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The initial phase of the early Sarmatian (Middle Miocene) transgression. Foraminiferal and ostracod assemblages from an incised valley fill in the Molasse Basin of Lower Austria.

Holger GEBHARDT*), Irene ZORN & Reinhard ROETZEL

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Geologische Bundesanstalt, Neulinggasse 38, 1030 Wien, Austria;

*) Corresponding author, holger.gebhardt@geologie.ac.at

Abstract

In order to document the foraminiferal and ostracod faunal changes between Badenian and Sarmatian strata, we investigated samples from a sediment core drilled at Hollabrunn in Lower Austria. Lower Badenian strata show typical normal marine, outer shelf to upper bathyal foraminferal and ostracod assemblages also known from other sections in the Molasse and Vienna Basins. The co-occurrence of *Praeorbulina glomerosa circularis* and *Orbulina suturalis* indicates a lower Badenian age for these samples, corresponding to the mid Langhian Zone M6. The investigated core lacks middle to upper Badenian strata. We were able to identify the Sarmatian samples by 1) index species and 2) by apparently unique autochthonous microfossil assemblages. We found the Sarmatian foraminiferal index species *Nonion bogdanowiczi* and *Anomalinoides dividens* in samples from the upper part of the core and did not find foraminifers or ostracods belonging to lower Sarmatian *Elphidium reginum* Zone or younger (eco-) Zones. Consequently, the drilled Sarmatian samples belong to the basal Sarmatian *Anomalinoides dividens* (eco-) Zone. The monospecific occurrence of *Aubignyna perlucida* in one older sample, however, suggests an extreme, most likely brackish environment with very different conditions from those prevailing earlier during the Badenian. Although no foraminiferal index species were found in the sample, we correlate this ecostratigraphic event with the basal Sarmatian transgression. Ilyocyrididae, Candonidae and Darwinulidae in younger but still basal Sarmatian samples indicate fresh to oligohaline waters and point to increased terrestrial influences. The inferred depositional history fits well with the idea of a Sarmatian incised valley fill within Badenian sediments. Presence of uncommon ostracods (*Nipponocythere karsyensis*) may point to intensive faunal exchange with the Carpathian Foredeep during the early Badenian.

Um Faunenveränderungen bei Foraminiferen und Ostrakoden zwischen badenischen und sarmatischen Schichten zu dokumentieren, wurden von uns Proben eines Sedimentkerns aus Hollabrunn in Niederösterreich untersucht. Unterbadenische Schichten zeigen typische normalmarine Foraminiferen- und Ostrakodenassoziationen des äußeren Schelfs bis oberen Bathyals, die auch aus anderen Profilen des Molassebeckens und des Wiener Beckens bekannt sind. Das gemeinsame Vorkommen von *Praeorbulina glomerosa circularis* und *Orbulina suturalis* zeigt das unterbadenische Alter dieser Proben an, das der Zone M6 des mittleren Langhiums entspricht. Der untersuchte Kern enthielt keine mittel- bis oberbadenischen Ablagerungen. Die sarmatischen Alter konnten 1) durch Index-Arten und 2) durch offensichtlich einzigartige autochthone Mikrofossilassoziationen identifiziert werden. Im oberen Teil des Kerns konnten die sarmatischen Foraminiferenindexarten *Nonion bogdanowiczi* und *Anomalinoides dividens* gefunden werden, jedoch keinerlei Foraminiferen oder Ostrakoden, die der untersarmatischen *Elphidium reginum*-Zone oder jüngeren Ökozonen zugeordnet werden können. Daraus folgt, dass die erbohrten sarmatischen Proben der basalen *Anomalinoides dividens* (Öko-) Zone angehören. Das monospezifische Auftreten von *Aubignyna perlucida* in einer älteren Probe weißt auf einen extremen, höchstwahrscheinlich brackischen Lebensraum hin, in dem Umweltbedingungen herrschten, die von denen im Badenium sehr verschieden waren. Obwohl in dieser Probe keine Index-Arten gefunden wurden, wird dieses ökostratigraphische Ereignis von uns mit der Transgression im basalen Sarmatium korreliert. Ilyocyrididae, Candonidae und Darwinulidae in jüngeren aber noch immer basalsarmatischen Proben zeigen Süsswasser oder oligohaline Verhältnisse an und verweisen auf zunehmende terrestrische Einflüsse. Die sich hieraus ergebende Ablagerungsgeschichte passt gut mit der Vorstellung der sarmatischen Verfüllung eines in badenische Sedimente eingeschnittenen Tals zusammen. Das Vorkommen ungewöhnlicher Ostracodenarten (*Nipponocythere karsyensis*) deutet auf einen intensiven Faunenaustausch mit der karpatischen Vortiefe während des frühen Badeniums hin.

1. Introduction and geological setting

Several earlier papers (e.g., Papp et al., 1974; Jiříček and Seifert, 1990) accentuate the transitional character of the Sarmatian (late Serravallian) sediments of the Vienna Basin and the adjacent parts of the Molasse Basin. The Sarmatian was simply thought to be characteristic for the transition of the Paratethys from a fully marine Badenian (Langhian to early Serravallian) sea to the freshwater continental lake system in the Pannonian (Tortonian). This general interpretation changed recently through several papers pointing to highly variable depositional environments. These range from continental to normal marine, and even hypersaline settings during the Sarmatian Stage, but normal marine facies prevails (Harzhauser and Piller 2004a,b; Piller and Harzhauser, 2005; Mandic et al., 2008).

A rather narrow and about 50 km long, roughly WSW-ENE trending belt of lower Sarmatian deposits is known within the Molasse Basin in Lower Austria. This zone is running from the Vienna Basin in the east via Hollabrunn and Ziersdorf to Langenlois close to the Bohemian Massif in the west (Papp, 1950, 1962; Milles and Papp, 1957; Fig. 1). It is assumed that the Sarmatian sediments were deposited in an incised valley formed earlier by a river during the Middle to Late Badenian (~ late Langhian – early Serravallian). This river (paleo-Zaya) transported conspicuous amounts of debris into the northwestern Vienna Basin forming huge deltaic bodies (Jiříček and Seifert, 1990). A sea level lowstand at the end of the Badenian resulted in further incisement of that paleo-Zaya river and a basin-ward progradation of the deltas (Strauss et al., 2006). During the early Sarmatian transgression at c. 12.5 Ma the sea entered from the east into this precasted depression. Large amounts of lower Badenian marine sediments as well as middle Badenian fluviatile gravel were eroded and re-deposited within the Sarmatian succession (e.g., Reisbergschotter; Roetzel, 2003, 2007, 2009).

Sarmatian sediments near Hollabrunn were first described by Suess (1866). Also Vetters (1914) referred to these deposits. A first thorough paleontological approach was given by Papp (1950) who afterwards also dealt with the deposits near Ziersdorf (Milles and Papp, 1957) and Langenlois (Papp, 1962). Later on, Papp and Steininger (in Papp et al., 1974) introduced the section Hollabrunn as a faciostratotype of the early Sarmatian. The early Sarmatian sediments of the Molasse Zone were formally combined to the Ziersdorf Formation by Roetzel et al. (1999) with its type locality in the former brickyard near Ziersdorf (description in Milles and Papp, 1957). Kowalke and Harzhauser (2004) referred to the section Hollabrunn when describing the rissoid fauna of the Central Paratethys. During recent geological mapping, Roetzel (2003, 2007, 2009) showed that these deposits are widespread east of Hollabrunn. Mandic et al. (2008) gave a detailed facies study of the Hollabrunn outcrop.

