Neugeboren		1			2	2	2				
Angulogerina angulosa (Williamson)	12	1	4	1	2	9	3				
Asterigerinata planorbis (d'Orbigny)			1								
Astrononion stelligerum (d'Orbigny)	2										
Aubignyna brixi Rögl			1								
Baggina arenaria (Karrer)						1					
Bolivina antiqua d'Orbigny	1										
Bolivina dilatata brevis Cicha & Zapletalova	4	10	7		5	29	19				
Bolivina dilatata dilatata Reuss	9	13	7	3	6	19	15				
Bolivina hebes Macfadyen	20	5	10	4	2	1	1				
Bolivina cf. lowmani Phleger & Parker	10	4			8	14	11				
Bolivina sagittula Didkovskyi	10	2				5	8				
Bolivina aff. simplex Phleger & Parker	2	2		1	1	5	1				
Bulimina rostrata Brady	1										
Bulimina striata mexicana Cushman	1	3	3	4	1						
Bulimina striata striata d'Orbigny	5	2	4	2	1						
Cancris auriculus (Fichtel & Moll)	1										
Cassidulina laevigata - C. carinata	17	20	8	2	12	20	17				

	M1	M2	Mü1	Mü2	M4	M5	M6	M3	M7	M8	Rew.
Caucasina cylindrica Zapletalova			4	1	2	15	10				
Caucasina elongata (d'Orbigny)	21	3		2	7						
Caucasina schischkinskayae Samoylova	4	18	9	6	7	28	14				
Caucasina subulata (Cushman & Parker)	9				3		2				
Ceratocancris haueri (d'Orbigny)	2		4	4	5						
Charltonina sp.	1					2					
Chilostomella ovoidea Reuss			1	1	1	1					
Cibicidoides spp.	6	2	2	2	3	1	3				
Cibicidoides austriacus (d'Orbigny)	1										
Cibicidoides lopjanicus (Myatlyuk)							5				
Cibicidoides ungerianus (d'Orbigny)	11	2	6	4	2	2	6				
Dentalina acuta d'Orbigny	6		1								
Dentalina beyrichana Neugeboren	1										
Dimorphina akneriana (Neugeboren)	6		2	4	1		1				
Discorbinoides sp.				1							
Elphidium advenum Cushman	2										
Elphidium cf. angulatum (Egger)	2										
Elphidium reussi Marks	2			1							
"Eponides" pusillus Parr	3	3				2					
Fursenkoina acuta (d'Orbigny)	5	4	3	3	1	12	4				
Globocassidulina globosa (Hantken)		1									
Globocassidulina oblonga (Reuss)	1	1									
Globocassidulina subglobosa (Brady)	2	2				3					
Globobulimina pupoides (d'Orbigny) s.l.	22	10	5	5	18	7					
Globobulimina pyrula (d'Orbigny)	19	7	2	4	10	21	1				
Globulina gibba d'Orbigny	1										
Grigelis pyrula (d'Orbigny)	1	1					1				
Guttulina communis d'Orbigny	5										
Gyroidinoides octocameratus (Cushman)	3				1	5	3				
Gyroidinoides soldanii (d'Orbigny)	1	1		2		1	4				
Gyroidinoides umbonatus (Silvestri)	3	2			2	5	3				
Hanzawaia boueana (d'Orbigny)	1										
Hemirobulina eximia (Neugeboren)	1										
Hemirobulina glabra (d'Orbigny)	4		1		1						

Tab. 1 (cont.)

	M1	M2	Mü1	Mü2	M4	M5	M6	M3	M7	M8	Rew.
Heterolepa praecincta (Karrer)	59	10	16	11	22	20	21				
Heterolepa dutemplei (d'Orbigny)				6			3				
Hyalinonetrion elongatum (Ehrenberg)	1										
Islandiella puctata (Reuss)	1			1							
Lagena haidingeri (Czjzek)	1										
Laevidentalina badenensis (d'Orbigny)	2			1							
Laevidentalina elegans (d'Orbigny)	1	3		1		1					
Laevidentalina inornata (d'Orbigny)	2		1				1				
Lapugyina schmidi Popescu	5										
Lenticulina americana (Cushman)	8	3	4	12	5	12	6				
Lenticulina austriaca (d'Orbigny)	10	8	16	22	14	8	11				
Lenticulina calcar (Linne)	2			3							
Lenticulina cf. echinata (Soldani)	1										
Lenticulina inornata (d'Orbigny)	26	14	14	35	21	25	11				
Lenticulina melvilli (Cushman & Renz)	3		2	6	3	1					
Lenticulina meynae Vespermann	3	1				3					
Lenticulina obtusa (Reuss)	2		4	7	1	2					
Lenticulina orbicularis (d'Orbigny)	9										
Lenticulina peregrina (Schwager)	2										
Lenticulina spinosa (Cushman)	21	2	7	6	4	5	3				
Lenticulina sp.1	5	1		1	1						
Lenticulina sp. 2	2										
Lenticulina sp. 3	1			1			1				
Marginulina hirsuta d'Orbigny	1			2							
Melonis pompilioides (Fichtel & Moll)	5	3	7	6	8	6	6				
Myllostomella advena (Cushman & Laiming)	8	4		2	1		2				
Myllostomella recta (Palmer & Bermudez)	19	1		1	3		2				
Neugeborina irregularis (d'Orbigny)	4										
Neugeborina longiscata (d'Orbigny)	2	3	2	2		2					
Nodosaria rudis d'Orbigny						1					
Nonion commune (d'Orbigny)	17	35	14	22	19	59	55				
Nonionella turgida (Williamson)	1										
Nonionoides karaganicus (Krasheninnikov)	1					1	1				
Nonionoides ventragranosus (Krasheninnikov)			2								

	M1	M2	Mü1	Mü2	M4	M5	M6	M3	M7	M8	Rew.
Oridorsalis umbonatus (Reuss)			1	1							
Orthomorphina ? sp.	3	4		2	1	7	1				
Pappina primiformis (Papp & Turnovsky)	2										
Planularia moravica (Karrer)	1		1								
Plectofrondicularia digitalis (Neugeboren)	1	1									
Plectofrondicularia raricosta (Karrer)						1					
Porosononion granosum (d'Orbigny)	4	5	4	2	1	9	1				
Pseudoparrella exigua (Brady)	15	1			2	12	3				
Pseudosolenia lateralis carinata (Buchner)	2										
Pullenia bulloides (d'Orbigny)	18	8	7	8	6	7					
Pullenia quinqueloba (Reuss)	6										
Pyramidulina continuicosta (Schubert)			2								
Pygmaeoseistron hispidum (Reuss)	2										
Reussella spinulosa (Reuss)	5	1	9	3		2	1				
Saracenaria aureola (Karrer)					1	2					
Siphonodosaria consobrina (d'Orbigny)	29	17	8	23	6	17	1				
Siphonodosaria nuttalli gracillima (Cushman & Jarvis)	7	4	3	5	2						
Siphonodosaria scripta (d'Orbigny)	12	7	9	6	4	23	4				
Sphaeroidina bulloides d'Orbigny	74			3							
Spiroloxostoma czechoviczi (Kantorova)	4	4									
Stainforthia sp.	3	1				2					
Stilostomella cf. scabra (Reuss)	5	5	6	4	4	12	6				
Uvigerina acuminata Hosius	2		1			1					
Uvigerina cf. barbatula Macfadyen	1			1							
Uvigerina graciliformis Papp & Turnovsky	1		2	2		1					
Uvigerina grilli Schmid				4							
Uvigerina macrocarinata Papp & Turnovsky						1					
Uvigerina mantaensis Cushman & Edwards	1		1	2		1					
Uvigerina pygmoides Papp & Turnovsky			2	1							
Vaginulinopsis pedum (d'Orbigny)				1			1				
Valvulineria complanata (d'Orbigny)	11	12	12	4	14	21	5				
Virgulopsis tuberculatus (Egger)	8										
Total benthic foraminifera	779	301	288	318	268	524	316	1		1	

Tab. 2: Distribution and abundances of planktonic foraminifera in the Mühlbach Section.

	M1	**M2**	**Mü1**	**Mü2**	**M4**	**M5**	**M6**	**M3**	**M7**	**M8**	Rew.
Globigerina bollii Cita & Premoli Silva	5	9	3	7	4	2	1				
Globigerina bulloides d'Orbigny	21	17	12	6	9	10					
Globigerina concinna Reuss	2		1	3		3	2				
Globigerina diplostoma Reuss	6			2	3	4	2				
Globigerina dubia Egger			2								r
Globigerina cf. falconensis Blow	7	7	7	7							
Globigerina ottnangiensis Rögl	45	102	25	9	26	52	9				
Globigerina praebulloides Blow	15	13	19	6	16	11	3				
Globigerina tarchanensis Subbotina & Chutzieva	25	22	10	2	15	17	4				
Globigerinella regularis (d'Orbigny) s.l.	4	2	5	1		6	1				
Globigerinoides bisphericus Todd	4	2	2	3	1						
Globigerinoides quadrilobatus (d'Orbigny)	16			3		1	1				
Globigerinoides trilobus (Reuss)	10	3	1	6	1	2				1	
Orbulina suturalis Brönnimann	1										
Praeorbulina glomerosa circularis (Blow)	2										
Globoturborotalita connecta (Jenkins)	3	12	15	2	2	2	3				
Globoturborotalita druryi (Akers)	5	3	2	1							
Globoturborotalita woodi (Jenkins)	2	2	8	7		1					
Subbotina gortanii (Borsetti)	1										r
Catapsydrax cf. unicavus Bolli, Loeblich & Tappan	1	2					1				r
Globoquadrina cf. altispira (Cushman & Jarvis)	8			4		1					
Globoquadrina globularis Bermudez			1	1			1				r
Globorotalia bykovae (Aisenstadt)	5					1					
Paragloborotalia? mayeri (Cushman & Ellisor)	2			2	1	1					
Paragloborotalia? inaequiconica (Subbotina)	1				1						
Globigerinita cf. glutinata (Egger)	9	6				6	1				
Globigerinita uvula (Ehrenberg)	13					5	4				
Tenuitella clemenciae (Bermudez)	2	4			1	9					
Tenuitella cf. minutissima (Bolli)	5	1				6					
Tenuitellinata angustiumbilicata (Bolli)	1	3		1		1					
Tenuitellinata selleyi Li, Radford & Banner	22	18		2	13	11	20				
Turborotalita neominutissima (Bermudez & Bolli)	5	1				6					
Turborotalita quinqueloba (Natland)	11	38			11	22	7				
Turborotalita sp. 1	3	3				5	2				
Cassigerinella globulosa (Egger)						1					r
Igorina pusilla (Bolli)							1				r
Pseudotextularia sp.	1										r
Hedbergella sp.									1		r
Total planktonic foraminifera	258	269	113	75	104	180	63		1	1	

et al. (subm.). Data were double-squared root transformed (no standardization, no further species reduction) in order to highlight the contribution of the less abundant species and to simplify the interpretation of the data structure (Field et al. 1982). Data were used for hierarchical agglomerative clustering based on the Bray-Curtis Similarity (Clifford & Stephenson 1975). Group Average Linking was used for both benthic and planktonic foraminifera. Based on the same similarity matrix, samples were ordered by non-metric Multi-Dimensional-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 in order to high-

Tab. 3: Ecological preferences of selected benthic foraminifera. Oxic, Suboxic A-C indicators are from KAIHO (1994). Terms "epipelic", "endopelic" and "epiphytic" are from RAMADE (1993). Coastal Terrigenous Mud = VTC; Coastal detritic = DC (PÉRÈS & PICARD 1964).

Species	Environment (when known)	Preferred depth range (m) (when known)	Preferred substratum (when known)	Living strategy (when known)	Comments (from Mediterranean and Oceans)
Angulogerina gr.	Circalit.- bathyal	20-2900 m			Relatively warm water; oxic
Ammonia beccarii/viennensis	Infralitoral, rarely circalitoral (Inner shelf)	Down to 100 m, more abundant 0-50 m	Fine infralit. sand, DC/red algae	Epipelic or shallow endopelic	Salinity >33%o
Ammonia tepida	Infralitoral, rarely circalitoral (Inner shelf)	Down to 100 m, more abundant 0-50 m	Muddy sand, sandy mud, DC	Epipelic or shallow endopelic	Low salinity (<33%o), river mouths, low energy
Amphicoryna gr.	Infralit.- bathyal	13-3000 m	Mud		Low oxygen, glacial water, typical of AABW
Bolivina dilatata	Infralitoral-bathyal (inner shelf to bathyal)	Abundant from 50 to 200	Mud	Shallow endopelic	Low oxygen, tolerant of low food availability
Bolivina hebes	Inner shelf to bathyal (inner shelf to bathyal)	Abundant from 50 to 200	Mud	Shallow endopelic or epiphytic	Low oxygen, tolerant of low food availability
Cassidulina gr.	Circalit.-bathyal	50-3000 m	Mud	Endopelic (3 cm and below)	High stress tolerant, high organic matter, Suboxic B
Caucasina elongata gr.	Infra-upper circalitoral (inner shelf to bathyal)	Abundant down to 80-100 m	Mud and muddy sand	Endopelic	River mouths, high organic matter, low oxygen
Cibicidoides gr.	Shelf to bathyal		Hard substrates	Epiphytic	Oxic
Caucasina schischkinskayae	Infra-upper circalitoral (inner shelf to bathyal)	Abundant down to 80-100 m	Mud and muddy sand	Endopelic	River mouths, high organic matter, low oxygen
Elphidium sp.	Inner shelf	0-50 m	Mud and sand	Epiphytic	Oxic
Globobulimina gr.	Circalitoral to bathyal	80-800	Mud		Dysoxic
Globocassidulina gr.	Circalit.-bathyal	50-3000 m	Mud	Endopelic (3 cm and below)	0.6-8 °C, Oxic, lower NADW
Gyroidinoides gr.	Infralit.- bathyal	16-4000 m	Mud	Endopelic (3 cm and below)	Lower NADW, Suboxic B
Heterolepa gr.	Shelf-upper bathyal	25-500			
Laevidentalina-Dentalina gr.	Circalit.-bathyal	100-4000 m	Mud		Suboxic B-Dysoxic
Lagena gr.	Infralit.- bathyal	20-4000 m			Suboxic B
Lenticulina gr.	Infralitoral to bathyal (outer shelf and bathyal)	from 20 m down	Mud		Suboxic B
Melonis pompilioides	Circalit - bathyal	50-4000 m	Mud		High organic matter, high primary productivity, Suboxic B

Species	Environment (when known)	Preferred depth range (m) (when known)	Preferred substratum (when known)	Living strategy (when known)	Comments (from Mediterranean and Oceans)
Nonion commune	Shelf	0-180 m	Mud and silt	Epipelic-Endopelic	Salinity 30-35‰, Suboxic B
Parrelloides gr.		100-3200	Mud		Oxic
Porosononion granosum	Infra-circalitoral	0-100M	Sand with Cymodocea, VTC and DC		Low salinity, river mouths, high energy
Pseudoparrella gr.		30-4700	Mud		Cold water, 1.9-3°C, NADW or AABW, ABW
Pullenia gr.	Circalit.-bathyal		Mud	Epipelic	Suboxic B
Reussella gr.	Infralit.- upper circalitoral	20-750 m, preferred 20-100 m	Mud and fine sand		
Siphonodosaria gr.	Bathyal		Mud	Endopelic	Suboxic B
Sphaeroidina bulloides	Circalit - bathyal	65-1300 m	Mud	Epipelic to endopelic	Lower NADW, Suboxic B
Stainforthia gr.	Infralit.- circalit.	16-250 m, preferred 16-100 m	Mud		
Stilostomella gr.	Outer shelf - bathyal	230 (?) - 2500	Mud	Endopelic	Suboxic B
Uvigerina gr.	Shelf to bathyal	100 to >4500m, rarely shallower than 100 m	Mud	Shallow endopelic, rarely epiphytic	Suboxic B, and high organic matter
Valvulineria sp.	Circalitoral to epibathyal	More abundant between 40-100 m	Mud, VTC		High organic matter, Suboxic B

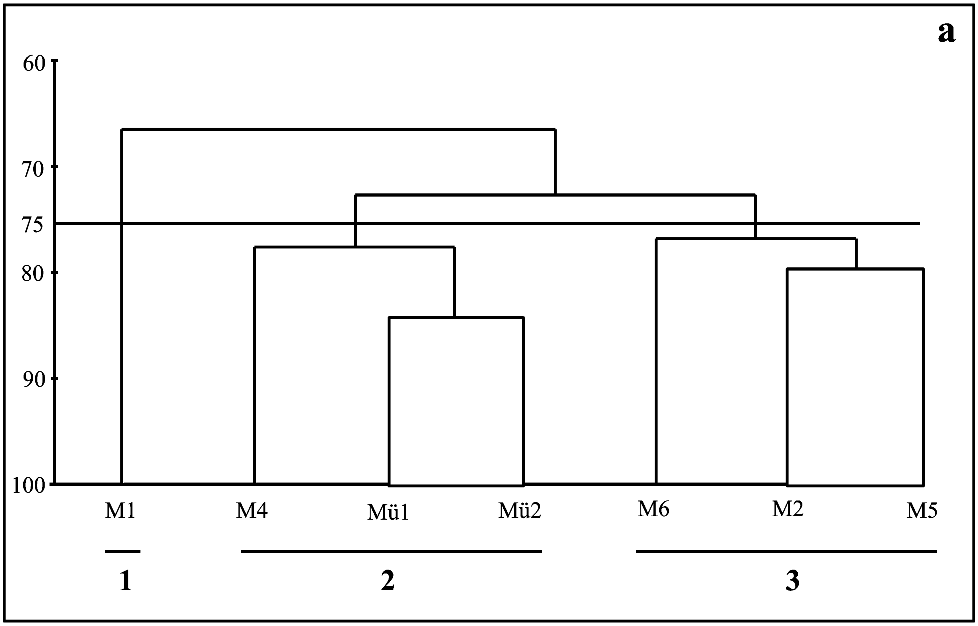
light the contribution of each species to the total average similarity and dissimilarity within each group and between different groups.