The sediments of the Ziersdorf Formation mainly show intensely interbeddings of silts and clays in alternation with fine to coarse sands and gravel (compare Fig. 2). The successions was interpreted as marine to brackish tidal-flat deposits with mainly planar to wavy ripple cross lamination and convolute bedding. In some areas east of Hollabrunn, polymict, well-rounded, and poorly sorted coarse gravel ("Reisbergschotter"), interpreted as debris flow deposits, are intercalated in the silty to sandy succession (Roetzel, 2003, 2007, 2009). In outcrops, the thickness of the Ziersdorf Formation is not more than a few meters, but a maximum thickness of 110 m was verified in the OMV-drilling Hollabrunn 1 (Brix et al., 1977). The nearby OMV explorational well Altenmarkt i.Th. 1 drilled through 63 m mostly clayey and sandy lower Sarmatian sediments.

An ecostratigraphic zonation based on foraminifera for Sarmatian sediments in Lower Austria was first established by Grill (1941) and complemented and discussed by Papp et al. (1974) and Cicha et al. (1998). It was also complemented by mollusc zonations (see Harzhauser and Piller, 2004a for review). Both groups allow a fourfold subdivision (foraminifera: *Anomalinoides dividens*, *Elphidium reginum*, *E. hauerinum*, and *Porosononion granosum* Zones; molluscs: *Mohrensternia*, lower and upper *Ervilia*, and *Mactra* Zones), which do not fully correlate.

The correlation of the Ziersdorf Formation with the Early Sarmatian *Mohrensternia* Zone is shown mainly in outcrops in the surroundings of Hollabrunn (indicated by the index genus *Moh-*

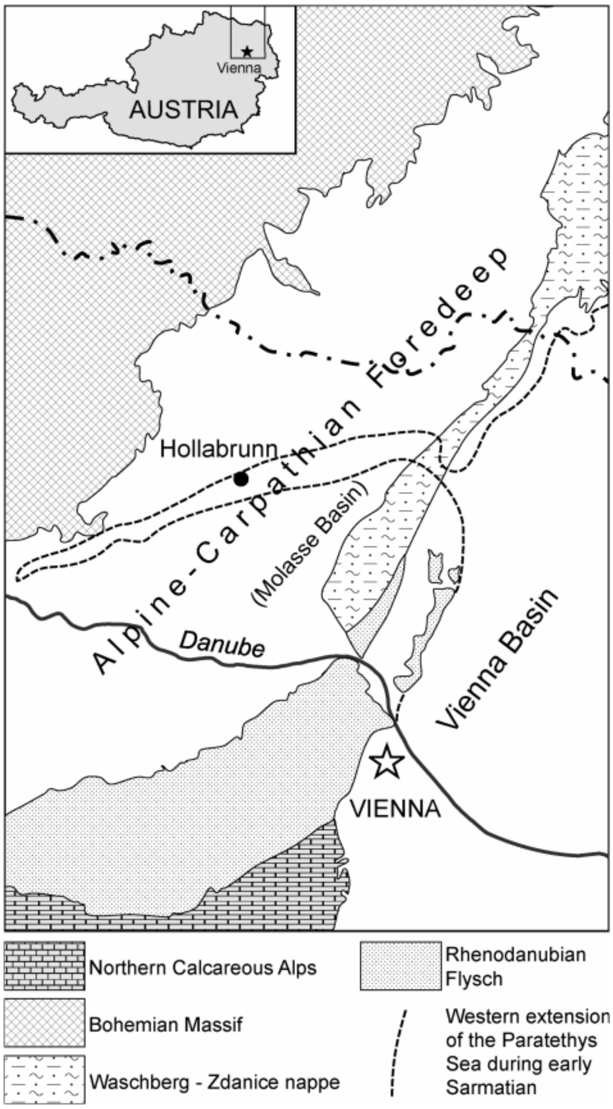

FIGURE 1: Simplified geological map of northeastern Austria and position of investigated site at Hollabrunn. White areas indicate Tertiary basin sediments outside the tectonic units shown in the legend (Molasse and Vienna Basins). Western extension of the Paratethys Sea during early Sarmatian according to Mandic et al. (2008).

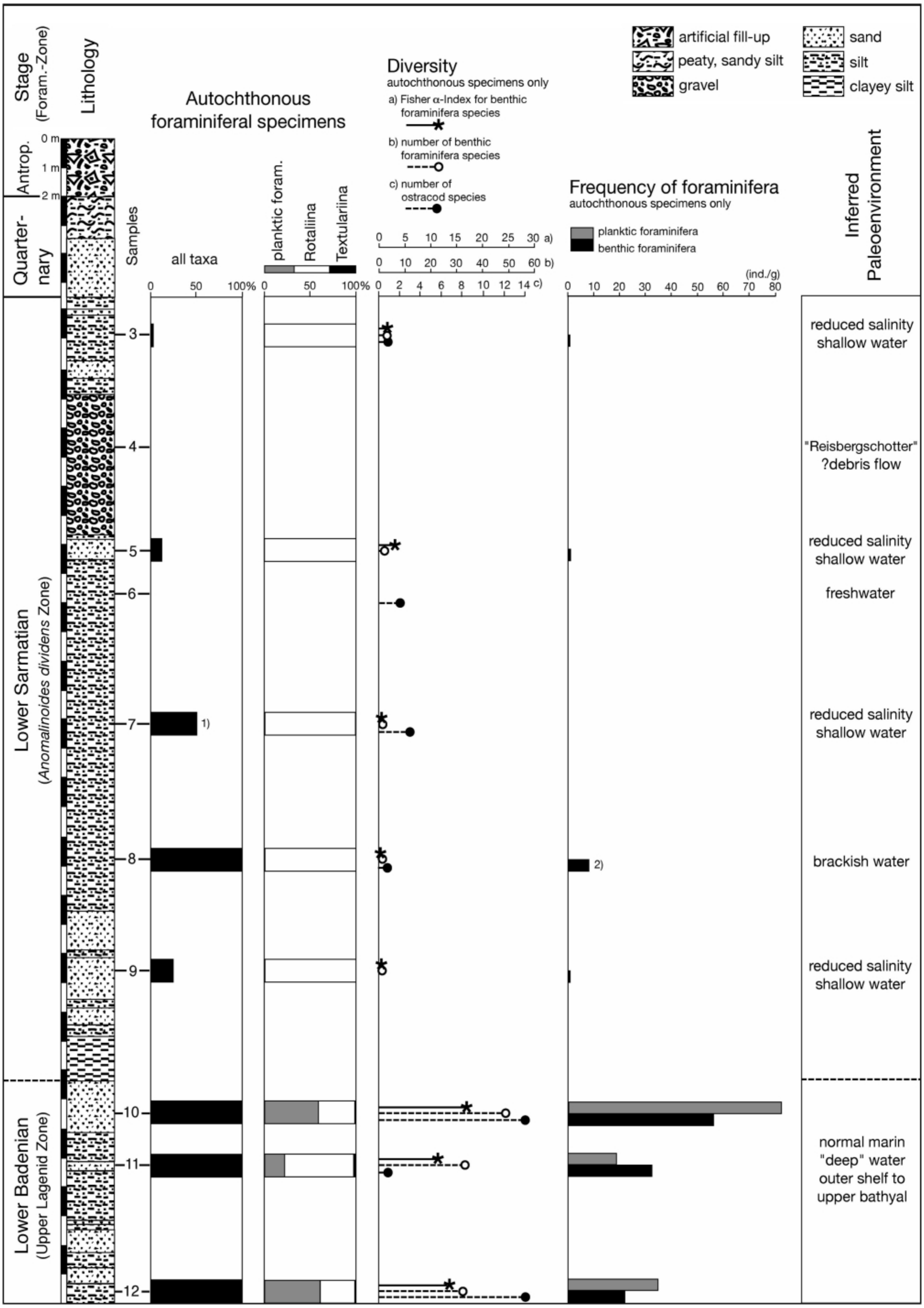

FIGURE 2: Lithologic section of borehole KB5 with biostratigraphic results, distribution of foraminiferal taxa, paleoecological proxies, and paleoecological interpretation of core KB5. 1) Only two specimens were found, 2) *Aubignyna* mass-occurrence.

rensternia as well as the occurrence of *Abra reflexa*, *Plicatiforma pseudoplicata*, and *Turritella eryna sarmatica*; Harzhauser and Piller, 2004a; Mandic et al., 2008). Additionally, the foraminiferal assemblage with large-sized elphidiids allows a correlation with the *Elphidium reginum* Zone (upper part of *Mohrensternia* Zone) in many outcrops. Furthermore, the ostracod-assemblages of these outcrops (*Aurila kollmanni*, *A. mehesi*, and *A. merita*) point to "Zone B" (*Cytheridea hungarica – Aurila mehesi* Assemblage Zone of Zelenka, 1990) of the early Sarmatian (cf. Zorn in Roetzel, 2003, 2007, 2009).

The lowermost *Anomalinoides dividens* Zone is usually widely ignored because of its poor preservation due to erosion and reworking during the early Sarmatian transgression. In the Molasse Basin of Lower Austria, partially large amounts of reworked Badenian microfossils within Sarmatian sediments and the rareness of Sarmatian index fossils make it difficult to mark a clear boundary between the two stages in this area (Roetzel, 2003, 2007, 2009). Most samples from field mapping and a number of reconnaisance drillings along the Göllersbach Valley east of Hollabrunn (Rupp in Roetzel, 2003, 2007) cannot be allocated offhand to either the Badenian (Grund Formation), Sarmatian (Ziersdorf Formation) or to younger stages. If Sarmatian deposits can be identified by typical foraminiferal and ostracod assemblages or by single Sarmatian index species, they are often interbedded into strata containing only reworked Badenian assemblages. Furthermore, basal Sarmatian assemblages were not yet found in this area. However, in the drill core presented in this paper, basal Sarmatian sediments are apparently preserved.

The aim of this contribution is to document the micropaleontological record (foraminifers and ostracods) over the Badenian-Sarmatian boundary, exemplified by a sediment core drilled beyond the Sarmatian coverage. We determine the ages of the sediments biostratigraphically, interpret the depositional environments, and confirm or disprove existing concepts on depositional processes for this interval.

Samples were taken from the sediment core KB5 drilled for ground water monitoring in 2005 in the premises of the company Frisch and Frost (BMN-coordinates 731306.09 E, 381326.29 N; sea-level: 224.3 m) at the northern margin of the town of Hollabrunn (Lower Austria, Fig. 1). This is a marginal position within the area flooded by the Sarmatian transgression. The location of KB5 is topographically lower than the nearby and well-known sand pit "Weik" with its lower (but not basal) Sarmatian mollusc assemblages (Mandic et al., 2008). Therefore, older strata can be expected in KB5. A simplified lithologic description of the investigated borehole is given in Appendix 1.

2. Material and methods

The 40 m long core consists of 5.4 m Quaternary peaty silts, sand and gravel, and 34.6 m Neogene alternations of clayey silt, silt and sand with a 5 m thick conglomeratic layer occurring in the upper part (see Fig. 2, Appendix 1). Sampling was not done for micropaleontological purposes during the time of drilling. All samples were soaked with hydrogen peroxide for disintegration and were washed through a 0.063 mm sieve. The majority of samples is rich in quartz sand, and their residues were floated with carbon tetrachloride in order to concentrate calcareous microfossils, i.e., foraminifers and ostracods. This procedure does not change the assemblage composition significantly, at least not for frequent taxa (Gibson and Walker, 1967; Gebhardt and Rupp, 2008). Samples KB5/7 and KB5/8 were marl samples with almost no sand content and consequently their residues were not floated. Only aliquots (splits) were scanned and picked from some samples with high contents of foraminifers (Table 1). We restricted classification of foraminiferal and ostracod species to the fraction > 0.125 mm because of severe uncertainties in species recognition of small or juvenile foraminifers, in particular of planktic foraminifers and ostracod larvae. To gain the complete assemblage of the rather rare ostracods, the complete residues > 0.125 mm were scanned and picked. However, the numbers of ostracods in the samples were too small for statistic investigations and only species occurrences are listed here (Table 2).

Planktic and benthic foraminifers were classified mainly on the basis of the following publications: AGIP (1982), Nomura (1983), Rupp (1986), Cicha et al. (1998), Rögl (1998), Rögl and Spezzaferri (2003), and Schütz et al. (2007). For rare ostracod species, we referred to Aiello et al. (1996), Szczechura and Aiello (2003), and Aiello and Szczechura (2004). Plates 1 to 3 show important Badenian and Sarmatian foraminifers and ostracods.

All sample material (including figured specimens) is stored in the collection of the Geologische Bundesanstalt, Vienna, Austria (collection sub-units 2009/006/ for ostracods, 2009/039/ for foraminifers).

3. Results

3.1 Microfauna

3.1.1 Planktic foraminifers

Planktic foraminifers (Plate 1, Fig. 10-25) were found in large numbers in samples KB5/3 and /10 to /12 and occasionally in some of the other samples. Most common is the genus *Globigerina* (*G. bulloides*, *G. diplostoma*, *G. falconensis*, *G. praebulloides*, *G.* cf. *tarchanensis*). *Globorotalia bykovae* is also a rather common species, but *Globigerinoides* (*G. bisphaericus*, *G. trilobus*) as well as *Orbulina suturalis*, *Paragloborotalia siakensis*, *Praeorbulina glomerosa circularis*, and *Tenuitellinata selleyi* are less common species. *Globigerinella obesa*, *Globigerinita glutinata*, and *Tenuitellinata angustiumbilicata* are rare and occur only in a few samples. All planktic species are representatives of the Badenian Stage (e.g., Cicha et al., 1998) and those found in the youngest sample KB5/3 are reworked ones (see below, only autochthonous species were considered for Fig. 2). Planktic species indicating a Sarmatian (or late Serravallian) age were not found. We did not distinguish among the *Globigerina* in Table 1 (generally small specimens of the *Globigerina* species listed above) because of difficulties in species recognition with light microscopy in many cases.

Species	**KB5/3**	**KB5/4**	**KB5/5**	**KB5/7**	**KB5/8**	**KB5/9**	**KB5/10**	**KB5/11**	**KB5/12**
Ammodiscus cretaceus Reuss						1			
Ammonia pseudobeccarii (Putrja)			1						
Ammonia viennensis (d'Orbigny)	15		1		1	5	5	9	
Amphicoryna badensis (d'Orbigny)	3					2	3	3	3
Amphicoryna hispida (d'Orbigny)	1						1	1	3
Amphimorphina haueriana Neugeboren	2						1		
Angulogerina angulosa (Williamson)	1						1		
Anomalinoides dividens Luczkowska			1						
Asterigerinata planorbis (d'Orbigny)	4								
Aubignyna perlucida (Heron-Allen andEarland)	3		1	1	747	10	1		
Aubignyna perlucida - aberant forms					31				
Baggina cf. *arenaria* (Karrer)							1		
Bolivina antiqua d'Orbigny	1								
Bolivina dilatata Reuss	8						5	5	2
Bolivina hebes Macfadyen	6						6	2	2
Bolivina viennensis Marks						1	2		
Bulimina striata d'Orbigny	7							3	2
Cassidulina laevigata d'Orbigny	7						2	2	10
Caucasina elongata (d'Orbigny)	41		2			9	40	18	9
Caucasina subulata (Cushman and Parker)	10					1	18	11	7
Cibicidoides cf. *lopjanicus* (Myatlyuk)	4					3			
Cibicidoides pachyderma (Rzehak)	1						1		
Cibicidoides ungerianus (d'Orbigny)	3						3	4	1
Dentalina acuta d'Orbigny	1								
Dimorphina akneriana (Neugeboren)	1								
Elphidiella minuta (Reuss)								1	
Elphidium fichtelianum (d'Orbigny)	1								
Elphidium cf. *grilli* Papp	2								1
Elphidium cf. *incertum* (Williamson)	1								
Elphidium reussi Marks	1								
Evolvocassidulina cf. *brevis* (Aoki)									1
Fursenkoina acuta (d'Orbigny)	5								
Gavelinopsis praegeri (Heron-Allen and Earland)								1	1
Geminiella gibbera (Buchner)							2		
Glandulina aequalis (Reuss)									2
Globigerina cf. *tarchanensis* Subbotina and Chutzieva	3					2	5	4	
Globigerina spp.	42		4				225	25	139
Globigerinella obesa (Bolli)	1						4		
Globigerinita glutinata (Egger)	1								
Globigerinoides bisphaericus Todd							1	1	3
Globigerinoides trilobus (Reuss)	8							4	7
Globobulimina pupoides (d'Orbigny)	45						6	11	2
Globocassidulina oblonga (Reuss)	3						1		
Globorotalia bykovae (Aisenstat)	51						151	20	32
Guttulina communis d'Orbigny							3		1
Gyroidinoides soldanii (d'Orbigny)	7		1				2	12	3
Gyroidinoides umbonatus (Silvestri)	4						15	4	
Hanzawaia boueana (d'Orbigny)	3						3		
Heterolepa dutemplei (d'Orbigny)	12					4	3	29	2

Table 1: Abundance of foraminifera (number of specimens picked) in the samples of core KB5.