Benthic foraminifera: at 75% of the Bray Curtis Similarity, three clusters separate (Fig. 3 a-b, Tab. 4). Cluster 1 is represented by sample M1 only. Cluster 2 groups samples M4, Mü1 and Mü2; fourteen species and/or groups account for the 90.81% of the average similarity within this group. Cluster 3 groups samples M2, M5 and M6; twelve species and/or groups account for 91.07 % of the average similarity within this group.

Planktonic foraminifera: at 67% of the Bray Curtis Similarity, three clusters separate (Fig. 4 a-b, Tab. 5). Cluster 1 groups samples Mü1 and Mü2; three species and/or groups account for 90.38 % average similarity within this group. Cluster 2 groups samples M1, M2 and M5; six species and/or groups account for 92.30 % average similarity within this group. Cluster 3 groups samples M4 and M6; five species and/or groups account for 93.18 % average similarity within this group.

Discussion

In addition to taxonomy and biostratigraphy, benthic and planktonic foraminifera can provide important information about changes in paleoenvironmental conditions. Combining the ecological data reported in the literature and shown in Tab. 3 with the distribution patterns of benthic and planktonic foraminifera (Tab. 1-2) and the statistical parameters (Tab. 4-5), we were able to reconstruct the paleoenvironment in which the sediments from the Mühlbach section were deposited.



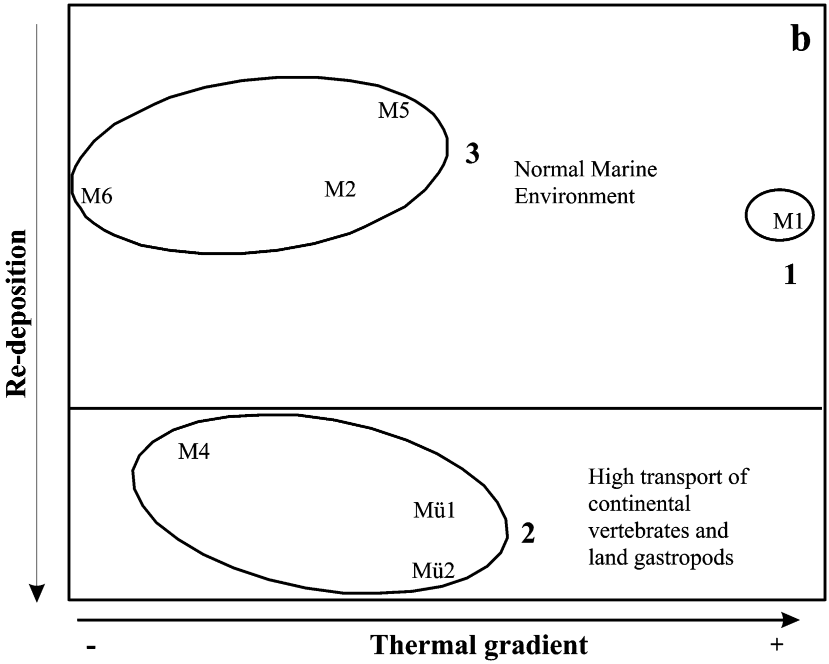


Fig. 3 a-b: (a) hierarchical agglomerative clustering based on the Bray-Curtis Similarity and (b) non-metric MultidimensionalScaling (nMDS) plot of benthic foraminifera from the Mühlbach Section. The stress represents the distortion involved in compressing the data from a multidimensional space into a smaller number of dimensions. A stress of 0.02 indicates minimum distortion and high reliability of results.

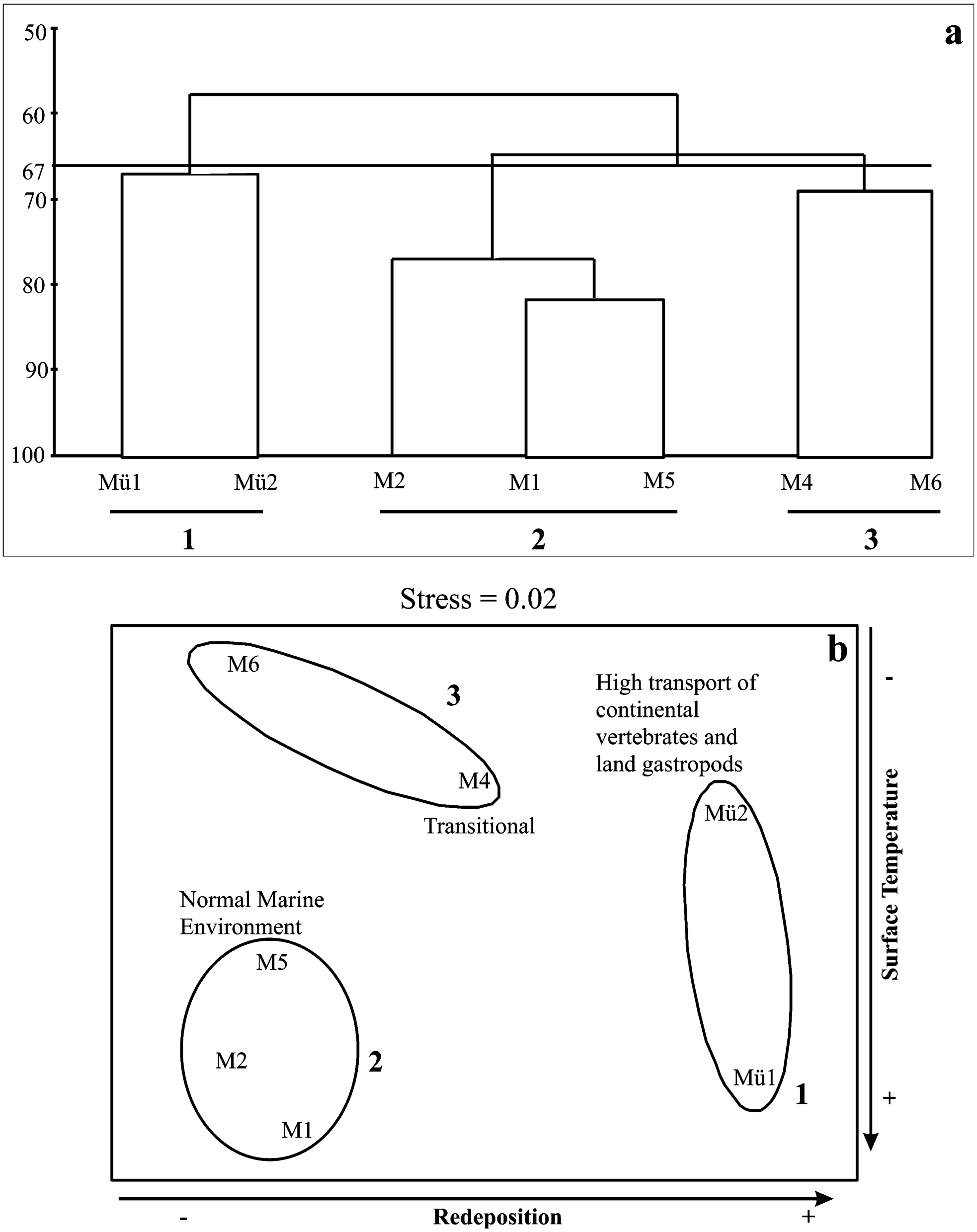


Fig. 4 a-b: (a) hierarchical agglomerative clustering based on the Bray-Curtis Similarity and (b) non-metric MultidimensionalScaling (nMDS) plot of planktonic foraminifera from the Mühlbach Section.

Tab. 4: Bray-Curtis Similarity and Dissimilarity of benthic foraminifera. Cassidul. = *Cassidulina;* Dimo = *Dimorphina;* Globocass. = *Globocassidulina;* Hemi. = *Hemirobulina;* Marg. = *Marginulina;* Myllo.= *Myllostomella;* Ortom. = *Orthomorphina;* Sipho.= *Siphonodosaria;* Vagin. = *Vaginulinopsis.*

Cluster 1- Sample M1 **Average similarity = 69.81**	**Avg. Ab.**	**Avg. Sim.**	**Contrib %**	**Cum%**
Lenticulina-Saracenaria gr.				
Siphonodosaria gr.				
Sphaeroidina bulloides				
Cibicidoides-Heterolepa gr.				
Ammonia gr.				
Amphicoryna gr.				

Average dissimilarity = 44.57	**Avg. Ab. Group 1**	**Avg. Ab. Group 3**	**Avg. Dis.**	**Contrib %**	**Cum%**
Sphaeroidina bulloides	74.00	0.00	6.43	14.42	14.42
Cibicidoides-Heterolepa	77.00	25.00	4.51	10.12	24.54
Lenticulina-Saracenaria gr.	90.00	39.67	4.46	10.02	34.56
Sipho.-Myllo.-Ortom. gr.	83.00	39.00	3.92	8.79	43.35
Amphicorina gr.	46.00	4.33	3.62	8.13	51.47
Nonion commune	17.00	49.67	2.79	6.25	57.72
Globobulimina gr.	41.00	15.33	2.29	5.14	62.86
Ammonia gr.	49.00	30.00	1.72	3.86	66.72
Pullenia gr.	24.00	5.00	1.66	3.72	70.44
Bolivina gr.	61.00	54.67	1.26	2.83	73.27
Reussella-Angulogerina	17.00	5.67	1.01	2.27	75.54
Parrelloides-Pseudoparrella	18.00	7.00	0.99	2.22	77.76
Hemi-Dimo-Vagin-Marg. gr.	12.00	0.67	0.98	2.20	79.96
Caucasina gr.	34.00	30.00	0.87	1.96	81.92

Cluster 2 **Average similarity = 72.61**	**Avg. Ab.**	**Avg. Sim.**	**Contrib %**	**Cum%**
Lenticulina-Saracenaria gr.	62.67	16.44	22.64	22.64
Cibicidoides-Heterolepa	24.67	8.05	11.09	33.73
Sipho.-Myllo.-Ortom. gr.	30.00	7.79	10.74	44.46
Ammonia gr.	24.00	6.02	8.29	52.75
Nonion commune	18.33	5.40	7.43	60.19
Bolivina gr.	18.00	4.44	6.12	66.31
Caucasina gr.	13.67	3.59	4.94	71.24
Globobulimina gr.	14.67	2.64	3.64	74.88
Valvulineria complanata	10.00	2.34	3.23	78.11
Melonis pompilioides	7.00	2.19	3.02	81.12
Pullenia gr.	7.00	2.18	3.00	84.13
Amphicoryna gr.	6.67	1.84	2.53	86.65
Globocass.-Cassidul. gr.	7.67	1.64	2.25	88.91
Ceratocancris haueri	4.33	1.38	1.90	90.81

Average dissimilarity = 48.10	**Avg. Ab. Group 1**	**Avg. Ab. Group 2**	**Avg. Dis.**	**Contrib %**	**Cum%**
Sphaeroidina bulloides	74.00	1.00	6.83	14.19	14.19
Sipho.-Myllo.-Ortom. gr.	83.00	30.00	4.97	10.33	24.52
Cibicidoides-Heterolepa	77.00	24.67	4.89	10.16	34.68
Bolivina gr.	61.00	18.00	4.01	8.33	43.01
Amphicorina gr.	46.00	6.67	3.68	7.64	50.66
Lenticulina-Saracenaria gr.	90.00	62.67	2.71	5.63	56.29
Globobulimina gr.	41.00	14.67	2.45	5.09	61.38
Ammonia gr.	49.00	24.00	2.35	4.88	66.26
Caucasina gr.	34.00	13.67	1.89	3.94	70.20
Parrelloides-Pseudoparrella	18.00	0.67	1.62	3.37	73.56
Pullenia gr.	24.00	7.00	1.59	3.31	76.87
Globocass.-Cassidul gr.	21.00	7.67	1.24	2.58	79.45
Reussella-Angulogerina	17.00	6.33	1.00	2.07	81.52

Cluster 3 **Average similarity = 69.81**	**Avg. Ab.**	**Avg. Sim.**	**Contrib %**	**Cum%**
Bolivina gr.	54.67	11.18	16.02	16.02
Nonion commune	49.67	10.99	15.75	31.76
Lenticulina-Saracenaria gr.	39.67	8.03	11.50	43.26
Sipho.-Myllo.-Ortom. gr.	39.00	6.40	9.17	52.44
Caucasina gr.	30.00	6.04	8.65	61.09
Ammonia gr.	30.00	5.49	7.87	68.95
Globocass.-Cassidul. gr.	21.33	5.05	7.24	76.19
Cibicidoides-Heterolepa	25.00	4.48	6.41	82.60
Valvulineria complanata	12.67	1.91	2.74	85.34
Globobulimina gr.	15.33	1.56	2.24	87.58
Gyroidinoides gr.	8.00	1.36	1.95	89.53
Amphicorina gr.	4.33	1.07	1.54	91.07

Average dissimilarity = 36.88	**Avg. Ab. Group 3**	**Avg. Ab. Group 2**	**Avg. Dis.**	**Contrib %**	**Cum%**
Bolivina gr.	54.67	18.00	5.28	14.32	14.32
Nonion commune	49.67	18.33	4.64	12.57	26.89
Lenticulina-Saracenaria gr.	39.67	62.67	4.25	11.51	38.40
Sipho.-Myllo.-Ortom gr.	39.00	30.00	2.68	7.28	45.68
Caucasina gr.	30.00	13.67	2.28	6.18	51.85
Globocass.-Cassidul. gr.	21.33	7.67	2.05	5.55	57.40
Globobulimina gr.	15.33	14.67	1.85	5.02	62.43
Ammonia gr.	30.00	24.00	1.78	4.82	67.25
Cibicidoides-Heterolepa	25.00	24.67	1.41	3.81	71.06
Valvulineria complanata	12.67	10.00	0.95	2.57	73.63
Gyroidinoides gr.	8.00	1.67	0.92	2.48	76.12
Parrelloides-Pseudoparrella	7.00	0.67	0.86	2.33	78.45
Uvigerina-Pappina gr.	1.33	5.33	0.74	2.01	80.46

Tab. 5: Bray-Curtis Similarity and Dissimilarity of planktonic foraminifera.