Species	KB5/3	KB5/4	KB5/5	KB5/7	KB5/8	KB5/9	KB5/10	KB5/11	KB5/12
Laevidentalina badensis (d'Orbigny)							2		
Lagena striata (d'Orbigny)							4	1	
Lagenonodosaria sublineata (Brady)									1
Lenticulina calcar (Linné)	1						3		
Lenticulina inornata (d'Orbigny)	5		2				6	7	
Lenticulina serpens (Seguenza)							1		
Lenticulina sp.								1	
Martinottiella karreri (Cushman)								4	
Martinottiella communis (d'Orbigny)	1						1		
Melonis pompilioides(Fichtel and Moll)	5						5	13	5
Myllostomella advena (Cushman and Laiming)	2								
Myllostomella recta (Palmer and Bermudez)	1								
Neugeborina irregularis (d'Orbigny)	6						3	2	
Neugeborina longiscata (d'Orbigny)									1
Nonion bogdanowiczi Voloshinova	3								
Nonion commune (d'Orbigny)	46		3			1	75	31	45
Nonion sp.								1	
Nonioniodes karaganicus (Krasheninnikow)							2		
Orbulina suturalis Brönnimann							2		12
Orthomorphina sp.							1		
Paragloborotalia siakensis (Le Roy)	1						3	4	8
Plectofrondicularia sp.	1						1		1
Praeorbulina glomerosa circularis (Blow)	3					1		1	3
Pseudosolenia lateralis carinata (Buchner)							1		
Pullenia bulloides (d'Orbigny)							5	6	1
Pyramidulina continuicosta (Schubert)	1								
Saracenaria arcuata (d'Orbigny)		1					1		
Semivulvulina pectinata (Reuss)	1								
Sigmoilinita tenuis (Czjzek)	2						2		1
Siphonodosaria consobrina (d'Orbigny)							3	1	
Siphonodosaria pyrula (d'Orbigny)							8		1
Siphotextularia concava (Karrer)							2		1
Spirorutilus carinatus (d'Orbigny)	3						2		
Stilostomella adolphina (d'Orbigny)	1						8	2	
Tenuitellinata angustiumbilicata (Bolli)									7
Tenuitellinata selleyi Li, Radford and Banner	6						4	2	15
Textularia gramen d'Orbigny	2						1		3
Turborotalita quinquelloba (Natland)							17	2	
Uvigerina grilli Schmid	5							1	1
Uvigerina macrocarinata Papp and Turnowsky	5						2	4	
Uvigerina semiornata d'Orbigny									1
Vaginulinopsis pedum (d'Orbigny)								2	
Valvulineria complanata (d'Orbigny)	31		3				12	9	12
?*Cibicidoides* sp.							2		
?*Gaudryina* sp.					1				
?*Glandulina sp.*	3								2
?*Gyroidinoides* sp.				1					
?*Heterolepa* sp.	1								
?*Melonis* sp. Schütz et al. 2007	1								

TABLE 1 CONTINUED

Species	KB5/3	KB5/4	KB5/5	KB5/7	KB5/8	KB5/9	KB5/10	KB5/11	KB5/12
?*Semivulvulina* sp.								1	
?*Siphonodosaria* sp.								1	3
Globotruncanita sp.								1	
sum	431	1	17	2	779	34	685	257	357
split (1/X)	2	1	1	1	1	2	32	32	32
dry rock weight (g)	194	200	173	200	200	200	159	200	199
Fisher a-Index (autochth. spec. only)	1.7	0	2.6	0.5	0.1	0.3	16.7	11.1	13.0
Ind/g benthic (autochth. spec. only)	0.082474	0	0.011561	0.005	3.89	0.1	56.3522	33.12	22.35176
Ind/g planktic (autochth. spec. only)	0	0	0	0	0	0	82.31447	9.44	35.05528

Table 1 continued

3.1.2 Benthic Foraminifers

Benthic foraminifers (Plate 1, Fig. 1-9, 26-39; Plate 2, Fig. 1-48; Plate 3, Fig. 1-6) were found in large numbers in most of the investigated samples. Contrary to this, samples KB5/4 to/7 yielded only a small number of individuals. Sample KB5/6 is even barren of foraminifers. Results of paleoenvironmental parameters such as planktic/benthic-ratio or diversity are described below. The most frequent species belong to the genera *Ammonia*, *Aubignyna*, *Bolivina*, *Caucasina*, *Globobulimina*, *Gyroidinoides*, *Heterolepa*, *Nonion* and *Valvulineria*. Table 1 shows a complete species list including a number of rare or reworked species, and such with uncertain taxonomic status or poor preservation. One sample (KB5/8) contains a monospecific assemblage with only *Aubignyna perlucida*, but assemblages of other samples with high numbers of foraminifers are diverse. In total, 83 autochthonous benthic foraminiferal species were found in the samples. The found genera and species are about the same as those recorded in field mapping reports (Rupp in Roetzel, 2003, 2007, 2009).

3.1.3 Ostracods

Twenty five ostracod species, belonging to 23 genera, were found in small numbers in 7 samples (Table 2). Samples KB5/4, /5, and /9 are free of any ostracods. Most of the samples yielded 1 to 3 different species, only samples KB5/10 and /12 are diverse and yielded 14 species each. The following species are common in samples KB5/10 and /12: *Bosquetina carinella*, *Buntonia subulata*, *Cytheropteron ascolii*, *Henryhowella asperrima*, *Krithe* sp., *Olimfalunia* ex gr. *plicatula*, *Sagmatocythere* ? sp. and *Xestoleberis glabrescens*. This assemblage indicates a Badenian age and normal marine conditions. Rare elements are *Argilloecia fatua*, *Aurila cicatricosa*, *Cytherella cercinata*, *Loxoconchidea minima*, *Nipponocythere karsyensis*, *Parakrithe rotundata*, *Pseudopsammocythere* cf. *kollmanni*, *Sagmatocythere tenuis* and a subtriangular, probably new species of the genus *Xestoleberis*. One *Cyamocytheridea* specimen seems to be re-deposited because of its corrosion traces and black color. Loxoconchidea minima and Nipponocythere karsyensis are recorded in the Austrian Molasse Zone for the first time. Their presence in Lower Badenian strata in Lower Austria may point to intensive faunal exchange with the Carpathian Foredeep.

The other samples did not yield marine faunal elements except for a fragment of *Costa* ? sp. in KB5/11 and *Eucytherura* sp. in sample KB 5/7. The latter is re-deposited due to its state of preservation (Pl. 3, fig. 9). Additionally to the lack of foraminifers, remnants of *Ilyocypris* cf. *expansa* and *Darwinula* ? sp. (Pl. 3, fig. 7-8) could be traced in sample KB5/7, indicating fresh- to brackish water influence. *Ilyocypris* cf. *expansa* also appears in sample KB5/6 together with *Fabaeformiscandona* cf. *pokornyi*. Sample KB 5/8 contains only *Hemicyprideis dacica*, a typical Sarmatian ostracod which can also be found in older brackish to brackish-limnic sediments.