Cluster 1 Average similarity = 56.52	Avg. Ab.	Avg. Sim.	Contrib %	Cum%	Average dissimilarity = 54.99	Avg. Ab. Group 2	Avg. Ab. Group 1	Avg. Dis.	Contrib %	Cum%
Globigerina gr.	33.50	28.26	50.00	50.00	*G. tarchanensis-ottnangiensis*	87.67	23.00	19.83	36.06	36.06
G. tarchanensis-ottnangiensis	23.00	11.96	21.15	71.15	*Turborotalita* gr.	27.67	0.00	8.63	15.70	51.75
Globoturborotalita gr.	17.50	10.87	19.23	90.38	*Tenuitellinata-Tenuitella* gr.	23.67	1.50	6.83	12.43	64.18
					Globigerinita gr.	13.00	0.00	4.04	7.34	71.52
					Globigerina gr.	39.00	33.50	3.87	7.04	78.56
					Globigerinoides gr.	12.67	7.50	3.17	5.76	84.32
					Globoturborotalita gr.	10.00	17.50	3.11	5.66	89.98
					G. concinna-diplostoma	5.00	3.00	1.24	2.25	92.23

Cluster 2 Average similarity = 72.03	Avg. Ab.	Avg. Sim.	Contrib %	Cum%	Average dissimilarity = 49.60	Avg. Ab. Group 2	Avg. Ab. Group 3	Avg. Dis.	Contrib %	Cum%
G. tarchanensis-ottnangiensis	87.67	29.85	41.45	41.45	*G. tarchanensis-ottnangiensis*	87.67	27.00	19.30	38.92	38.92
Globigerina gr.	39.00	12.85	17.83	59.28	*Globigerina* gr.	39.00	16.50	7.79	15.71	54.63
Tenuitellinata-Tenuitella gr.	23.67	9.56	13.27	72.55	*Turborotalita* gr.	27.67	9.00	6.06	12.22	66.85
Turborotalita gr.	27.67	8.69	12.06	84.61	*Globigerinoides* gr.	12.67	1.50	3.37	6.80	73.65
Globigerinita gr.	13.00	3.35	4.65	89.27	*Globigerinita* gr.	13.00	2.50	3.31	6.67	80.32
Globoturborotalita gr.	10.00	2.19	3.04	92.30	*Globoturborotalita* gr.	10.00	2.50	2.19	4.41	84.73
					Tenuitellinata-Tenuitella gr.	23.67	17.00	2.01	4.04	88.78
					G. concinna-diplostoma	5.00	3.50	1.23	2.47	91.25

Cluster 3 Average similarity = 53.76	Avg. Ab.	Avg. Sim.	Contrib %	Cum%	Average dissimilarity = 53.28	Avg. Ab. Group 1	Avg. Ab. Group 3	Avg. Dis.	Contrib %	Cum%
Tenuitellinata-Tenuitella gr.	17.00	17.07	31.82	31.82	*Globigerina* gr.	33.50	16.50	11.37	21.34	21.34
G. tarchanensis-ottnangiensis	27.00	15.85	29.55	61.36	*Tenuitellinata-Tenuitella* gr.	1.50	17.00	9.29	17.44	38.78
Turborotalita gr.	9.00	8.54	15.91	77.27	*G. tarchanensis-ottnangiensis*	23.00	27.00	8.52	16.00	54.78
Globigerina gr.	16.50	4.88	9.09	86.36	*Globoturborotalita* gr.	17.50	2.50	8.35	15.68	70.46
G. concinna-diplostoma	3.50	3.66	6.82	93.18	*Turborotalita* gr.	0.00	9.00	5.17	9.70	80.15
					Globigerinoides gr.	7.50	1.50	3.87	7.26	87.41
					Globigerinita gr.	0.00	2.50	1.67	3.13	90.54

Benthic Foraminifera:

Cluster 1 (sample M1) is characterized by large amounts of *Sphaeroidina bulloides, Amphicoryna* spp., *Siphonodosaria, Myllostomella, Pseudoparrella exigua, Lenticulina* spp., and bolivinids. *Sphaeroidina bulloides, Amphicoryna* spp., and *Pseudoparrella exigua* are known to characterize cool bottom waters like the North Atlantic Deep Water (NADW), Antarctic Bottom Water (AABW), or the Arctic Bottom Waters (ABW) (e.g. Weston & Murray 1983; McDougall 1996). Kaiho (1994) includes *Lenticulina* spp., *S. bulloides, Pullenia bulloides*, stilostomellids, and nodosariids as suboxic indicators of Group B, which includes both epifaunal and infaunal dwellers under high-oxygen bottom conditions that are commonly epifaunal dwellers in low-oxygen bottom-water conditions. Oxic indicators such as *Cibicidoides* and *Heterolepa* are abundant in this cluster (Average abundance = 77 %). Infaunal bolivinids and globobuliminids are, in contrast, attributed to the dysoxic indicators group (Kaiho 1994). The presence of large amount of stilostomellids, myllostomellids, and siphonodosariids is also indicative of water depths ranging from outer shelf to bathyal (Hayward 2002). Almost all the taxa identified in sample M1 are mud-preferring species (Table 3). The presence of shallow-water species like the *Ammonia* group is interpreted as being due to re-deposition processes.

Cluster 2 groups samples Mü1, Mü2, and M4 and is characterized by the mud-preferring taxa *Lenticulina*, siphonodosariids, and *Nonion commune*. Suboxic B indicators such as *Lenticulina* spp. and *Nonion commune* and low abundances of oxic indicators like *Cibicidoides* spp. (avergae abundance = 24.67 %) suggest possible slight oxygen depletion at the sea floor. Low abundance of infaual dysoxic indicators suggests relatively oxygenated sediments. In this cluster the *Ammonia* group is associated with large amounts of vertebrate remains and land gastropods (ROETZEL, this volume).

Cluster 3 groups samples M2, M5, and M6 and is characterized by the mud-preferring taxa bolivinids (average abundance = 54.67%), *Nonion commune, Lenticulina , Caucasina* group, and siphonodosariids. The presence of siphonodosariids and stilostomellids (Tables 1, 3, 4) indicate that the water depth is similar to that observed for Cluster 1, although their reduced abundance may suggest slightly shallower water. High abundance of bolivinids suggests oxygen depletion in the superficial layer of the sediments. Suboxic B indicators such as *Lenticulina* spp and *Nonion commune,* and low abundances of *Cibicidoides* spp., suggest slight oxygen depletion at the sea floor as observed for Cluster 2. Re-deposition is suggested by the presence of the *Ammonia* group.

Planktonic Foraminifera:

Cluster 1 groups samples Mü1 and Mü2 and is characterized by the *Globigerina* sensu strictu group, five-chambered globigerinids, the *Globoturborotalita* group.

Cluster 2 groups samples M1, M2, and M5 and is characterized by five-chambered globigerinids, the *Globigerina* s.str. group, and the *Tenuitellinata-Tenuitella* group.

Cluster 3 groups samples M6 and M4 and is characterized by the *Tenuitellinata-Tenuitella* group, five-chambered globigerinids, and the *Turborotalita* group.

All the species listed above are known to be cool-water indicators (e.g., SPEZZAFERRI 1995, SPEZZAFERRI & CORIC 2001). However, several lines of evidence argue against the hypothesis of cool climate in the Badenian (e.g., BELLWOOD & SCHULTZ 1991, PISERA 1996, RÖGL & BRANDSTÄTTER 1994). The overall increase in abundance of the *Globigerinoides* group warm-water indicators (e.g., SPEZZAFERRI et al., subm.) and the decrease in abundance of *Coccolithus pelagicus* (CORIC & SPEZZAFERRI 2002.) indicate climatic amelioration in the Central Paratethys during this time. In addition, starting for the Early Badenian, warm-water carbonate platforms developed in the Central Paratethys (e.g., FRIEBE 1990).

The *Globigerina* s.str. group is known in the literature to be abundant in upwelling areas, where upwelled cool waters bring nutrients to the surface (e.g., KROON 1988). Also, the five-chambered globigerinids seem to be related to cool water and high productivity (SPEZZAFERRI et al., subm.). The highest abundance of these forms is observed in Cluster 1. This Cluster also groups those samples recording high input of continental material. This cluster is therefore interpreted to represent an environment characterized by possible local upwelling which brings cool water to the surface and/or by nutrient input from the continent by rivers or slumping of coastal deposits carrying continental material into the basin. The oxygenated sea-floor inferred from the micropaleontological content of Cluster 2 of benthic foraminifera may support the interpretation of discharge of coarse material (vertebrate remains) from the continent to the sea-floor. In fact, this discharge may have produced remobilization and consequent oxygenation of the upper layer of the sediments.

A real warm-water signal is recorded in Cluster 2 and in particular in Sample M1, which yields *Globigerinoides, Praeorbulina-Orbulina,* and the *Globigerina concinna-G. diplostoma* group (Tables 2, 5). Cluster 3 seems to represent the transition between Cluster 1 and 2 (Fig. 4b). In particular, Sample M4 contains more numerous evidence of terrestrial input than sample M6.

Conclusions

The sediments from the Mühlbach Section were deposited in a water depth ranging from outer shelf to upper bathyal with muddy substratum. Sample M1 represents an environment characterized by the highest thermal gradient (warmest water at the surface and coolest at the bottom), slightly oxygen-depleted or oxic sea-floor with a dysoxic layer at least down to 6 cm within the sediments (Suboxic B of KAIHO 1994). Re-deposition processes displace only the finest fraction of the sediments, including small benthic foraminifera such as the *Ammonia* group.

Samples Mü1, Mü2, and M4 probably represent an environment characterized by slight oxygen depletion at the sea-floor but by oxygenated sediments. Oxygenation of bottom sediments may derive from complex re-deposition processes involving the displacement of fine sediments and coarser continental material. Samples M2, M5, and M6 probably represent an environment with slight oxygen depletion at the sea-floor and dysoxia in the superficial layer of the sediments. As in sample M1, re-deposition processes generally displace only the fine fraction of the sediments. Local upwelling may account for the observed cool-water planktonic fauna.

According to the evolutionary level at the transition from *Praeorbulina glomerosa circularis* to *Orbulina suturalis,* the section Mühlbach is placed at the top of planktonic foraminiferal zone M5b/Mt5b, around 15.1 Ma (BERGGREN et al. 1995). For the regional ecostratigraphic zonation of GRILL (1941) and PAPP (1963), the additional occurrence of *Uvigerina grilli* and *U. macrocarinata* points to the Early Badenian Lower Lagenidae Zone (Lanzendorf fauna), comp. RÖGL et al. (2002). The total range of the Gaindorf Formation extends down into Zone M5b, where *Po. glomerosa circularis* s.str. is present but *Po. glomerosa glomerosa* is missing. The upper range of the formation extends to Zone M6/Mt6 based on the occurrence of *O. suturalis* (CICHA 1996).

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APPENDIX 1

Taxonomic Notes

***Amphicoryna badenensis* (d'ORBIGNY)** (pl. 4, figs. 1-6; pl. 9, fig. 2)

1846 *Nodosaria badenensis* d'ORBIGNY, p. 38, pl. 1, figs. 34-35
1846 *Nodosaria spinicosta* d'ORBIGNY, p. 37, pl. 1, figs. 32-33
1850 *Nodosaria venusta* REUSS, p. 367, pl. 46, fig. 5
1877 *Nodosaria knihnitziana* KARRER, p. 379, pl. 16b, fig. 22

Rich occurrence of the species with a strong variation in sculptures from costate to smooth.

***Amphicoryna hispida* (d'ORBIGNY)** (pl. 4, figs. 7-11; pl. 9, fig. 3)

1846 *Nodosaria hispida* d'ORBIGNY, p.35, pl. 1, figs. 24-25
1846 *Nodosaria aculeata* d'ORBIGNY, p. 35, pl. 1, figs. 26-27
1846 *Dentalina floscula* d'ORBIGNY, p.50, pl. 2, figs. 16-17
1985 *Nodosaria hispida* (SOLDANI) - PAPP & SCHMID, p.25, pl. 5, figs. 1-8

The generic classification of the species has been solved by the occurrence of the typical microspheric generation of *Amphicoryna*. This is in agreement with the overall shape of irregular chamber growth and arrangement, the apertural neck with concentric ridges, and a radial aperture. The authorship of SOLDANI (1791) has to be abandoned based on not using continuously Linnean nomenclature in his work. In the case of "*Orthoceratina hispida*" there exists only a Latin descriptive text mentioning in italics *hispidum* without following the nomenclatorial rules (combination of genus and species).

***Bulimina* ? sp.** (pl. 5, fig. 13; pl. 9, fig. 10)

Small species with a short, indistinctive trochospiral initial stage, followed by a buliminid triserial arrangement, and ending with two inflated chambers in a biserial arrangement; the final chambers comprise more then half of the entire test size. The wall shows relatively large pores. Therefore it does not belong to the *Caucasina* group as formerly believed.

***Cassidulina laevigata* d'ORBIGNY** (pl. 5, fig. 7)

1826 *Cassidulina laevigata* d'ORBIGNY, p. 282, pl. 15, figs. 4-5

Lenticular compressed test with angled periphery. Common in some samples. The other common species *Cassidulina carinata* SILVESTRI possesses a sharp keel.

***Caucasina elongata* (d'ORBIGNY)** (pl. 5, figs. 14-15)

1846 *Bulimina elongata* d'ORBIGNY, p. 187, pl. 11, figs. 19-20
1985 *Bulimina elongata* d'ORBIGNY - PAPP & SCHMID, p. 73, pl. 63, figs. 5-9
1988 *Bulimina elongata* d'ORBIGNY - CICHA & CTYROKA, p.502, pl. 1, figs. 1-4

This species bears an intial trochospire with more than 3 chambers per whorl, very distinct in the microspheric generation. This initial coiling is typical for *Caucasina*, and the wall structure and development of the apertural lip also compares well (comp. figs. in CICHA & CTYROKA 1988). This paper generally separates the genus *Caucasina* from *Bulimina*.

***Dentalina beyrichana* NEUGEBOREN** (pl. 1, figs. 15-16)

1856 *Dentalina Beyrichana* NEUGEBOREN, p. 25, pl. 4, fig. 11

Small and slender species; 8-10 continuous costae, slightly twisted along the axis, ending at base of final chamber; final chamber slightly inflated, separated, and costae ending at the base.

***Discorbinoides* sp.** (pl. 6, fig. 25)

Single, transported specimen of this shallow-water form, which is common in shallow environments of carbonate platforms, e.g., at the "Leithakalk" of St. Margarethen (SCHMID et al. 2001).

***"Eponides" pusillus* PARR** (pl. 6, fig. 34)

1950 *Eponides pusillus* PARR, p. 360, pl. 14, fig. 16
1986 *"Eponides" pusillus* PARR - RUPP, p. 61, pl. 17, figs. 8-11
1994 *Eponides pusillus* PARR - LOEBLICH & TAPPAN, p. 135, pl. 270, figs. 1-10

This very small species is characterized by a biconvex test; periphery rounded; at the spiral side with 2-3 elevated narrow inner whorls, and a flat outer whorl with about four elongated chambers; the umbilical side shows the four chambers of the final whorl meeting in the slightly elevated umbonal area without an umbonal boss; aperture interiomarginal extending at the base of the final chamber with broad lip. As demonstrated by RUPP (1986) the chamber interior is subdivided by a plate extending between the foramen and the aperture. This structure is also present in *Nuttallides*, which has an umbonal boss and a keeled periphery. The generic position of the species is still not solved, but it is placed here in relation to *Nuttallides* in the family Epistomeriidae.

***Globobulimina pupoides* (d'ORBIGNY)** (pl. 5, fig. 20)

1846 *Bulimina pupoides* d'ORBIGNY, p. 185, pl. 11, figs. 11-12
1951 *Protoglobobulimina pupoides* (d'ORBIGNY) - HOFKER, p. 252,
1985 *Bulimina pyrula* d'ORBIGNY - PAPP & SCHMID, p. 69, pl. 62, figs. 5-7
1988 *Praeglobobulimina pupoides* (d'ORBIGNY) - CICHA & CTYROKA, p. 503, p. 2, figs. 12-15

This species suffered a continuous change in taxonomy. According to the chamber arrangement of d'ORBIGNY's figure and the lectotype of PAPP & SCHMID (1985), a specific separation of *G. pyrula* seems to be justified. The best generic position seems to be within *Globobulimina* CUSHMAN (1927). In the well-preserved Mühlbach material the apertural structure compares well with the type species *G. pacifica* CUSHMAN (see LOEBLICH & TAPPAN 1987). In the detailed study of *Globobulimina auriculata* by REVETS (1989), this is explained by a large, prominent, spoon-like tooth sticking out from the aperture, fusing inwards with the foraminal tongue of the previous chamber. This can be observed in opened specimens. Commonly, this "spoon" is broken off or only slightly developed. It is not fixed to both sides of the aperture as shown in *G. auriculata*. The figures of HOFKER (1951) of a *Bulimina pupoides* from Rimini, the type species for the new genus *Protoglobobulimina,* are insufficient and do not compare with the Badenian topotype material.

The reasons why CICHA & CTYROKA (1988) place the species in *Praeglobobulimina* are not explained. It may be the figure of the lectotype of *Bulimina pyrula* by PAPP & SCHMID (1985), which implies the same "cockscomb" lip as in *Praeglobobulimina spinescens*.

***Globobulimina pyrula* (d'ORBIGNY)** (pl. 5, fig. 21)

1846 *Bulimina pyrula* d'ORBIGNY, p. 184, pl. 11, figs. 9-10
1985 *Bulimina pyrula* d'ORBIGNY - PAPP & SCHMID, p. 69, pl. 62, figs. 8-10
1988 *Praeglobobulimina pyrula* (d'ORBIGNY) - CICHA & CTYROKA, p. 503, pl. 2, figs. 9-10

As discussed above, the generic position is the same as for *G. pupoides*. As a species it is distinguished by sack-like, elongate chambers of the final whorl, embracing the older test, and forming a flat to slightly conical base.

***Globigerina* cf. *falconensis* BLOW** (pl. 10, fig. 12)

cf. 1959 *Globigerina falconensis* BLOW, p. 177, pl. 9, fig. 40

A small *Globigerina* with variable shape, slender elongate or square as figured, with a distinct apertural lip. It is provisionally positioned in the *G. falconensis* group.

***Globigerina ottnangiensis* RÖGL** (pl. 11, figs. 1-2)

1969 *Globigerina ciperoensis ottnangiensis* RÖGL, p. 221, pl. 2, figs. 7-10; pl. 4, figs. 1-7
1994 *Globigerina ciperoensis ottnangiensis* RÖGL - RÖGL, p. 137, pl. 1, figs. 11-16; pl. 4, fig. 2

Small, five-chambered, with a flat initial trochospire, and an initial whorl with 5 or more chambers. Common occurrence in the Early Miocene of the Central Paratethys, and also in the Mediterranean Burdigalian.

***Globigerina tarchanensis* SUBBOTINA & CHUTZIEVA** (pl. 11, figs. 3-4)

1950 *Globigerina tarchanensis* SUBBOTINA & CHUTZIEVA in BOGDANOWICZ, p. 173, pl. 10, fig. 5

Similar to *G. ottnangiensis*, probably phylogenetically related. Five chambers in the final whorl and 5 or more chambers in the initial whorl. Differs from *G. ottnangiensis* by the higher trochospire and in the higher number of whorls.

Globoturborotalita connecta (JENKINS) (pl. 10, figs. 16-19; pl. 12, fig. 15)

1964 *Globigerina woodi* JENKINS subsp. *connecta* JENKINS, p. 72, text-fig. 1
1983 *Globigerina (Zeaglobigerina) connecta* JENKINS - KENNETT & SRINIVASAN, p. 44, pl. 8, figs 1-3
1994 *Zeaglobigerina connecta* (JENKINS) - SPEZZAFERRI, p. 32, pl. 4, fig. 4

Small, three- to four-chambered, chambers tightly coiled, apertural slit very narrow, wall texture cancellate with thick gametogenic overgrowth. In a few samples of the Mühlbach section this species is rather common. It is more abundant in the southern hemisphere, occurring in subtropical to tropical waters, and has a range in the Early Miocene acc. KENNETT & SRINIVASAN (1983). The range is extended from the Late Oligocene to Late Miocene by SPEZZAFERRI (1994).

Lenticulina americana (CUSHMAN) (pl. 3, fig. 1)

1918 *Cristellaria americana* - CUSHMAN, p. 50, pl. 10, figs. 5-6
1978 *Lenticulina americana* (CUSHMAN) - MOLCIKOVA, p. 129, pl. 1, fig. 1; text-fig. 2

Belongs to the group of *Lenticulina inornata* sensu PAPP & SCHMID (1985). Differs by a thin keel and a large protruding umbonal boss.

Lenticulina austriaca (d'ORBIGNY) (pl. 3, figs. 2, 4)

1846 *Robulina austriaca* - d'ORBIGNY, p. 103, pl. 5, figs. 1-2
1985 *Lenticulina inornata* (d'ORBIGNY) - PAPP & SCHMID, p. 44, pl. 32, figs. 5-8

This species was also included in *L. inornata* by PAPP & SCHMID (1985). It differs by a small keel and according to d'ORBIGNY a more compressed test; the umbonal boss is distinctly smaller than in *L. americana*.

Lenticulina meynae VESPERMAN (pl. 2, fig. 5)

1846 *Cristellaria crasssa* - d'ORBIGNY, p. 90, pl. 4, figs. 1-3
non 1841 *Robulina crassa* - ROEMER, p. 98, pl. 15, fig. 32
1985 *Lenticulina inornata* (d'ORBIGNY) - PAPP & SCHMID, p. 40, pl. 27, figs. 1-3
1995 *Lenticulina meynae* - VESPERMANN, p. 446, pl. 2, fig. 1

In contrast to *L. inornata*, this keeled species does not possess an umbonal boss, and the sutures are distinctly curved; the apertural face is bordered by strongly angled edges.

Lenticulina obtusa (REUSS) (pl. 2, fig. 2)

1850 *Robulina obtusa* REUSS, p. 369, pl. 46, fig. 18
1978 *Lenticulina rotulata* (LAMARCK) - MOLCIKOVA, p. 157, pl. 22, figs. 1-2; text-fig. 22

Up to 12 small chambers in the final whorl, sutures strongly curved, with large glassy umbonal boss; periphery rounded. In the figure of REUSS the umbonal boss is not clearly visible, but is described as an indistinct disk, probably due to its lobate outline.

Lenticulina spinosa (CUSHMAN) (pl. 3, fig. 3)

1918 *Cristellaria americana* var. *spinosa* - CUSHMAN, p. 51, pl. 10, fig. 7
1978 *Lenticulina americana spinosa* CUSHMAN - MOLCIKOVA, p. 129, pl. 1, fig. 2; text-fig. 3

It differs from *L. americana* by bearing small spikes irregularly distributed along the small keel. It is possible that both species are only ecophenotypic variants.

Lenticulina sp. 1 (pl. 2, fig. 10)

Flat lenticular shape, nearly circular outline with a thin, sharp keel extending onto the apertural face; apertural face oval and closed; coiling slightly asymmetrical; sutures thin, indistinct, somewhat curved, meeting in the centre. The general shape has some similarities with *L. convergens* (BORNEMANN) of MOLCIKOVA (1978, p. 141).

Lenticulina sp. 2 (pl. 2, figs. 8-9)

Small, inflated species with a rounded square outline; three intersecting chambers per whorl, separated by straight flush sutures, arranged similar as in *Neolenticulina*; aperture protruding, with short radial slits, closed in the centre.

Lenticulina sp. 3 (pl. 2, figs. 6-7)

Only damaged specimens are available. Flat lenticular test, with a small keel; chambers separated by broad, sharply angled sutures which meet in an indistinct glassy umbonal field.

Myllostomella advena (CUSHMAN & LAIMING) (pl. 6, figs. 14-17; pl. 9, fig. 9)

1931 *Nodogenerina advena* CUSHMAN & LAIMING, p. 106, pl. 11, fig. 19
2002 *Myllostomella advena* (CUSHMAN & LAIMING) - HAYWARD, p. 303, pl. 3, figs. 6-9

A revision of Stillostomellidae, HAYWARD separates those species with a phialine lip around the apertural neck and with one tooth and internal denticles around the aperture from *Stillostomella*. The latter genus possesses a neck but no lip around the aperture, and one or more internal teeth.

Myllostomella recta (PALMER & BERMUDEZ) (pl. 6, figs. 18-19; pl. 9, fig. 6)

1936 *Ellipsonodosaria recta* PALMER & BERMUDEZ, p. 297, pl. 18, figs. 6-7
1994 *Siphonodosaria recta* (PLAMER & BERMUDEZ) - BOLLI, BECKMANN & SAUNDERS, p.359, fig. 63.21

Based on the apertural features this species is transferred to the genus *Myllostomella*.

Neugeborina irregularis d'ORBIGNY (pl. 6, figs. 5-6)

1846 *Nodosaria irregularis* d'ORBIGNY, p. 32, pl. 1, figs. 13-14
1985 *Nodosaria irregularis* d'ORBIGNY - PAPP & SCHMID, p. 23, pl. 3, figs. 6-9; pl. 4, fig. 1

Small, thin tube subdivided into chambers which gradually increase in length; aperture a round opening at the end of a small tube at the constriction of the final chamber. Similar to *Neugeborina longiscata* but distinctly smaller and with more chambers.

***Neugeborina longiscata* d'ORBIGNY** (pl. 6, fig. 4)

1846 *Nodosaria longiscata* d'ORBIGNY, p. 32, pl. 1, figs. 10-12
1985 *Nodosaria longiscata* d'ORBIGNY - PAPP & SCHMID, p. 23, pl. 3, figs. 1-5

Broken pieces of the long, slender, tube-like chambers have been found.

***Nonionoides karaganicus* (KRASHENINNIKOV)** (pl. 7, figs. 1-4)

1959 *Nonionella karaganica* KRASHENINNIKOV in ZHIZHCHENKO, p.41, pl. 7, fig. 4

As the genus *Nonionella* differs by a flaplike projection of the chamber, overhanging the umbilicus, the species is transferred to *Nonionoides* SAIDOVA (1975).

***Nonionoides vetragranosus* (KRASHENINNIKOV)** (pl. 7, fig. 5)

1958 *Nonionella ventragranosa* KRASHENINNIKOV, p. 119, pl. 2, fig. 5

In this species the spiral side shows a distinct flat area of the initial coiling, whereas the umbilicus is filled by granular material. A sack-like projection of the final chamber is missing. In some Badenian beds this species is rather common, and is probably confused with *Nonion commune*. In the Mühlbach beds it is rare.

***Praeorbulina glomerosa circularis* (BLOW) - *Orbulina suturalis* BRÖNNIMANN transition** (pl. 10, figs. 1-2)

1956 *Globigerinoides glomerosa circularis* BLOW, p. 65, text-figs. 2.3-2.4
1951 *Orbulina suturalis* BRÖNNIMANN, p. 135, text-figs. 2-4

The present orbulinas are nearly complete spheres, but otherwise show the semicircular intersutural apertures with a distinct lip, as characteristic in *Po. glomerosa circularis*. A close relation with *O. suturalis* is indicated by the beginning development of a few areal apertures in the final chamber.

***Pseudoparrella exigua* (BRADY)** (pl. 6, figs. 30-33)

1884 *Pulvinulina exigua* BRADY, p. 696, pl. 103, figs. 13-14
1994 *Pseudoparrella exigua* (BRADY) - LOEBLICH & TAPPAN, p. 146, pl. 307, figs. 1-7

Very small; not yet recorded from Badenian sediments but common in the Gaindorf Formation. The form described by POPESCU (1975) as *Alabamina exigua* from the Chechis Clay does not compare to this species.

***Pyramidulina continuicosta* (SCHUBERT)** (pl. 1, figs. 9-10)

1900 *Nodosaria (Dentalina) catenulata* Brady var. *continuicosta* - SCHUBERT, p. 51, pl. 1, fig. 2.

The species is characterized by few prominent (4-5) costae, continuous over the entire length of the test, and by distinct, broad, translucent sutures; only broken pieces are present.

Saracenaria aureola (KARRER) (pl. 2, figs. 11-12)

1877 *Cristellaria aureola* KARRER, p. 388, pl. 16b, fig. 39

Slightly curved; chambers strongly increasing in size in the younger part; periphery with a thin broad keel; apertural face large, bordered by thin keels.

Siphonodosaria nuttalli gracillima (CUSHMAN & JARVIS) (pl. 6, figs. 9-10; pl. 9, fig. 5)

1934 *Ellipsonodosaria nuttalli* var. *gracillima* CUSHMAN & JARVIS, p. 72, pl. 10, fig. 7
1994 *Siphonodosaria nuttalli gracillima* (CUSHMAN & JARVIS) - BOLLI, BECKMANN & SAUNDERS, p. 359, fig. 63.20

This species is the small counterpart of *Siphonodosaria consobrina* (d'ORBIGNY), which is also commonly present in the samples.

Siphonodosaria scripta (d'ORBIGNY) (pl. 6, figs. 11-12; pl. 9, figs. 7-8)

1846 *Dentalina scripta* d'ORBIGNY, p. 51, pl. 2, figs. 21-23
1985 *Dentalina scripta* d'ORBIGNY - PAPP & SCHMID, p. 31, pl. 15, figs. 21-23

Under normal preservation condition the aperture is destroyed. Therefore, d'ORBIGNY and PAPP & SCHMID believed this to be *Dentalina* because of the slightly curved test. In our material, apertures are preserved, showing a neck with a strong tooth. The everted lip is serrate at the outer side. The chamber surface is covered by small spikes arranged along shallow grooves.

Siphotextularia sp. (pl. 1, fig. 4)

In contrast to *Siphotextularia concava* (KARRER) the chambers are inflated with a distinctly rounded periphery, and in *S. inopinata* (LUCZKOWSKA) the test has a lozenge-shaped cross-section.

Stainforthia sp. (pl. 5, fig. 10)

A very small species with a biserial chamber arrangement in a twisted coil; chambers increase gradually in size.

Tenuitella clemenciae (BERMUDEZ) (pl. 12, figs. 7-8)

1961 *Turborotalia clemenciae* BERMUDEZ, p. 1321, pl. 17, fig 10

Small, microperforate, 4-5 chambers in the final whorl; aperture umbilical-extraumbilical, low, with a flap-like lip; wall covered with small pustules. Stratigraphic distribution acc. to KENNETT & SRINIVASAN (1983) from the Early Miocene, N 5 zone to the Late Miocene, in tropical to subtropical regions.

***Tenuitellinata selleyi* LI, RADFORD & BANNER (pl. 9, fig. 15; pl. 12, figs. 9-11)**

1992 *Tenuitellinata selleyi* LI, RADFORD & BANNER, p. 581, pl. 4, figs. 1-4

This is another microperforate, low trochospiral species with 5 globular chambers in the final whorl. The low aperture is distinctly umbilical, bordered by a small lip. The generic distinction between *Tenuitella* and *Tenuitellinata* is in the position of the aperture, which is umbilical-extraumbilical in *Tenuitella* (LI QUIANYU 1987). The growth of this species and position of the final chamber is rather variable. It has been described from the lower Middle Miocene of ODP hole 747A in the Southern Indian Ocean.

***Turborotalita neominutissima* (BERMUDEZ & BOLLI) (pl. 9, fig. 14; pl. 12, figs 2-3)**

1969 *Globorotalia neominutissima* BERMUDEZ & BOLLI, p. 175, pl. 13, figs. 10-12
1981 *Globorotalia neominutissima* BERMUDEZ & BOLLI - SAITO, THOMPSON & BERGER, p. 122, pl. 40, figs. 1-2

Small species with 5 chambers in the final whorl, spiral side flat; aperture umbilical, low, extending towards the periphery, with a distinct lip. Thin wall, microperforate, texture with small pustules, probably bases of flexible spines as in *T. quinqueloba*. Distribution in Venezuela from the Miocene *Globorotalia menardii* to the Pleistocene *Globorotalia truncatulinoides* Zone.

***Turborotalita* sp. 1 (pl. 12, figs. 5-6)**

In the Mühlbach assemblages, a further species of *Turborotalita* appears. Five chambers in the final whorl, the final chamber is overhanging towards the umbilicus, bulla-like, and with very thin wall. The spiral side is vaulted, with a flat initial spire consisting of two multichambered whorls, resembling that of *Globorotaloides*. The wall is microperforate with pustules, similar to that in *T. quinqueloba.*

***Uvigerina graciliformis* PAPP & TURNOVSKY (pl. 5, fig. 24)**

1953 *Uvigerina graciliformis* PAPP & TURNOVSKY, p. 122, pl. 5/A, figs. 5-7

Originally this species was described from the localities Grund and Laa in Lower Austria for the "Helvetian" stage. Later the first appearance was used to define the base of the Karpatian stage (PAPP et al. 1971). The top of this species has now been recorded to be in the Grund Formation (CICHA 1999), which lies in the Lower Badenian (RÖGL et al. 2002).

***Uvigerina ? pygmoides* PAPP & TRUNOVSKY (pl. 5, fig. 28; pl. 9, fig. 11)**

1846 *Uvigerina pygmaea* d'ORBIGNY, p. 190, pl. 11, figs. 25-26
1953 *Uvigerina pygmoides* PAPP & TURNOVSKY, p. 131, pl. 5/C, fig. 4
1985 *Uvigerina pygmoides* PAPP & TURNOVSKY - PAPP & SCHMID, p. 74, pl. 65, figs. 1-5

Characteristic are the inflated barrel shape, the curved costae, meeting at the upper rim of the chamber, and the broad and short apertural neck with phialine lip. For the first time, a covering lid fastened at one side of the aperture is observed. It remains to be clarified in other well-preserved material whether this is a constant feature. For the time being the species is placed in *Uvigerina*.

Plate 1

Textulariina

Fig. 1: ***Martinottiella communis*** **(d'ORBIGNY)** – not very scarce but rather small for the species; sample Mühlbach M1.

Fig. 2: ***Semivulvulina pectinata*** **(REUSS)** – sample Mühlbach Mü1.

Fig. 3: ***Textularia gramen*** **d'ORBIGNY** – only juvenile specimens of *Textularia* are present; sample Mühlbach Mü1.

Fig. 4: ***Siphotextularia*** **sp.** – in contrast to *S. concava,* this single specimen has inflated chambers and a rounded periphery; sample Mühlbach M1.