3.2 Biostratigraphy

3.2.1 Badenian

Samples KB5/10 to/12 show typical Badenian foraminferal and ostracod assemblages also known from other sections in the Molasse (e.g., Rögl and Spezzaferri, 2003; Zorn, 2003, 2004; Holcová and Zágoršek, 2008) and Vienna Basins (e.g., Báldi and Hohenegger, 2008) or Hungary (e.g., Báldi, 2006). Sample KB5/9 yielded elements from the Badenian and the ongoing Sarmatian brackish environments. The co-occurrence of *Praeorbulina glomerosa circularis* and *Orbulina suturalis* indicates a lower Badenian age (Upper Lagenid Zone; Rögl et al., 2002, 2008) for samples KB5/10 to/12, corresponding to the mid Langhian Zone M6 of Berggren et al. (1995). We did not find any foraminifers or ostracods indicating a younger stratigraphic age than lower Badenian (Upper Lagenid Zone) in these samples and therefore suggest this age for samples KB5/10 to/12. The rare ostracod *Nipponocythere karsyensis* in sample KB5/10 has hitherto only been found in the Lower Badenian of the Carpathian Foredeep of Poland and Czech Republic (Szczechura and Aiello, 2003).

The Sarmatian sample KB5/3 is also dominated by reworked Badenian foraminifers but contains the Sarmatian index species *N. bogdanowiczi*. The lithological change at 32.30 m depth in core KB5 probably indicates the beginning of the Sarmatian transgression (Fig. 2), because the prominent bioturbation and frequently alternating sandy and silty layers in the underlying sandy stratum are typical for Badenian Sediments in adjacent areas.

3.2.2 Sarmatian

The partially large amounts of reworked Badenian microfossils within Sarmatian sediments and the rareness of Sarmatian index species make it difficult to mark a clear boundary between the two stages. However, based on our counts of foraminifers and ostracods, we were able to identify the Sarmatian samples by 1) index species as indicated in Cicha et al. (1998) and Schütz et al. (2007) and 2) by apparently unique autochthonous microfossil assemblages (i.e., different from all known Badenian assemblages in Lower Austria, see below).

We identified the Sarmatian foraminiferal index species *Nonion bogdanowiczi* in sample KB5/3 and *Anomalinoides dividens* in sample KB5/5. *A. dividens* is very similar to basal Sarmatian *A. badensis* of Brestenská (1974). The species *Elphidium* cf. *incertum* and *Melonis* ? sp. of Schütz et al. (2007) are restricted to Sarmatian samples at Hollabrunn but their exact stratigraphic ranges are not known. We did not find foraminifers or ostracods indicating the lower, middle or upper Sarmatian *Elphidium reginum*- *Elphidium hauerianum*-, and *Porosononion granosum* (eco-)-Zones. Consequently, sample KB5/5 and subsequent samples belong to the basal Sarmatian *Anomalinoides dividens*-(eco-) Zone (Harzhauser and Piller, 2004a; Piller and Harzhauser, 2005; Mandic et al., 2008).

Species	KB5/ 3	KB5/ 6	KB5/ 7	KB5/ 8	KB5/ 10	KB5/ 11	KB5/ 12
Argilloecia fatua Barra et al.							x
Aurila cicatricosa (Reuss)							x
Bosquetina carinella (Reuss)					x		x
Buntonia subulata (Ruggieri)					x		x
Costa? sp.						x	
Cushmanidea? sp.					x		
Cyamocytheridea sp.							x
Cytherella cercinata Aiello et al.							x
Cytherella sp. juv.					x		
Cytheropteron ascolii Carbonnel					x		x
Darwinula? sp.	x		x				
Eucytherura sp.			x				
Fabaeformiscandona cf. *pokornyi* (Kheil)		x					
Hemicyprideis dacica (Héjjas)				x			
Henryhowella asperrima (Reuss)					x		x
Ilyocypris cf. *expansa* (Reuss)		x	x				
Krithe sp.					x		x
Loxoconchidea minima Bonaduce et al.							x
Nipponocythere karsyensis Szczechura and Aiello					x		
Olimfalunia ex gr. *plicatula* (Reuss)					x		x
Parakrithe rotundata Aiello et al.					x		
Pseudopsammocythere cf. *kollmanni* Carbonnel					x		
Sagmatocythere tenuis (Ciampo)					x		
Sagmatocythere ? sp.					x		x
Xestoleberis glabrescens (Reuss)					x		x
Xestoleberis sp.							x

Table 2: Occurrence of ostracods in the samples of core KB5.

Aubignyna perlucida is known from older sediments of the study area (e.g., Rögl 1998, Karpatian; Rupp 1986, Spezzaferri 2004, Badenian) and also from modern environments (e.g., Heron-Allen and Earland, 1913). Thus, this species cannot be used as an index species. The almost monospecific occurrence of this species in sample KB5/8, however, suggests an extreme, most likely brackish environment (see paleoenvironmental interpretation) with conditions very different from those prevailing during the Badenian. Although no further foraminiferal index species were found in this sample, we correlate this ecostratigraphic event to the deposition of marginal marine sediments under brackish conditions during the Sarmatian transgression, i.e., to the basal Sarmatian. The occurrence of the brackish water indicating ostracod *Hemicyprideis dacica* in the same sample confirms the transitional character of these strata. *Fabaeformiscandona* cf. *pokornyi*, *Darwinula* ? sp. and *Ilyocypris* cf. *expansa* in samples KB5/3, /6, and /7 indicate fresh to oligohaline waters (Pipik and Bodergat, 2003) and point to increased terrestrial influences. We therefore allocate sample KB5/8 and all younger samples to the Sarmatian Stage (Fig. 2).

Because of common mass-replacements of Badenian foraminifers also in other Sarmatian sediments of the surrounding area as reported by Milles and Papp (1957) and Roetzel (2003, 2007), the Sarmatian age of such samples may not be easily recognized. Additionally, such samples are frequently size-fractionated (Rupp in Roetzel, 2003, 2007), which is not the case with the Badenian samples KB5/10-12. The total thickness of Sarmatian strata elsewhere in the Hollabrunn area may reach up to 110 m (OMV borehole Hollabrunn 1; Roetzel, 2009). The Sarmatian sediments in core KB5 (c. 27 m thickness) therefore represent only the basal part of the Sarmatian.

3.3 Paleoenvironmental interpretation

3.3.1 Badenian

The percentage of planktic foraminifers (planktic/benthic foraminifer ratio) is frequently used for estimates of paleo-water depths. Planktic percentages increase with water depths (Van der Zwan et al., 1990) but are also dependant on food availability for benthic foraminifers (Van der Zwaan et al., 1999). The ratio works well in oligotrophic settings of modern environments (e.g., Szarek, 2001) but is disturbed with increasing eutrophication or riverine influence (e.g., Gibson, 1989). Planktic percentages for samples KB5/10-12 of 59, 22 and 61% point to paleo-water depths of 80 to 300 m (according to the formula of Van der Zwaan et al., 1990), i.e., to outer shelf to upper bathyal depositional environments. The assemblages found correspond to the *N. commune-Bulimina* cluster of Holcová and Zágoršek (2008, 100-300 m paleo-water depth), supporting our depth estimation. This is further confirmed by the occurrence of the deep-water ostracod genera *Bosquetina*, *Buntonia*, *Henryhowella*, *Cytheropteron*, *Krithe*, and *Parakrithe*.

Diversity of benthic foraminiferal faunas increases with distance from marginal environments and with water depth (Murray, 1991). The measured Fisher α-Indices range from 11.1 to 16.7 (Table 1). Such diversities are typical for middle Miocene suboxic to oxic outer shelf to bathyal environments in the Mediterranean (e.g., Gebhardt, 1994) and the Paratethys (Rögl and Spezzaferri, 2003; Spezzaferri, 2004), but are much higher than at the Badenian type locality in the Vienna Basin (2.2 to 3.8; Báldi and Hohenegger, 2008). The latter authors, however, applied a generalizing (lumping) species concept, which may explain the low indices to some extent.