Miliolina

Fig. 5. ***Quinqueloculina*** **sp**. – a single corroded specimen of *Quinqueloculina* has been found; sample Mühlbach Mü1.

Fig. 6: ***Sigmoilopsis celata*** **(COSTA)** – only corroded specimens have been found; sample Mühlbach M1.

Lagenina

Nodosariidae

Figs. 7-8: ***Dentalina acuta*** **d'ORBIGNY** – sample Mühlbach M1 (for detail of aperture see pl. 9, fig. 1).

Figs. 9-10: ***Pyramidulina continuicosta*** **(SCHUBERT)** – sample Mühlbach Mü1.

Figs. 11-12: ***Laevidentalina badenensis*** **(d'ORBIGNY)** – test slightly curved, sutures distinctly oblique, apical spine may be present; sample Mühlbach M1.

Figs. 13-14: ***Laevidentalina elegans*** **(d'ORBIGNY)** – more stout and straight than *L. badenensis,* sutures only slightly oblique; sample Mühlbach M5.

Figs. 15-16: ***Dentalina beyrichana*** **NEUGEBOREN** – in contrast to *D. acuta,* this form is small and possesses few costae and distinct translucent sutures; sample Mühlbach M1.

Fig. 17: ***Amphimorphina haueriana*** **NEUGEBOREN** – sample Mühlbach M2.

Figs. 20-21: ***Plectofrondicularia raricosta*** **(KARRER)** – sample Mühlbach M5.

Vaginulinidae

Figs. 18-19: ***Dimorphina akneriana*** **(NEUGEBOREN)** – in contrast to *Vaginulinopsis pedum,* chambers inflated; sample Mühlbach M1.

Magnification: figs. 1-6, 9-10, 17-21: x 85; figs. 7-8, 11-16: x 40; scale bar 100 µm

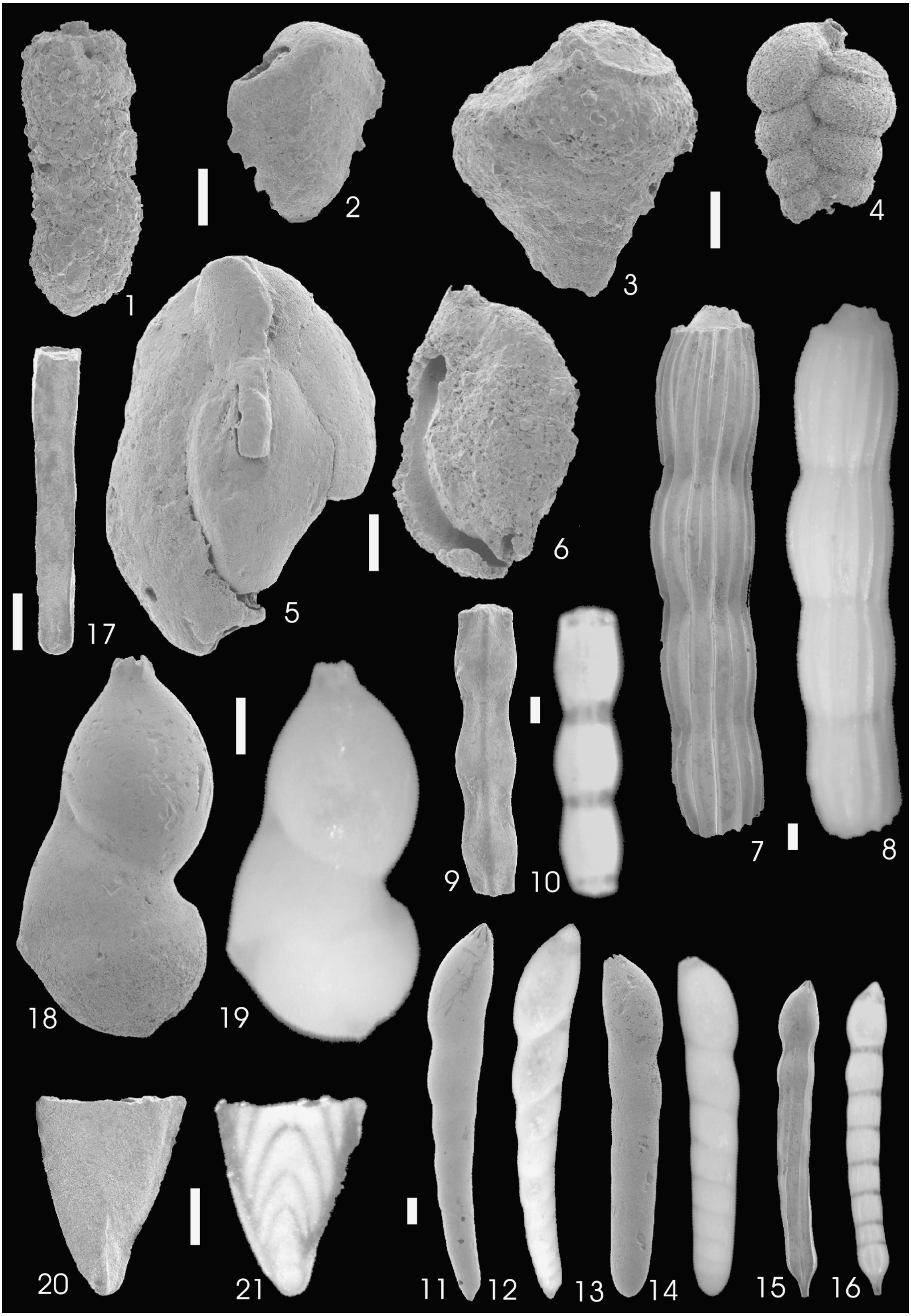
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Plate 2

Vaginulinidae

Fig. 1: ***Lenticulina orbicularis*** **(d'ORBIGNY)** – maximum diameter 1.78 mm; sample Mühlbach M1.

Fig. 2: ***Lenticulina obtusa*** **(REUSS)** – maximum diameter 2.04 mm; sample Mühlbach Mü1.

Fig. 3: ***Lenticulina calcar*** **(LINNE)** – keeled, with distinct spines; maximum diameter 0.77 mm; sample Mühlbach M1.

Fig. 4: ***Lenticulina melvilli*** **(CUSHMAN & RENZ)** – maximum diameter 1.18 mm; sample Mühlbach M4.

Fig. 5: ***Lenticulina meynae*** **VESPERMANN** – maximum diameter 0.71 mm; sample Mühlbach M1.

Figs. 6-7: ***Lenticulina*** **sp. 3** – sample Mühlbach M6; scale bar 100 µm.

Figs. 8-9: ***Lenticulina*** **sp.2** – sample Mühlbach M1; scale bar 100 µm.

Fig. 10: ***Lenticulina*** **sp. 1** – maximum diameter 1.24 mm; sample Mühlbach M1.

Figs. 11-12: ***Saracenaria aureola*** **(KARRER)** – maximum diameter 1.43 mm; sample Mühlbach M5.

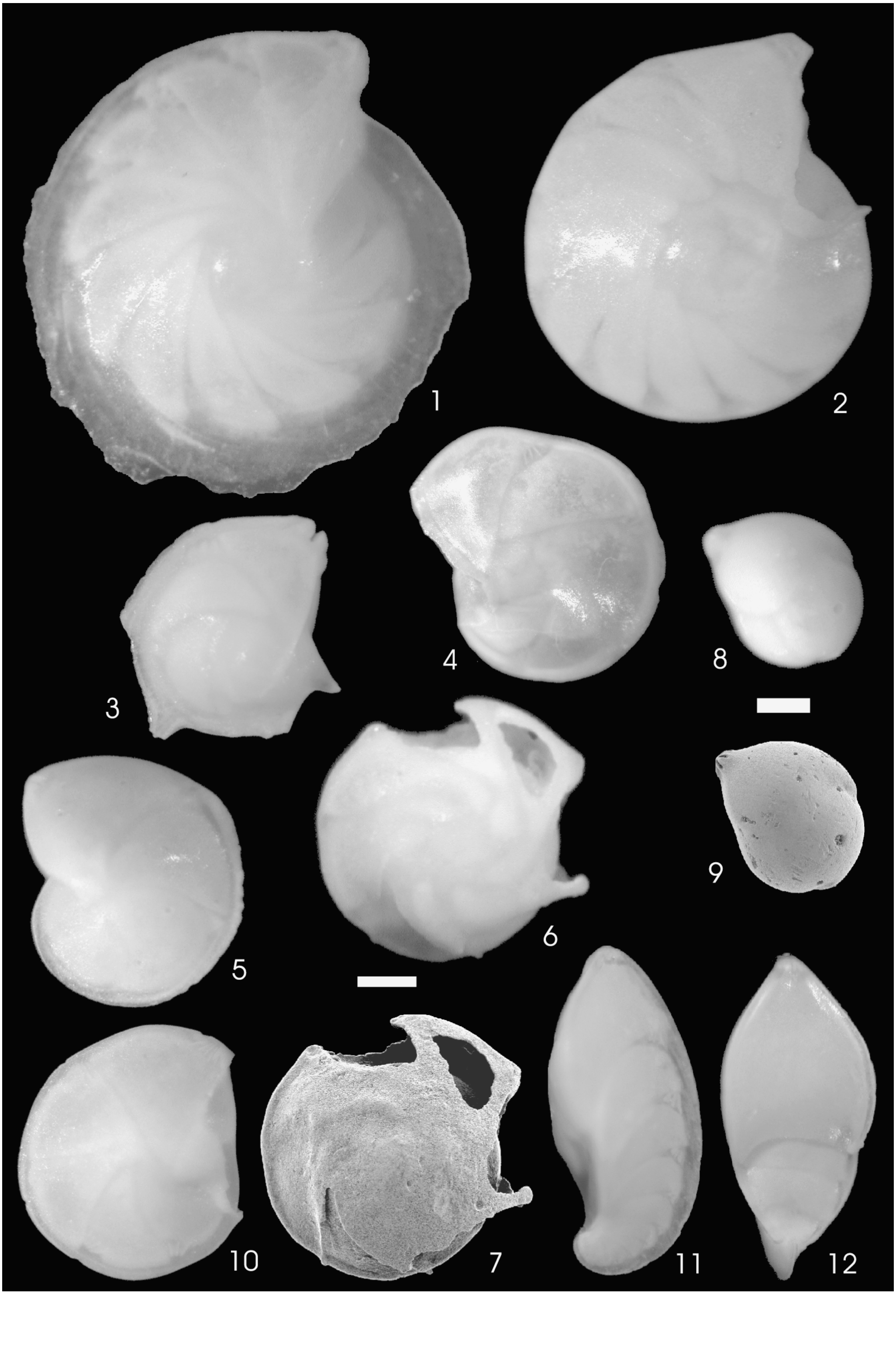
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Plate 3

Vaginulinidae

Fig. 1: ***Lenticulina americana* (CUSHMAN)** – biumbonate, with large umbilical boss, straight sutures, and a small keel; maximum diameter 1.74 mm; sample Mühlbach M5.

Fig. 2: ***Lenticulina austriaca* (d'ORBIGNY)** – described by PAPP & SCHMID (1985) as keeled *L. inornata;* with small umbilical boss, curved sutures, and small keel; maximum diameter 1.27 mm; sample Mühlbach Mü2.

Fig. 3: ***Lenticulina spinosa* (CUSHMAN)** – maximum diameter 1.22 mm; sample Mühlbach M2.

Fig. 4: ***Lenticulina austriaca* (d'ORBIGNY)** – maximum diameter 1.13 mm;sample Mühlbach M1.

Fig. 5: ***Lenticulina inornata* (d'ORBIGNY)** – maximum diameter 0.75 mm;sample Mühlbach M1.

Fig. 6-7: ***Planularia moravica* (KARRER)** – sample Mühlbach M1; scale bar 100 µm.

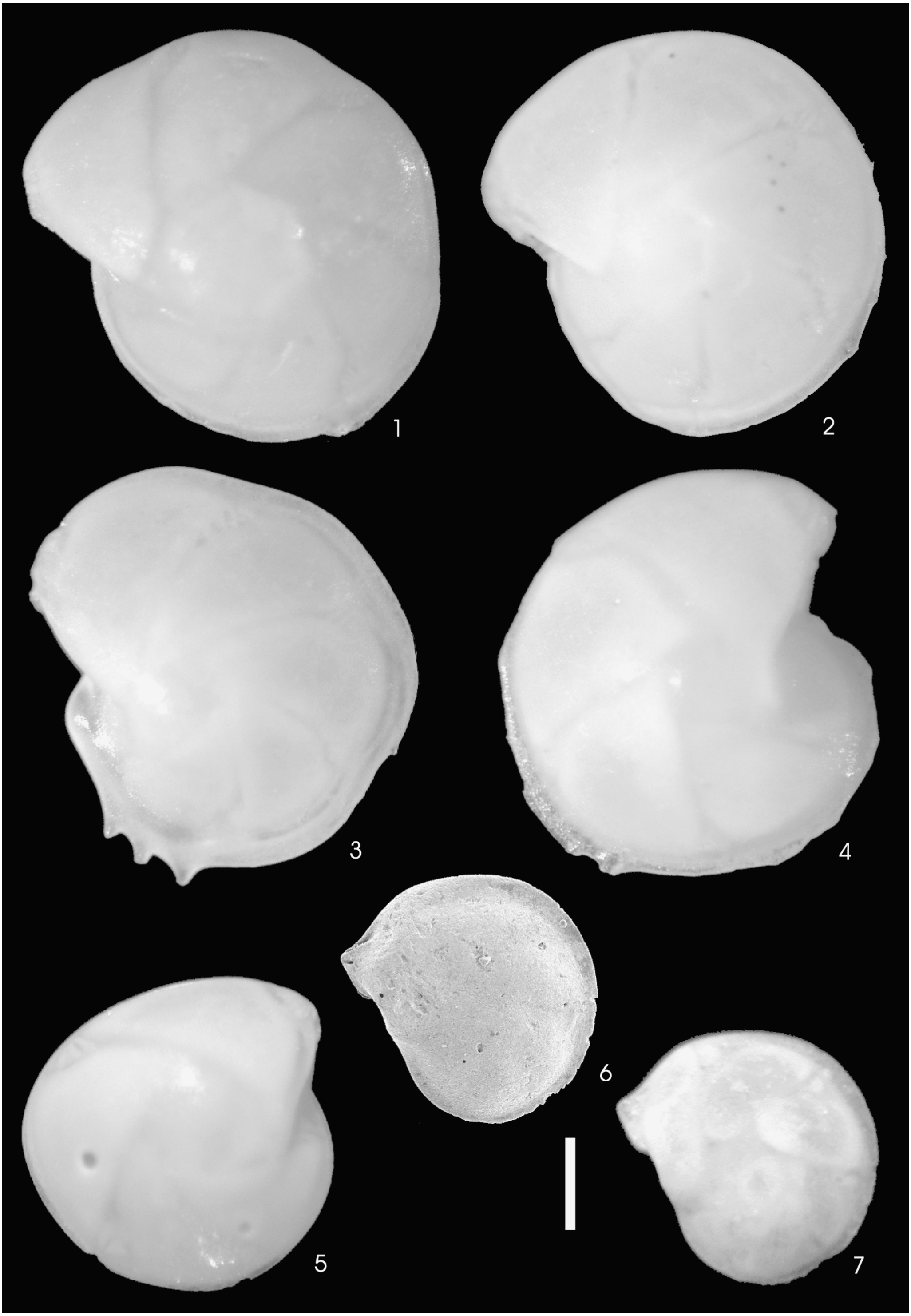
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Plate 4

Vaginulinidae

Figs. 1-6: ***Amphicoryna badenensis* (d'ORBIGNY)** – strong variation in ornamentation from costate to smooth; details of aperture pl. 9, fig. 2; sample Mühlbach M1.

Figs. 7-11: ***Amphicoryna hispida* (d'ORBIGNY)** – figs. 7-8, very small microspheric generation; figs. 9-10, common megalospheric generation (for ornamentation see pl. 9, fig. 3); fig. 10, juvenile specimen; sample Mühlbach M1.

Figs. 12-13: ***Hemirobulina eximia* (NEUGEBOREN)** – sample Mühlbach M1.

Figs. 14-15: ***Hemirobulina glabra* (d'ORBIGNY)** – sample Mühlbach M1.

Figs. 16-17: ***Vaginulinopsis pedum* (d'ORBIGNY)** – initial spire compressed, dorsal periphery angled; sample Mühlbach M6.

Fig. 18: ***Marginulina hirsuta* d'ORBIGNY** – sample Mühlbach Mü2.

Lagenidae

Fig. 19: ***Lagena haidingeri* (CZJZEK)** – sample Mühlbach M1.

Fig. 20: ***Pygmaeoseistron hispidum* (REUSS)** – sample Mühlbach M1.

Polymorphinidae

Figs. 21-22: ***Globulina gibba* d'ORBIGNY** – sample Mühlbach M1.

Fig. 23: ***Guttulina communis* d'ORBIGNY** – sample Mühlbach M1.

Ceratobuliminidae

Fig. 24: ***Ceratocancris haueri* (d'ORBIGNY)** – sample Mühlbach M4.

Ellipsolagenidae

Figs. 25-26: ***Pseudosolenia lateralis carinata* (BUCHNER)** – sample Mühlbach M1.

Rotaliina

Bolivinidae

Fig. 27: ***Bolivina dilatata brevis* CICHA & ZAPLETALOVA** – sample Mühlbach M5.

Fig. 28: ***Bolivina dilatata dilatata* REUSS** – sample Mühlbach M5.

scale bar 100 µm

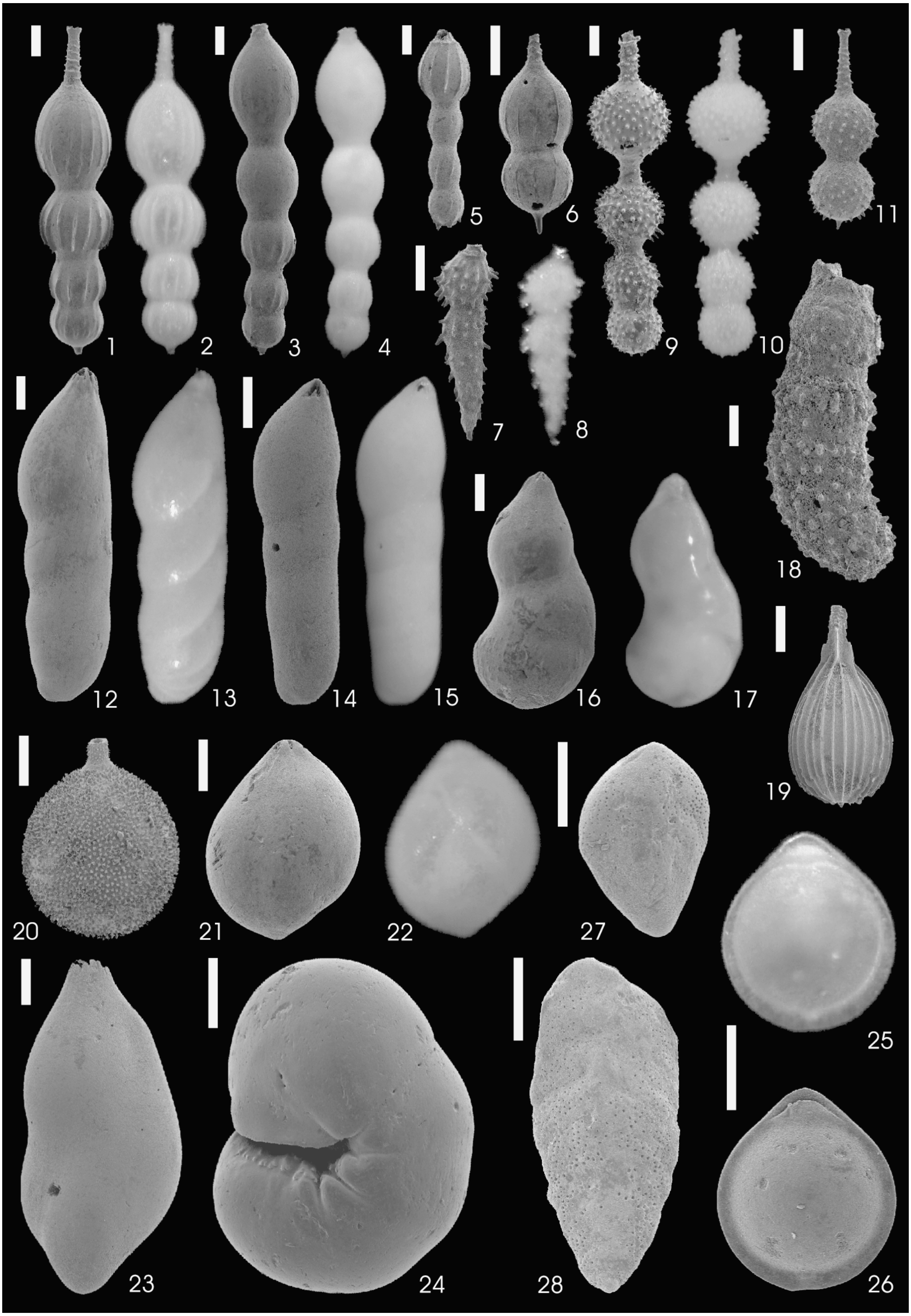
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Plate 5

Fig. 1: ***Bolivina* cf. *lowmani* Phleger & Parker –** sample Mühlbach M1.

Fig. 2: ***Bolivina sagittula* Didkovskyi** – sample Mühlbach M1.

Figs. 3-4: ***Bolivina* aff. *simplex* Phleger & Parker** – sample Mühlbach M5.

Fig. 5: ***Bolivina hebes* Macfadyen** – sample Mühlbach M1.

Fig. 6: ***Lapugyina schmidi* Popescu** – sample Mühlbach M1.

Cassidulinidae

Fig. 7: ***Cassidulina laevigata* d'Orbigny** – sample Mühlbach M1.

Fig. 8: ***Globocassidulina subglobosa* (Brady)** – sample Mühlbach M5.

Fig. 9: ***Islandiella puctata* (Reuss)** – sample Mühlbach Mü2.

Stainforthiidae

Fig. 10: ***Stainforthia* sp.** – sample Mühlbach M1.

Fig. 11: ***Virgulopsis tuberculatus* (Egger)** – sample Mühlbach M1.

Siphogenerinoididae

Fig. 12: ***Spiroloxostoma czechoviczi* (Kantorova)** – sample Mühlbach M1.

Caucasinidae

Figs. 14-15: ***Caucasina elongata* (d'Orbigny)** – sample Mühlbach M1.

Fig. 16: ***Caucasina subulata* (Cushman & Parker)** – sample Mühlbach M1.

Fig. 17: ***Caucasina schischkinskayae* Samoylova** – sample Mühlbach M4.

Buliminidae

Fig. 13: ***Bulimina* sp.** – detail of initial part on pl. 9, fig. 10; sample Mühlbach M1.

Fig. 18: ***Bulimina striata striata* d'Orbigny** – sample Mühlbach M4.

Fig. 19: ***Bulimina striata mexicana* Cushman** – sample Mühlbach Mü1.

Fig. 20: ***Globobulimina pupoides* (d'Orbigny)** – sample Mühlbach M1.

Fig. 21: ***Globobulimina pyrula* (d'Orbigny)** – sample Mühlbach M2.

Figs. 22-23: ***Uvigerina macrocarinata* Papp & Turnovsky** – sample Mühlbach M5.

Fig. 24: ***Uvigerina graciliformis* Papp & Turnovsky** – sample Mühlbach Mü2.

Fig. 25: ***Uvigerina mantaensis* Cushman & Edwards** – sample Mühlbach Mü2.

Fig. 26: ***Uvigerina cf. barbatula* Macfadyen** – sample Mühlbach Mü2.

Fig. 27: ***Uvigerina grilli* Schmid** – sample Mühlbach Mü2.

Fig. 28: ***Uvigerina pygmoides* Papp & Turnovsky** – for apertural details see pl. 9, fig. 11; sample Mühlbach Mü2.

scale bar 100 µm

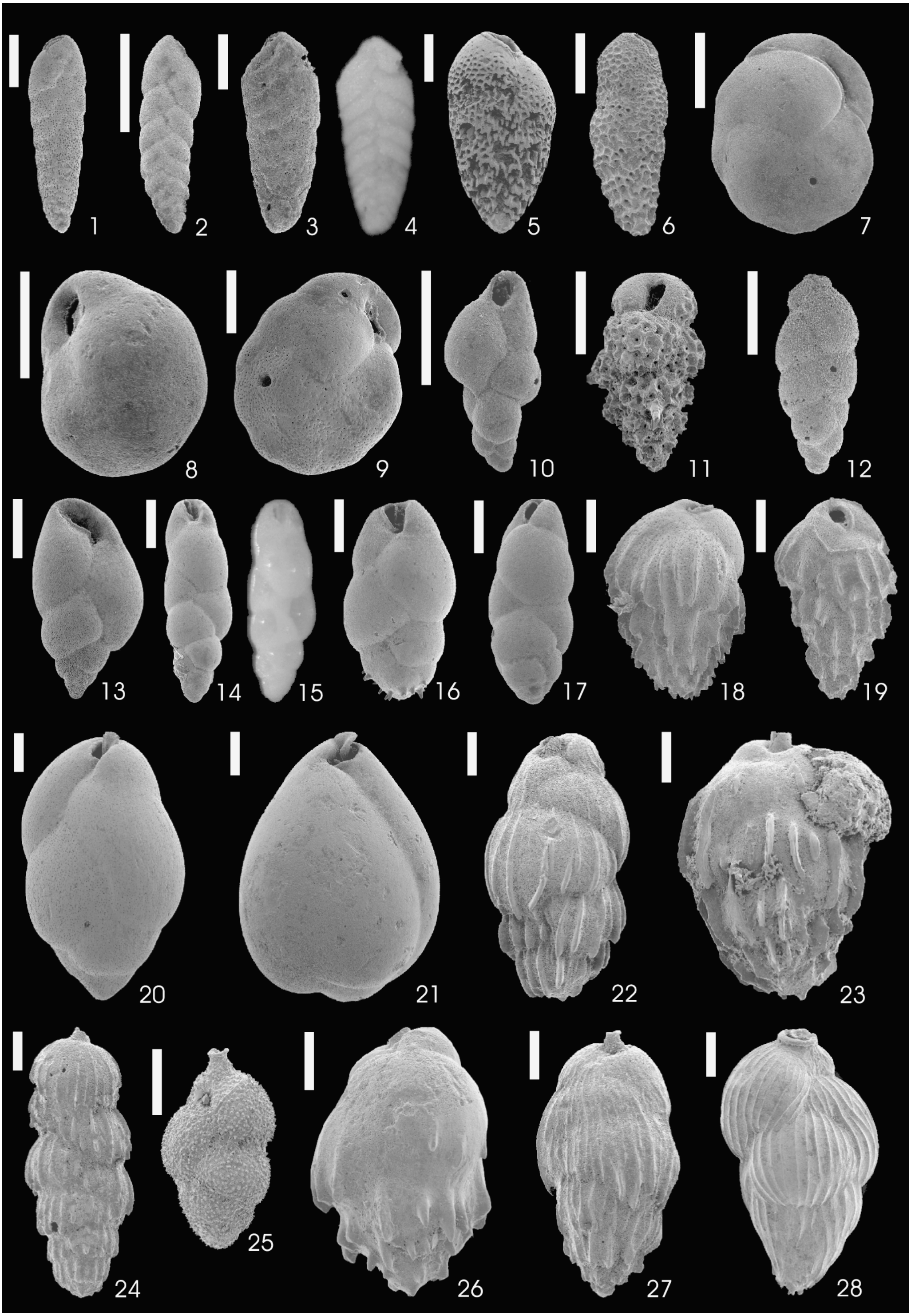
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Plate 6

Fursenkoinidae

Fig. 1: ***Pappina primiformis* (Papp & Turnovsky)** – sample Mühlbach M1.

Buliminidae

Fig. 2: ***Angulogerina angulosa* (Williamson)** – sample Mühlbach M1.

Fig. 3: ***Reussella spinulosa* (Reuss)** – sample Mühlbach M5.

Stilostomellidae

Fig. 4: ***Neugeborina longiscata* (d'Orbigny)** – sample Mühlbach M1.

Figs. 5-6: ***Neugeborina irregularis* (d'Orbigny)** – sample Mühlbach M1.

Figs. 7-8: ***Siphonodosaria consobrina* (d'Orbigny)** – details of aperture pl. 9, fig. 4; sample Mühlbach M1.

Figs. 9-10: ***Siphonodosaria nuttalli gracillima* (Cushman & Jarvis)** – details of aperture pl. 9, fig. 5; sample Mühlbach M1.

Figs. 11-12: ***Siphonodosaria scripta* (d'Orbigny)** – details of aperture pl. 9, fig. 7; surface ornamentation on pl. 9, fig. 8; sample Mühlbach Mü1.

Fig. 13: ***Orthomorphina* sp.** – sample Mühlbach M1.

Figs. 14-17: ***Myllostomella advena* (Cushman & Laiming)** – details of aperture pl. 9, fig. 9; figs. 14-15, megalospheric generation; figs. 16-17, microspheric generation; sample Mühlbach M1.

Figs. 18-19: ***Myllostomella recta* (Palmer & Bermudez)** – sample Mühlbach Mü1.

Bagginidae

Fig. 20: ***Baggina arenaria* (Karrer)** – sample Mühlbach M5.

Figs. 21-23: ***Valvulineria complanata* (d'Orbigny)** – sample Mühlbach M1.

Sphaeroidinidae

Fig. 24: ***Sphaeroidina bulloides* d'Orbigny** – sample Mühlbach M1.

Glabratellidae

Fig. 25: ***Discorbinoides* sp.** – sample Mühlbach Mü2.

Parrelloididae

Figs. 26-29: ***Cibicidoides ungerianus* (d'Orbigny)** – sample Mühlbach M1.

Pseudoparrellidae

Figs. 30-33: ***Pseudoparrella exigua* (Brady)** – sample Mühlbach M5.

Epistomariidae

Fig. 34: ***"Eponides" pusillus* Parr** – sample Mühlbach M5.

Nonionidae

Fig. 35: ***Nonion commune* (d'Orbigny)** – sample Mühlbach M2.

scale bar 100 µm

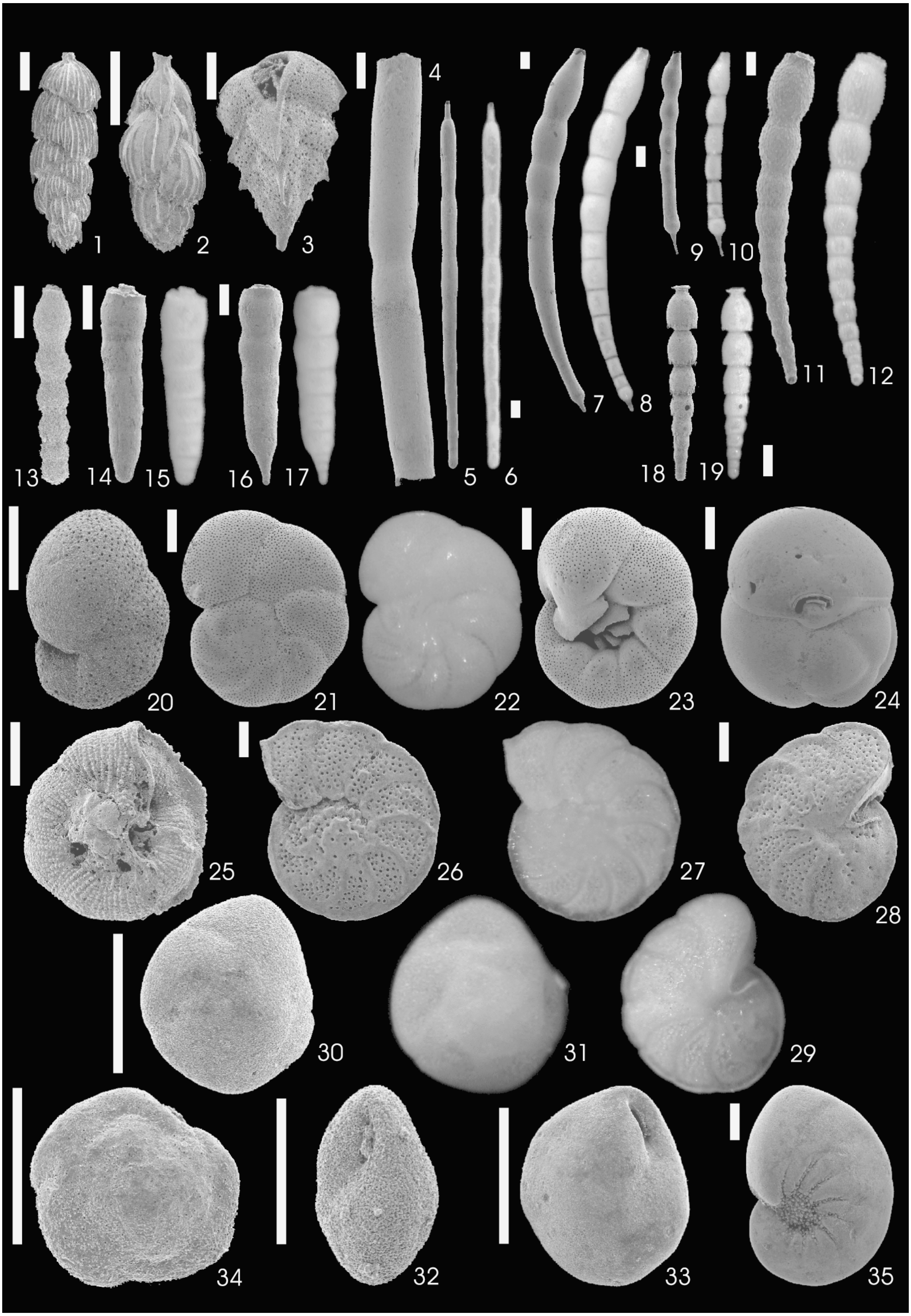
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Plate 7

Nonionidae

Figs. 1-4: ***Nonionoides karaganicus* (KRASHENINNIKOV)** – figs. 1-2, sample Mühlbach M5; figs. 3-4, sample Mühlbach M1.