Oxyphylic taxa such as *Sigmoilinita*, *Cibicidoides*, *Hanzawaia*, *Heterolepa*, *Lenticulina* or *Miliolids* are rather rare in the Badenian samples. Endobenthic, dysoxic taxa (*Bolivina*, *Bulimina*, *Caucasina*, *Cassidulina*, *Pullenia*, *Uvigerina*, *Valvulineria*) are much more common (see Corliss, 1985, 1991; Corliss and Chen, 1988; Kaiho, 1994, 1999; Báldi and Hohenegger, 2008; Holcová and Zágoršek, 2008 for classification). However, large oxyphylic species occur in all three samples in considerable numbers and semi-infaunal (or non-infaunal, neutral, e.g., *Nonion*) species are most abundant within the assemblages. Thus, well oxygenated bottom waters with dysoxic conditions in the upper centimeters of the seafloor can be assumed. This assumption is confirmed by the presence of large, oxygen consuming Cytheracean ostracods (Whatley, 1995). All occurring benthic foraminifers and ostracod species indicate normal marine salinities for the Badenian assemblages (e.g., Van Morkhoven, 1963; Murray, 1991).

Based on a two-layer circulation model, Báldi (2006) assumes an anti-estuarine circulation pattern for the early to mid Badenian Central Paratethys, associated to high temperatures of the Mid-Miocene Climatic Optimum. The foraminiferal assemblages of this study fit well in such a scenario. Rupp and Hohenegger (2008) classify *Globorotalia* as a cool-temperate indicator. *Globorotalia bykovae* is very frequent in the youngest Badenian sample KB5/10. This sample lacks well established warm water taxa like *Globigerinoides* spp., *Orbulina suturalis* or *Praeorbulina glomerosa circularis* (based on recent and ancient latitudinal distribution patterns, and stable oxigen isotope ratios; Hemleben et al. 1989; Bicchi et al., 2003; Rupp and Hohenegger, 2008). Contrary to this, such warm-water species are rather common in samples KB5/11 and 12. Furthermore, *Globigerina* spp. with dominant *G. praebulloides* becomes very frequent in sample KB5/10, indicating decreasing temperatures and/or increasing nutrient supply (Rögl and Spezzaferri, 2003; Spezzaferri, 2004). We therefore interpret the Badenian succession in KB5 to represent a transition from warm to temperate paleo-temperatures together with possible increasing nutrient availability in the upper water collumn (mixed layer). The occurrence of *Nipponocythere karsyensis* in sample KB5/10 fits well with this interpretation. Szczechura and Aiello (2003) found this species associated with bathyal, cold and oligotrophic conditions on the seafloor.

3.3.2 Sarmatian

A basal Sarmatian age was assigned to samples KB5/3 to 9. Except for sample 8, autochthonous foraminifers are rare in these samples and a paleo-environmental interpretation based on a few specimens is at least arguable. Only 2% of the foraminiferal assemblage of sample KB5/3 is classified as autochthonous Sarmatian, the remainder is made up of reworked Badenian specimens.

Foraminifer bearing Sarmatian samples are free of autochthonous planktic foraminifers, pointing to marginal marine or brackish depositional environments. The Fisher α-Indices of autochthonous assemblages are very low and range from 0.1 to 2.6, which confirms this categorization (Murray, 1991). The occurring biostratigraphic index species (*Anomalinoides dividens*, *Nonion bogdanoviczi*) and *Melonis* ? sp. of Schütz et al. (2007) may point to normal marine to slightly reduced salinities if compared with modern equivalent species or genera (Murray, 1991), which is in the range of salinities between 18 and 25 psu as suggested by Brestenská (1974) for early Sarmatian paleo-environments. Because of the exceptional good state of preservation, we cannot distinguish between autochthonous and reworked specimens of *Ammonia* in Sarmatian samples. However, the assumption of a Sarmatian origin of these specimens would not change the paleo-environmental interpretation.

Samples KB5/8 and 9 contain larger numbers of *Aubignyna perlucida*. In sample 9, this species is very common and in sample 8 it composes the entire assemblage (monospecific). About 4% of the assemblage are abnormal specimens (Plate 1, Figs 4-6) with increased and reduced chamber sizes, development of two whorls with different axes of rotation, or irregular coiling axes. Abnormal *A. perlucida* tests were also found in modern environments (Adriatic Sea, Coccioni, 2000). Abnormal test in shallow water benthic foraminifers may be caused by abrupt salinity fluctuations during reproduction periods as assumed for modern environments (Yanko et al., 1998; Geslin et al., 2002; Polovodova and Schönfeld, 2008). Other discussed reasons for increased percentages of abnormal tests such as pollution by heavy metals, municipal sewage or acidification (Alve, 1991; Coccioni, 2000; Geslin et al., 2000, 2002; Yanko et al., 1998, 1999; among others) can either be excluded for Sarmatian times or are nearly impossible to prove (further examples and discussion in Murray, 2006). Compared to some partially polluted fjords of the southern Baltic Sea (4-

26%, Polovodova and Schönfeld, 2008), 4% abnormal tests in sample KB5/8 are low and close to about 1% abnormal tests in assemblages from unstressed environments (Alve, 1991; Yanko et al., 1998; Geslin et al., 2000). Under hypersaline conditions, proportions of abnormal tests may reach up to 50% (Geslin et al., 2000). A further argument for hyposaline depositional environments is the exclusive occurrence of the predominantly brackish ostracod *Hemicyprideis dacica* in sample KB5/8. Therefore, the monospecific *Aubignyna perlucida* assemblage of sample KB5/8 with a considerable amount of abnormal tests represents a rather stressful hyposaline (brackish) paleo-environment (Fig. 2).

The freshwater to oligohaline water inhabiting ostracod *Ilyocypris* (Van Morkhoven, 1963) occurs in the younger sample KB5/6 with *Fabaeformiscandona* (foraminifers are absent in this sample) and therefore probably indicate a freshwater environment. The normal marine *Eucytherura* in sample KB5/7 is most likely reworked from older deposits, since foraminifers (one specimen of *A. perlucida* only) and the presence of *Ilyocypris* and *Darwinula?* indicate strongly reduced salinity.

4. Discussion

Our study revealed the deposition of basal Sarmatian sediments directly on Lower Badenian (Upper Lagenid Zone) strata at the drill site of KB5. Middle and Upper Badenian sediments were either not deposited or eroded before deposition of the Sarmatian sediments. In most Paratethyan basins, the Badenian-Sarmatian boundary is indicated by a considerable hiatus and corresponding erosive discordances (Harzhauser and Piller, 2007), just like in core KB5. The brackish depositional environment of sample KB5/8 within deposits of apparently even lower salinities may represent the initial part of a transgressive systems tract (TST) beginning during the *Anomalinoides dividens* Zone. The maximum flooding surface would have been reached during the upper *Elphidium reginum* Zone (Harzhauser and Piller, 2004b), which is not exposed in the KB5 core, but verified in many outcrops in the surrounding area (Roetzel, 2003, 2007, 2009). Harzhauser and Piller (2004b) correlated the Sarmatian Stage with the TB 2.6 3rd order cycle of Haq et al. (1988) and the unconformity between Badenian and Sarmatian deposits in the eastern Austrian basins with the Ser-3 and Ser-4/Tor-1 boundaries of Hardenbol et al. (1998). Consequently, the Sarmatian sediments of KB5 would have been deposited close to this boundary during the early TST.