Fig. 5: ***Nonionoides ventragranosus* KRASHENINNIKOV** – sample Mühlbach Mü1.

Fig. 6: ***Nonionella turgida* (WILLIAMSON)** – sample Mühlbach M1.

Fig. 8: ***Astrononion stelligerum* (d'ORBIGNY)** – details of umbilical structure on pl. 9, fig. 12; sample Mühlbach M1.

Figs. 9-10: ***Melonis pompilioides* (FICHTEL & MOLL)** – sample Mühlbach M4.

Figs. 11-12: ***Pullenia bulloides* (d'ORBIGNY)** – sample Mühlbach M1.

Fig. 13: ***Pullenia quinqueloba* (REUSS)** – sample Mühlbach M1.

Elphidiidae

Fig. 7: ***Porosononion granosum* (d'ORBIGNY)** – sample Mühlbach M4.

Chilostomellidae

Fig. 14: ***Allomorphina trigona* REUSS** – sample Mühlbach M1.

Fig. 15: ***Chilostomella ovoidea* REUSS** – sample Mühlbach M4.

Osangulariidae

Figs. 16-17: ***Charltonina* sp.** – sample Mühlbach M1.

Heterolepidae

Figs. 18-22: ***Heterolepa praecincta* (KARRER)** – sample Mühlbach M1.

Figs. 23-25: ***Heterolepa dutemplei* (d'ORBIGNY)** – fig 23, sample Mühlbach M6; figs. 24-25, sample Mühlbach Mü2.

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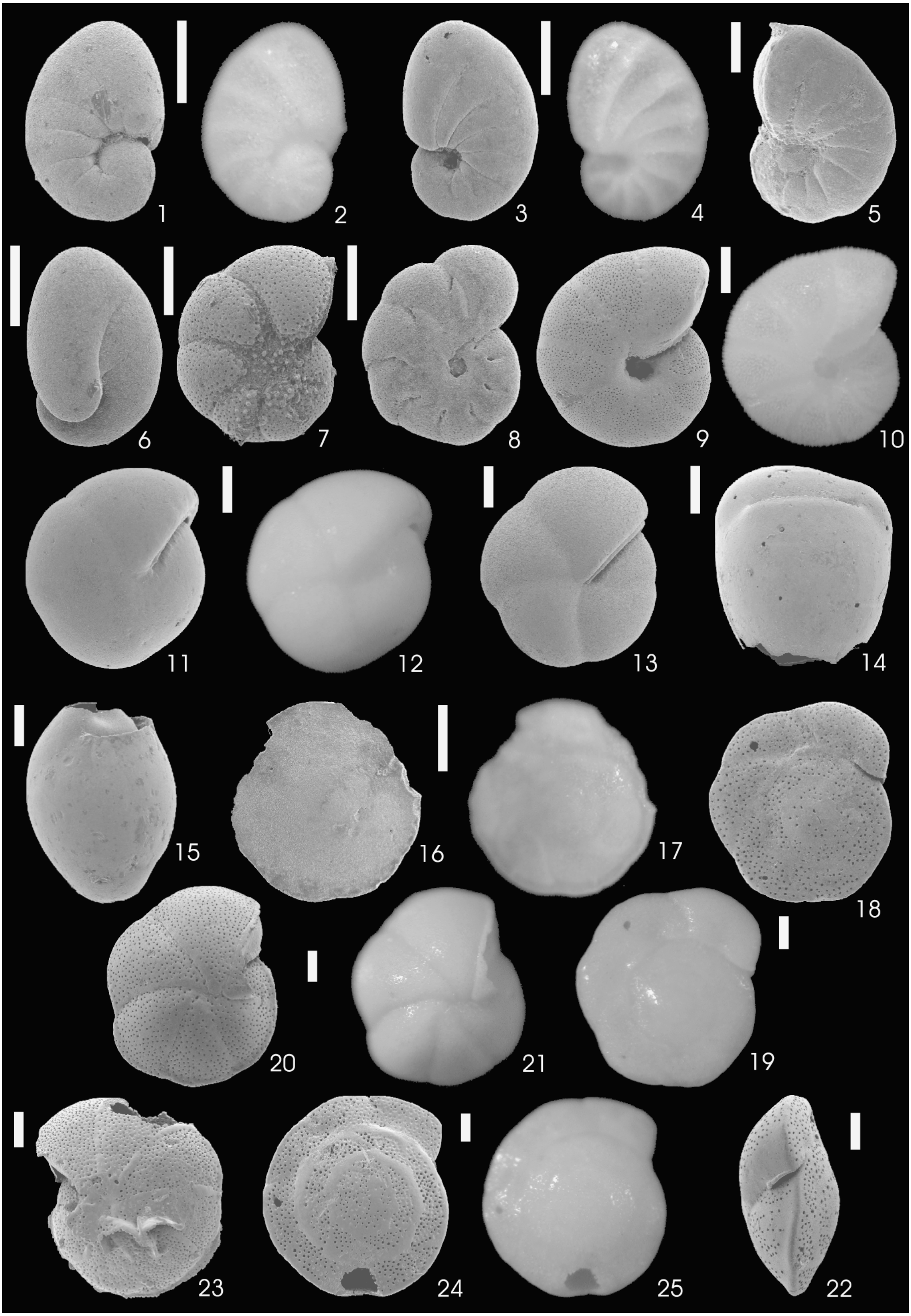
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Plate 8

Gavelinellidae

Figs. 1-3: ***Gyroidinoides octocameratus* (CUSHMAN)** – sample Mühlbach M6.

Fig. 4: ***Gyroidinoides soldanii* (d'ORBIGNY)** – sample Mühlbach M1.

Figs. 5-7: ***Gyroidinoides umbonatus* (SILVESTRI)** – figs. 5-6, sample Mühlbach M6; fig. 7, sample Mühlbach M1.

Rotaliidae

Fig. 8: ***Ammonia pseudobeccarii* (PUTRJA)** – umbilical view, sample Mühlbach M1.

Figs. 9-10: ***Ammonia* cf. *beccarii* (LINNE)** – sample Mühlbach M1.

Figs. 11-12: ***Ammonia viennensis* (d'ORBIGNY)** – sample Mühlbach M1.

Figs. 13-14: ***Ammonia tepida* (CUSHMAN)** – sample Mühlbach Mü2.

Fig. 15-16: ***Ammonia pseudobeccarii* (PUTRJA)** – fig. 15, sample Mühlbach M6; fig. 16, sample Mühlbach Mü1.

Elphidiidae

Fig. 17: ***Elphidium* cf. *angulatum* (EGGER)** – sample Mühlbach M1.

Fig. 18: ***Elphidium advenum* CUSHMAN** – sample Mühlbach M1.

Fig. 19: ***Elphidium reussi* MARKS** – sample Mühlbach M1.

scale bar 100 µm

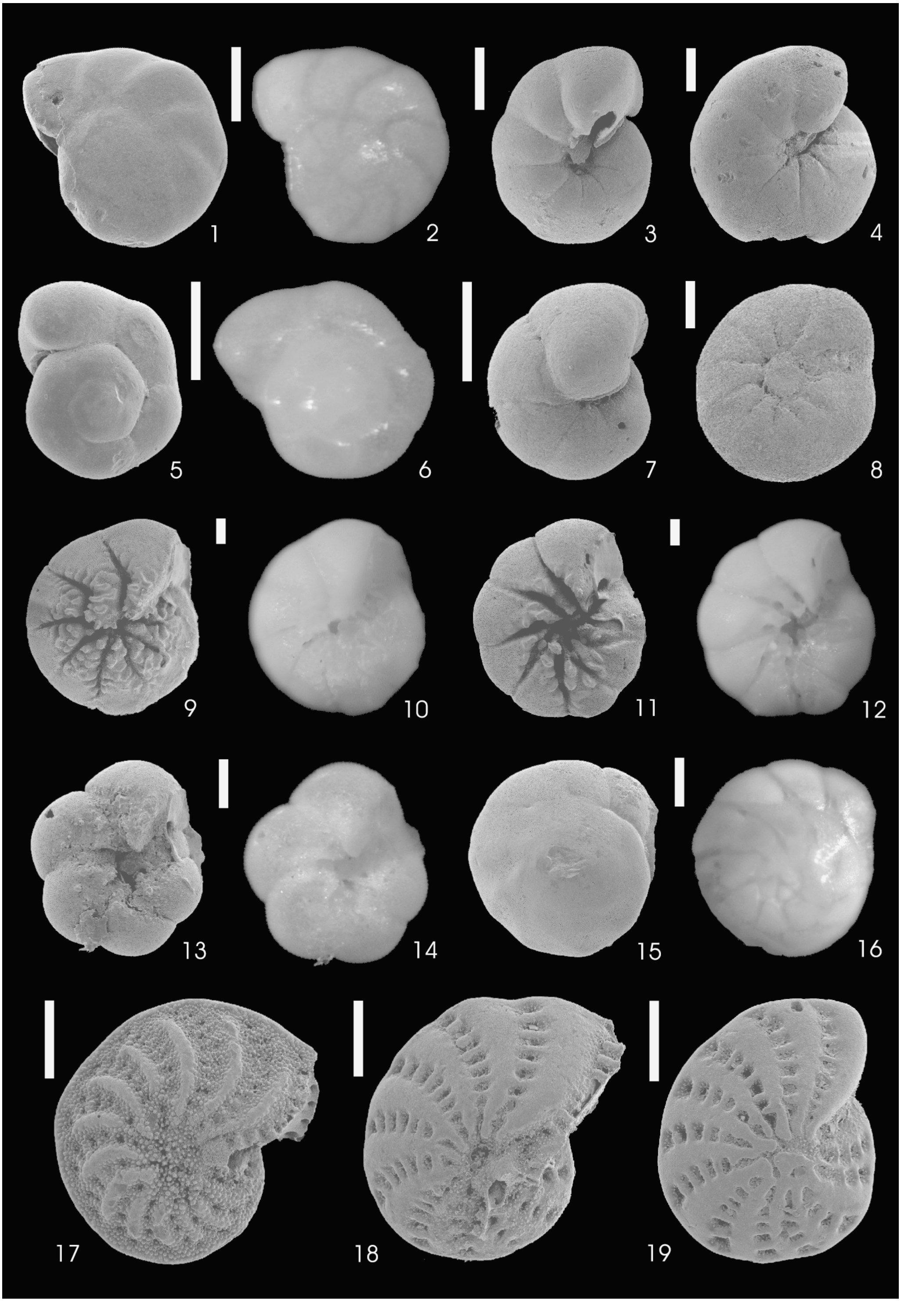
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Plate 9

Fig. 1: ***Dentalina acuta* d'ORBIGNY** – detail of aperture with radial slits; sample Mühlbach M1.

Fig. 2: ***Amphicoryna badenensis* (d'ORBIGNY)** – detail of aperture with internal denticles; neck with concentric collars; sample Mühlbach M1.

Fig. 3: ***Amphicoryna hispida* (d'ORBIGNY)** – second chamber of specimen pl. 4, fig. 9; sample Mühlbach M1.

Fig. 4: ***Siphonodosaria consobrina* (d'ORBIGNY)** – aperture with strong T-shaped tooth and internal denticles; sample Mühlbach M1.

Fig. 5: ***Siphonodosaria nuttalli gracillima* (CUSHMAN & JARVIS)** – aperture similar as in *S. consobrina* with strong tooth and internal denticles; sample Mühlbach M1.

Fig. 6: ***Myllostomella recta* (PALMER & BERMUDEZ)** – aperture with everted lip and internal simple tooth and denticles; base of chamber with short spines; sample Mühlbach M1.

Fig. 7: ***Siphonodosaria scripta* (d'ORBIGNY)** – aperture with broad serrate lip and strong internal tooth; sample Mühlbach Mü1.

Fig. 8: ***Siphonodosaria scripta* (d'ORBIGNY)** – second chamber of specimen pl. 6, fig. 11; sample Mühlbach Mü1.

Fig. 9: ***Myllostomella advena* (CUSHMAN & LAIMING)** – foramen with aperture of prelast chamber showing an apertural neck with phialine lip and internal denticles; sample Mühlbach M1.

Fig. 10: ***Bulimina ?* sp.** – initial part of specimen pl. 5, fig. 13; sample Mühlbach M1.

Fig. 11: ***Uvigerina ? pygmoides* PAPP & TURNOVSKY** – aperture on short neck, with a lid attached at one side of the apertural lip; detail of aperture in pl. 5, fig. 28; sample Mühlbach Mü1.

Fig. 12: ***Astrononion stelligerum* (d'ORBIGNY)** – an umbilical, imperforate, platelike prolongation of the chamber wall extends in posterior direction, leaving open a slitlike sutural aperture; detail of specimen pl. 7, fig. 8; sample Mühlbach M1.

Fig. 13: ***Turborotalita quinqueloba* (NATLAND)** – wall texture with medium-sized pores and hispid with small spine bases of flexible spines; detail of wall texture in pl. 12, fig. 1; sample Mühlbach M1.

Fig. 14: ***Turborotalita neominutissima* (BERMUDEZ & BOLLI)** – wall texture with medium-sized pores as in *T. quinqueloba*, and with small spine bases; detail in pl. 12, fig. 2; sample Mühlbach M1.

Fig. 15: ***Tenuitellinata selleyi* (LI, RADFORD & BANNER)** – wall texture microperforate, smooth with small crystallites; wall texture in pl. 12, fig. 10; sample Mühlbach M5.

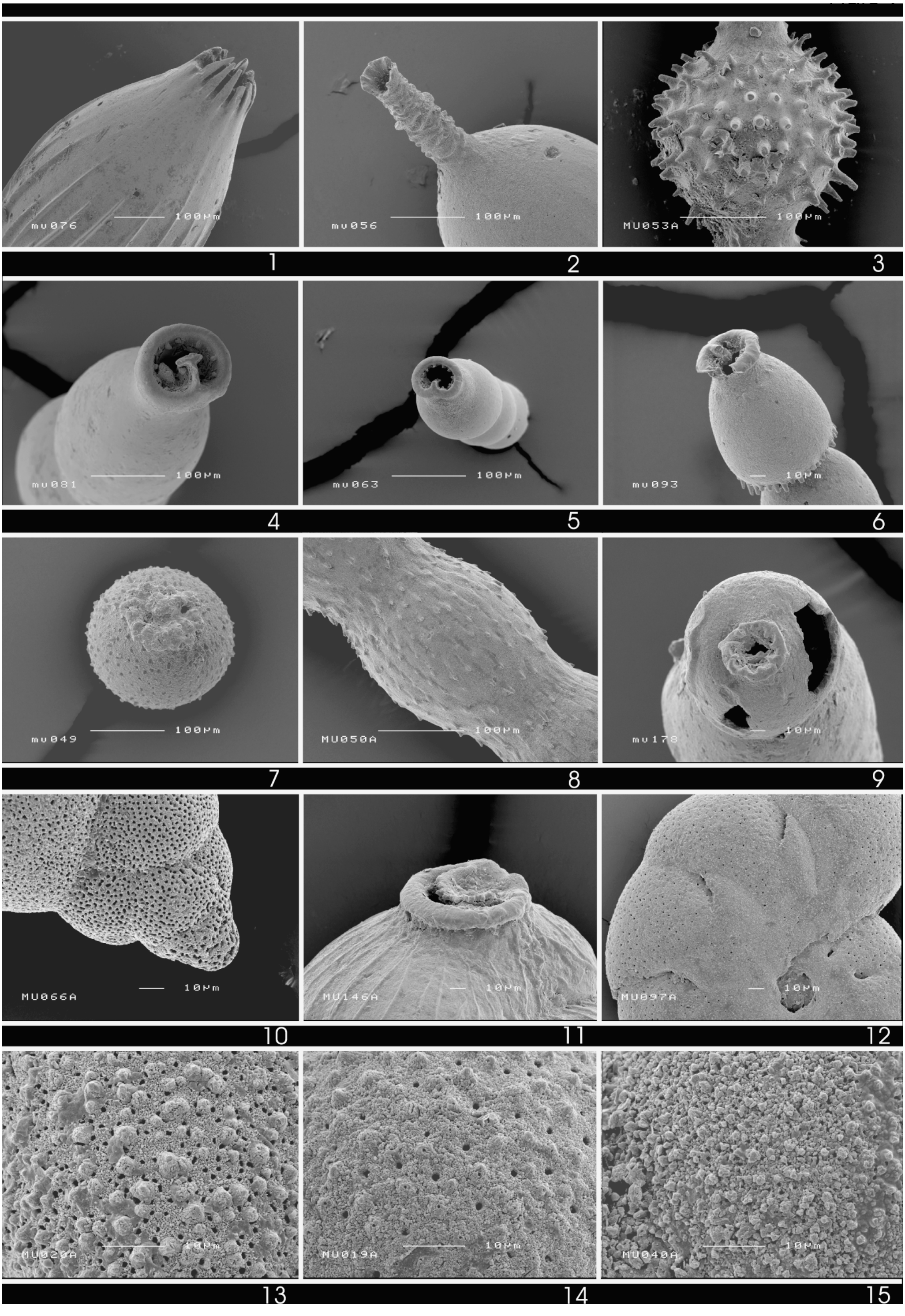
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Plate 10

Globigerinacea

Figs 1-2: ***Praeorbulina glomerosa circularis* (BLOW) - *Orbulina suturalis* BRÖNNIMANN transition** – sutural apertures with distinct lips as in *Praeorbulina*, first few additional apertures occur on the surface of final embracing chamber; sample Mühlbach M1.