The incision of the paleo-Zaya River within the Zaya-Graben (Jiříček and Seifert, 1990) into late early to middle Badenian sediments in this area lead to strong erosion on the exposed land during the middle (?late) Badenian and deposition of corresponding sediments during the early Sarmatian (incised valley fill, Mandic et al. 2008). This valley also allowed the transgression of the Sarmatian sea far to the west (Fig. 1), the deposition of at least brackish (this contribution) and marine sediments under partially hypoxic conditions (Mandic et al., 2008) during the early Sarmatian, and fully marine to hypersaline conditions later on (Piller and Harzhauser, 2005). The paleoenvironments inferred from micropaleontological results of the drill core KB5 fit well into such a scenario. They complement and confirm existing data and interpretations and the river and delta system shown in Seifert (1992) was probably less active in the Molasse basin during the basal Sarmatian.

5. Conclusions

1. The drilled sediments of core KB/5 consist of about 7 m of early Badenian deposits (Upper Lagenid Zone, corresponding to the mid Langhian Zone M6) and about 27 m of basal Sarmatian deposits (*Anomalinoides dividens* Zone).
2. Early Badenian samples show typical normal marine, outer shelf to upper bathyal foraminferal and ostracod assemblages also known from other sections in the Molasse and Vienna Basins.
3. Sarmatian samples were identified by 1) index species and 2) by apparently unique autochthonous microfossil assemblages. Sarmatian foraminiferal index species *Nonion bogdanowiczi* and *Anomalinoides dividens* were found in samples from the upper part of the core.
4. The monospecific occurrence of the foraminifer *Aubignyna perlucida* in one sample suggests an extreme, most likely brackish environment during the basal Sarmatian, an interpretation confirmed by the occurrence of the brackish to marine ostracod *Hemicyprideis dacica*.
5. Ilyocyprididae, Candonidae and Darwinulidae in younger but still basal Sarmatian samples indicate fresh to oligohaline waters and point to increased terrestrial influences.
6. The inferred depositional history fits well with the idea of a Sarmatian incised valley fill within Badenian sediments of previous authors. Presence of uncommon ostracods (*Nipponocythere karsyensis*) may point to intensive faunal exchange with the Carpathian Foredeep during the early Badenian.

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References

AGIP, 1982. Foraminiferi padani. Atlante iconografico e distribuzione stratigrafica. Agip Mineraria, San Donato Milanese, 52 plates.

Aiello, G., Barra, D., Bonaduce, G. and Russo, A., 1996. The genus Cytherella Jones, 1849 (Ostracoda) in the Italian Tortonian-Recent. Revue de Micropaléontologie, 39, 171-190.

Aiello, G. and Szczechura, J., 2004. Middle Miocene ostracods of the Fore-Carpathian Depression (Central Paratethys, southwestern Poland). Bolletino della Società Paleontologica Italiana, 43, 11-70.

Alve, E., 1991. Benthic foraminifers in sediment cores reflecting heavy metal pollution in Soerfjord, western Norway. Journal of Foraminiferal Research, 21, 1-19.

Báldi, K., 2006. Paleoceanography and climate of the Badenian (Middle Miocene, 16.4-13.0 Ma) in the Central Paratethys based on foraminifera and stable isotope ($\delta^{18}O$ and $\delta^{13}C$) evidence. International Journal of Earth Sciences, 95, 119-142.

Báldi, K. and Hohenegger, J., 2008. Paleoecology of benthic foraminifera of the Baden-Sooss section (Badenian, Middle Miocene, Vienna Basin, Austria). Geologica Carpathica, 59, 411-424.

Berggren, W.A., Kent, D.V., Swisher, C.C. and Aubry, M.-P., 1995. A revised Cenozoic geochronology and chronostratigraphy. SEPM (Society for Sedimentary Geology) Special Publications, 54, 129-212.

Bicchi, E., Ferrero, E. and Gonera, M., 2003. Palaeoclimatic interpretation based on Middle Miocene planktonic Foraminifera: the Silesia Basin (Paratethys) and Monnferrato (Tethys) records. Palaeogeography, Palaeoclimatology, Palaaeoecology, 196, 265-303.

Brestenská, E., 1974. Die Foraminiferen des Sarmatien s. str. In: A. Papp, F. Marinescu and J. Senes (eds.), M5 Sarmatien. Die Sarmatische Schichtengruppe und ihr Stratotypus. Slovakische Akademie der Wissenschaften, Bratislava, pp. 243-293.

Brix, F., Kröll, A. and Wessely, G., 1977. Die Molassezone und deren Untergrund in Niederösterreich. Erdöl-Erdgas-Zeitschrift, 93, 12-35.

Cicha, I., Rögl, F., Rupp, C. and Ctyroka, J., 1998. Oligocene - Miocene foraminifera of the Central Paratethys. Abhandlungen der senckenbergischen naturforschenden Gesellschaft, 549, 1-325.

Coccioni, R., 2000. Benthic Foraminifera as bioindicators of heavy metal pollution. A case study from the Goro Lagoon (Italy). In: R.E. Martin (ed.), Environmental Micropaleontology. Topics in Geobiology. Kluver Academic/Plenum Publishers, New York, pp. 71-103.

Corliss, B., 1985. Microhabitats of benthic foraminifera within deep-sea sediments. Nature, 314, 435-438.

Corliss, B.H., 1991. Morphology and Microhabitat preferences of benthic foraminifera from the northwest Atlantik Ocean. Marine Micropaleontology, 17, 195-236.

Corliss, B.H. and Chen, C., 1988. Morphotype patterns of Norwegian Sea deep-sea benthic foraminifera and ecological implications. Geology, 16, 716-719.

Gebhardt, H., 1994. Die Tap-Mergel in der Provinz Alicante (Südostspanien, Langhium bis Tortonium): Biostratigraphie, Paläogeographie und Paläoökologie. Berliner Geowissenschaftliche Abhandlungen (A), 163, 1-175.

Gebhardt, H and Rupp, C., 2008. Vergleich der Anreicherung von Foraminiferenschalen und anderer Mikrofossilien mit Hilfe von Zinkchlorid-Lösung und Tetrachlorkohlenstoff. Jahrbuch der Geologischen Bundesanstalt, 148, 177-181.

Geslin, E., Stouff, V., Debenay, J.-P. and Lesourd, M., 2000. Environmental variation and foraminiferal test abnormalities. In: R.E. Martin (ed.), Environmental Micropaleontology. Topics in Geobiology. Kluver Academic/Plenum Publishers, New York, pp. 191-215.

Geslin, E., Debenay, J.P., Duleba, W. and Bonetti, C., 2002. Morphological abnormalities of foraminiferal tests in Brazilian environments: comparison between polluted and non-polluted areas. Marine Micropaleontology, 45, 151-168.

Gibson, T.G., 1989. Planktonic-benthonic foraminiferal ratios: modern patterns and Tertiary applicability. Marine Micropaleontology, 15, 29-52.

Gibson, T.G. and Walker, W.M., 1967. Flotation methods for obtaining foraminifera from sediment samples. Journal of Paleontology, 41, 1294-1297.

Grill, R., 1941. Stratigraphische Untersuchungen mit Hilfe von Mikrofaunen im Wiener Becken und den benachbarten Molasse-Anteilen. Oel und Kohle, 37, 595-602.

Haq, B.U., Hardenbol, J. and Vail, P.R., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea level changes. Society of Economic Paleontologists and Mineralogists, Special Publications, 42, 71-108.

Hardenbol, J., Thierry, J., Farley, M.B., Jaquin, T., Graciansky, P.-C. and Vail, P.R., 1998. Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins. SEPM (Society for Sedimentary Geology) Special publications, 60, 3-13.

Harzhauser, M. and Piller, W.E., 2004a. Integrated stratigraphy of the Sarmatian (Upper Middle Miocene) in the western Central Paratethys. Stratigraphy, 1, 65-86.

Harzhauser, M. and Piller, W.E., 2004b. The Early Sarmatian - hidden seesaw changes. Courier Forschungsinstitut Senckenberg, 246, 89-111.