Figs. 3-4: ***Globigerinoides bisphericus* TODD** – fig. 3, sample Mühlbach Mü2; fig. 4, sample Mühlbach M1.

Figs. 5-6: ***Globigerinoides trilobus* (REUSS)** – sample Mühlbach M1.

Figs. 7-8: ***Globigerinoides quadrilobatus* (d'ORBIGNY)** – sample Mühlbach M1.

Fig. 9: ***Globigerina praebulloides* BLOW** – sample Mühlbach M1.

Fig. 10: ***Globigerina bulloides* d'ORBIGNY** – sample Mühlbach M1.

Fig. 11: ***Globigerina diplostoma* REUSS** – sample Mühlbach M1.

Fig. 12: ***Globigerina* cf. *falconensis* BLOW** – sample Mühlbach Mü2.

Figs. 13-14: ***Globigerina concinna* REUSS** – sample Mühlbach M1.

Fig. 15: ***Globigerina bollii* CITA & PREMOLI SILVA** – sample Mühlbach M4.

Figs. 16-19: ***Globoturborotalita connecta* (JENKINS)** – figs. 16 and 17 same specimen, spiral side; figs. 18-19, umbilical side; wall texture in pl. 12, fig. 15; sample Mühlbach Mü1.

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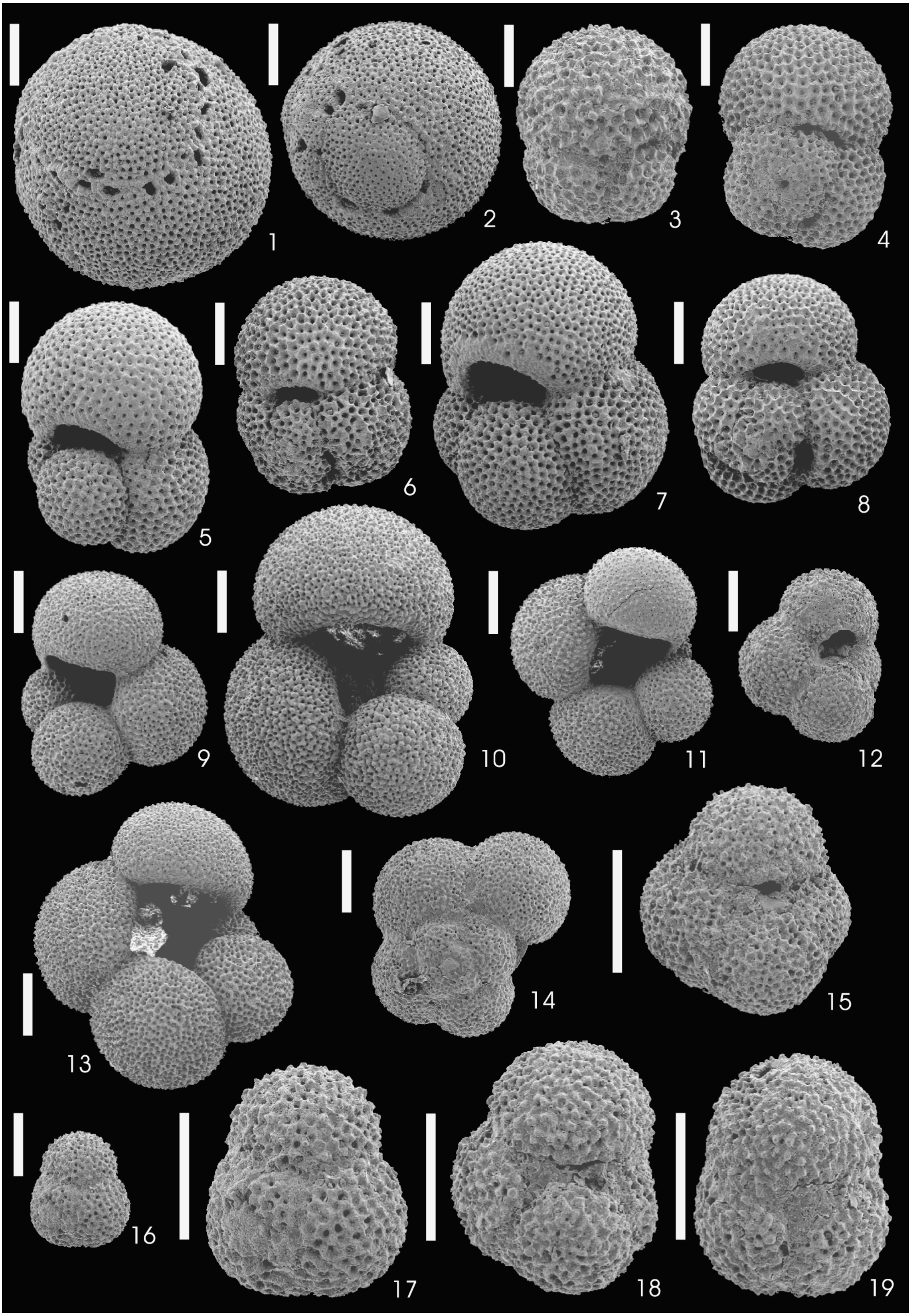
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Plate 11

Figs. 1-2: ***Globigerina ottnangiensis* RÖGL** – sample Mühlbach M5.

Figs. 3-4: ***Globigerina tarchanensis* SUBBOTINA & CHUTZIEVA** – sample Mühlbach M1.

Fig. 5: ***Globigerinella regularis* (d'ORBIGNY)** – sample Mühlbach M1.

Figs. 6-7: ***Globoturborotalita woodi* (JENKINS)** – fig. 6, sample Mühlbach M1; fig. 7, sample Mühlbach Mü2.

Figs. 8-9: ***Globoturborotalita druryi* (AKERS)** – sample Mühlbach M1.

Figs. 10-11: ***Globoquadrina* cf. *altispira* (CUSHMAN & JARVIS)** – sample Mühlbach M1.

Figs. 12-13: ***Globorotalia bykovae* (AISENSTADT)** – sample Mühlbach M1.

Fig. 14: ***Paragloborotalia? mayeri* (CUSHMAN & ELLISOR)** – sample Mühlbach Mü2.

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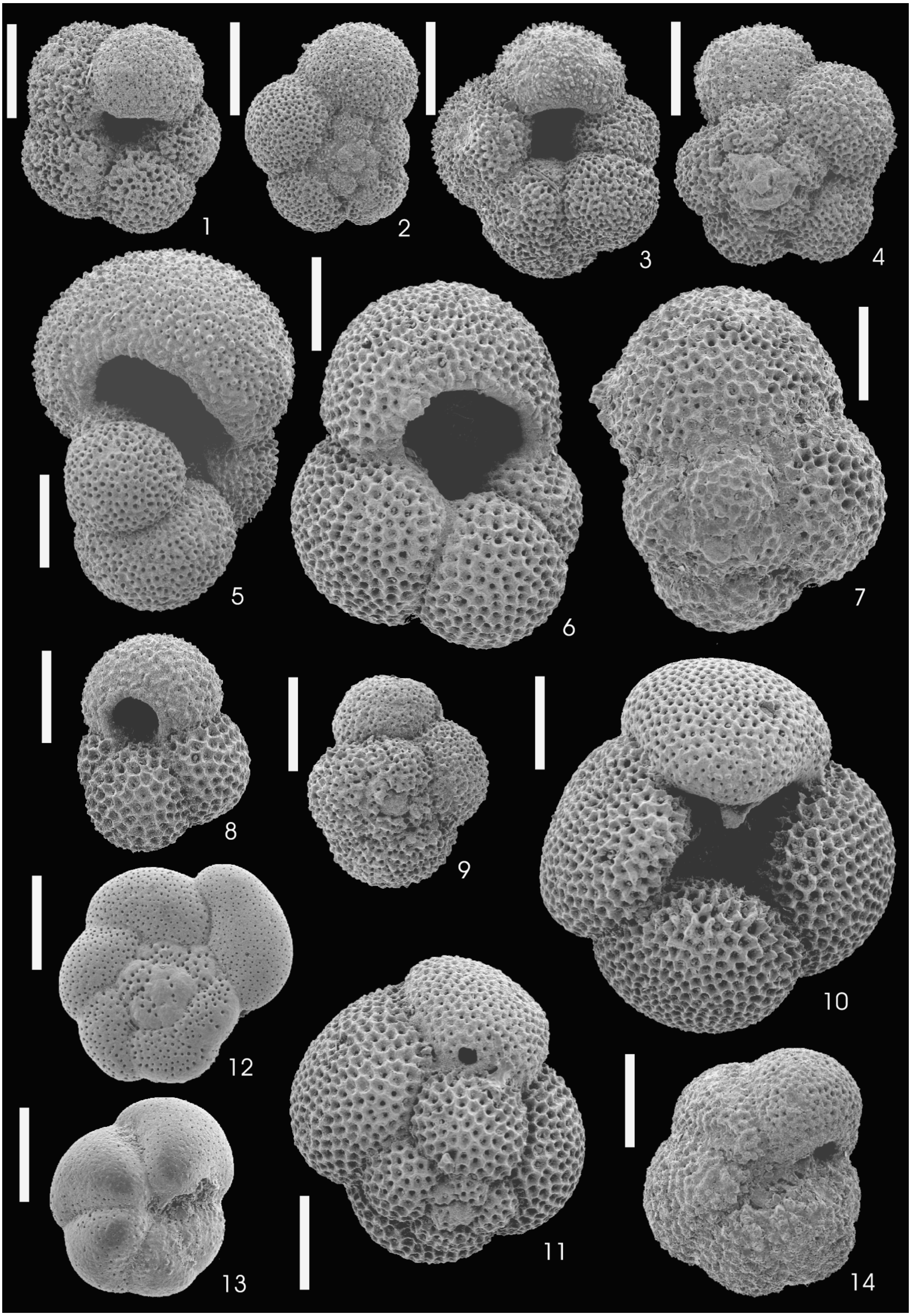
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Plate 12

Figs. 1-2: ***Turborotalita quinqueloba* (Natland)** – fig. 1, sample Mühlbach M1, fig. 2, sample Mühlbach M5.

Figs. 3-4: ***Turborotalita neominutissima* (Bermudez & Bolli)** – sample Mühlbach M5.

Figs. 5-6: ***Turborotalita* sp.** – sample Mühlbach M5.

Figs. 7-8: ***Tenuitella clemenciae* (Bermudez)** – fig. 7, umbilical view, sample Mühlbach M5; fig. 8, spiral view, sample Mühlbach M1.

Fig. 9-11: ***Tenuitellinata selleyi* Li, Radford & Banner** – fig. 9, spiral view; fig. 10, umbilical view; fig. 11, lateral view; sample Mühlbach M5.

Figs. 12-13: ***Globigerinita uvula* (ehrenberg)** – fig. 12, lateral view; fig. 13, detail of final chamber showing microperforate wall texture with small pustules; sample Mühlbach M1.

Fig. 14: ***Globigerinita glutinata* (Egger)** – umbilical view, sample Mühlbach M1.

Fig. 15: ***Globoturborotalita connecta* (Jenkins)** – cancellate wall texture obscured by thick gametogenic calcification; detail of pl. 10, fig. 18, final chamber; sample Mühlbach Mü1.

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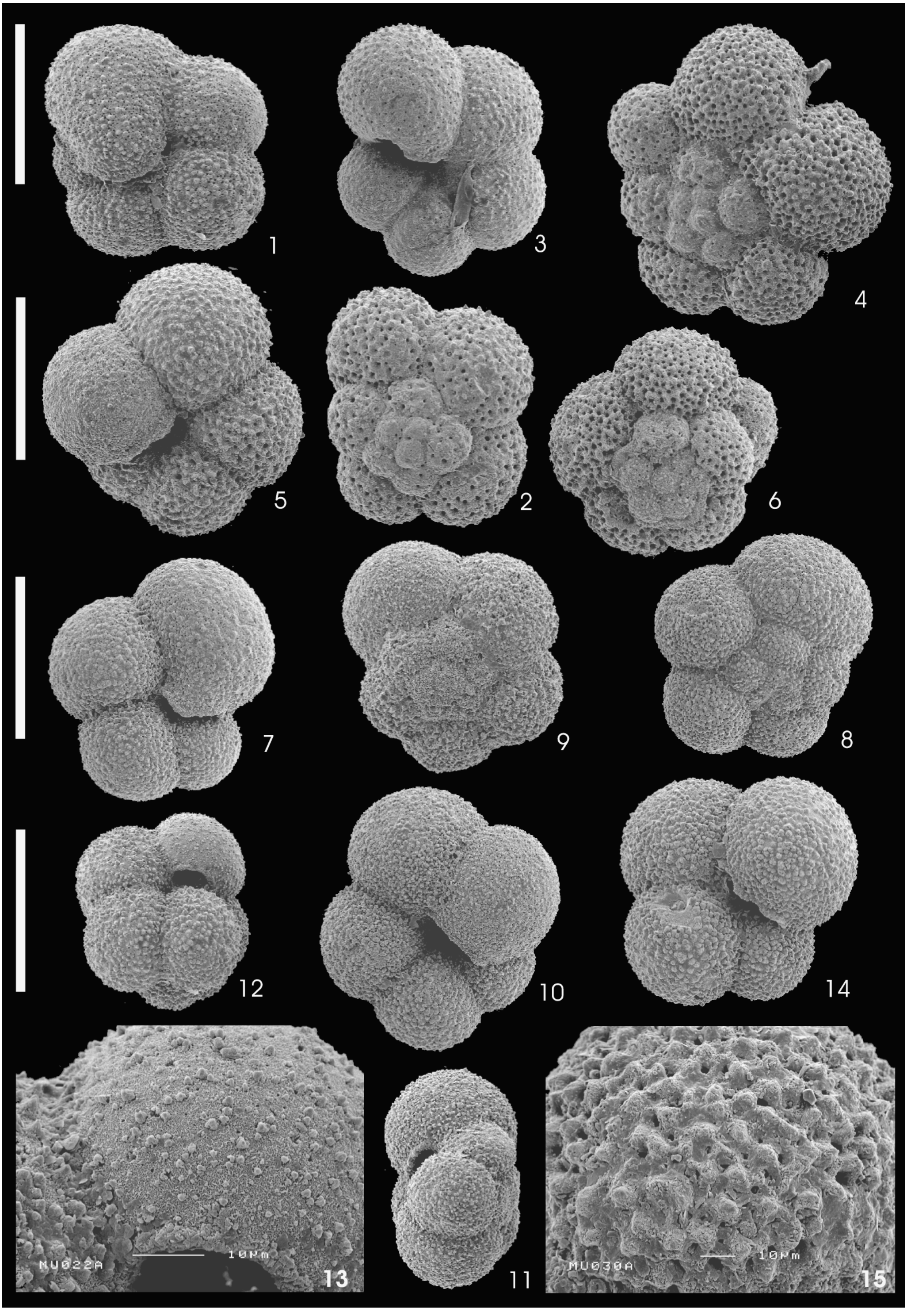
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