Harzhauser, M. and Piller, W.E., 2007. Benchmark data of a changing sea - Palaeogeography, Palaeobiogeography and events in the Central Paratethys during the Miocene. Palaeogeography, Palaeoclimatology, Palaeoecology, 253, 8-31.

Hemleben, C., Spindler, M. and Anderson, O.R., 1989. Modern Planktonic Foraminifera. Springer, New York, Berlin, 363 pp.

Heron-Allen,E. and Earland, A., 1913. The foraminifera of the Clare Island District, County Mayo, Ireland. Proceedings of the Royal Irish Academy, 31, 1-188.

Holcová, K. and Zágoršek, K., 2008. Bryozoa, foraminifera and calcareous nannoplankton as environmental proxies of the "bryozoan event" in the Middle Miocene of the Central Paratethys (Czech Republic). Palaeogeography, Palaeoclimatology, Palaeoecology, 267, 216-234.

Jiříček, R. and Seifert, P.H., 1990. Paleogeography of the Neogene in the Vienna Basin and the adjacent part of the foredeep. In: D. Minaríková and H. Lobitzer (eds.), Thirty years of geological cooperation between Austria and Czechoslovakia. Geologische Bundesanstalt, Ústrední ústav geologicky, Praha, pp. 89-105.

Kaiho, K., 1994. Benthic foraminiferal dissolved-oxygen index and dissolved-oxygen levels in the modern ocean. Geology, 22, 719-722.

Kaiho, K., 1999. Effect of organic carbon flux and dissolved oxygen on the benthic foraminiferal oxygen index (BFOI). Marine Micropaleontology, 37, 67-76.

Kowalke, T. and Harzhauser, M., 2004. Early ontogeny and paleoecology of the mid-Miocene rissoid gastropods of the Central Paratethys. Acta Palaeontologica Polonica, 49, 111-134.

Mandic, O., Harzhauser, M., Roetzel, R. and Tibuleac, P., 2008. Benthic mass-mortality events on a Middle Miocene incised-valley tidal-flat (North Alpine Foredeep Basin). Facies, 54, 343-359.

Milles, R. and Papp, A., 1957. Über das Vorkommen sarmatischer Schichten im Außeralpinen Wiener Becken. Verhandlungen der Geologischen Bundesanstalt, 1957, 130-136.

Murray, J.W., 1991. Ecology and palaeoecology of benthic foraminifera. Longman Scientific and Technical, Harlow, 397 pp.

Murray, J.W., 2006. Ecology and applications of benthic foraminifera. Cambridge University Press, Cambridge, 426 pp.

Nomura, R., 1983. Cassidulinidae (Foraminiferida) from the uppermost Cenozoic of Japan (Part 2). Tohoku University, Scientific Reports, 2nd Series (Geology), 54, 1-93.

Papp, A., 1950. Das Sarmat von Hollabrunn. Verhandlungen der Geologischen Bundesanstalt, 1948, 110-112.

Papp, A., 1962. Über das Vorkommen sarmatischer Schichten bei Langenlois am Kamp (N.-Ö.). Verhandlungen der Geologischen Bundesanstalt, 1962, 361-363.

Papp, A.,Marinescu, F. and Senes, J. (eds.), 1974. M5 Sarmatien. Die Sarmatische Schichtengruppe und ihr Stratotypus. Slovakische Akademie der Wissenschaften, Bratislava, 707 pp.

Piller, W.E. and Harzhauser, M., 2005. The myth of the brackish Sarmatian Sea. Terra Nova, 17, 450-455.

Pipik, R. and Bodergat, A.-M. 2003. Ostracodes du Miocène supérieur du Bassin de Turiec (Slovaquie): Familles Darwinulidae et Ilyocyprididae. Revista Espanola de Micropaleontologia, 35, 345-355.

Polovodova, I. and Schönfeld, J., 2008. Foraminiferal test abnormalities in the western Baltic Sea. Journal of Foraminiferal Research, 38, 318-336.

Rögl, F., 1998. Foraminiferenfauna aus dem Karpat (Unter-Miozän) des Korneuburger Beckens. In: W. Sovis and B. Schmid (eds.), Das Karpat des Korneuburger Beckens, Teil 1. Verein zur Förderung der Paläontologie, Wien, pp. 123-173.

Rögl, F. and Spezzaferri, S., 2003. Foraminiferal paleoecology and biostratigraphyn of the Mühlbach section (Gaindorf Formation, Lower Badenian), Lower Austria. Annalen des Naturhistorischen Museum in Wien, 104 A, 23-75.

Rögl, F., Spezzaferri, S. and Coric, S., 2002. Micropaleontology and biostratigraphy of the Karpatian-Badenian transition (Early-Middel Miocene boundary) in Austria (Central Paratethys). Courier Forschungsinstitut Senckenberg, 237, 47-67.

Rögl, F., Coric, S., Harzhauser, M., Jiménez-Moreno, G., Kroh, A., Schultz, O., Wessely, G. and Zorn, I., 2008. The Middle Miocene Badenian stratotype at Baden-Sooss (Lower Austria). Geologica Carpathica, 59, 367-374.

Roetzel, R., Mandic, O, Steininger, F.F. (1999): Lithostratigraphie und Chronostratigraphie der Tertiären Sedimente im westlichen Weinviertel und angrenzenden Waldviertel. Arbeitstagung der Geologischen Bundesanstalt 1999, Retz-Hollabrunn. Geologischen Bundesanstalt, Wien, pp. 38-54.

Roetzel, R. 2003. Bericht 1998, 2000, 2001 über geologische Aufnahmen im Tertär und Quartär auf Blatt 23 Hadres. Jahrbuch der Geologischen Bundesanstalt, 143, 397-404.

Roetzel, R. 2007. Bericht 2002, 2003, 2004, 2005 und 2006 über geologische Aufnahmen im Tertär und Quartär auf Blatt 23 Hadres. Jahrbuch der Geologischen Bundesanstalt, 147, 615-623.

Roetzel, R., 2009. Erläuterungen zu Blatt 23 Hadres. Geologische Bundesanstalt, Wien, 150 pp. (mit Beiträgen von Ahl., A., Götzinger, M.A., Kociu, A., Pristacz, H., Schubert, G., Slapansky, P. and Wessely, G.).

Rupp, C., 1986. Paläökologie der Foraminiferen in der Sandschalerzone (Badenien, Miozän) des Wiener Beckens. Beiträge zur Paläontologie Österreichs, 12, 1-180.

Rupp, C. and Hohenegger, J., 2008. Paleoecology of planktonic foraminifera from the Baden-Sooss section (Middle Miocene, Badenian, Vienna Basin, Austria). Geologica Carpathica, 59, 425-445.

Seifert, P., 1992. Palinspastic reconstruction of the easternmost Alps between Upper Eocene and Miocene. Geologica Carpathica, 43, 327-331.

Schütz, K., Harzhauser, M., Rögl, F., Coric, S. and Galovic, I., 2007. Foraminiferen und Phytoplankton aus dem unteren Sarmatium des südlichen Wiener Beckens (Petronell, Niederösterreich). Jahrbuch der Geologischen Bundesanstalt, 147, 449-488.

Spezzaferri, S., 2004. Foraminiferal paleoecology and biostratigraphy of the Grund Formation (Molasse Basin, Lower Austria). Geologica Carpathica, 55, 155-164.

Strauss, P., Harzhauser, M., Hinsch, R. and Wagreich, M., 2006. Sequence stratigraphy in a classic pull-apart basin (Neogene, Vienna Basin). A 3D seismic based integrated approach. Geologica Carpathica, 57,185–197.

Suess, E., 1866. Untersuchungen über den Charakter der österreichischen Tertiärablagerungen. II. Über die Bedeutung der sogenannten ”brackischen Stufe” oder der ”Cerithienschichten”. Sitzungsberichte der k.k. Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Klasse, 54, 1–40.

Szarek, R., 2001. Biodiversity and biogeography of recent benthic foraminiferal assemblages in the south-western South China Sea (Sunda Shelf). Ph.D. Thesis, Christian-Albrechts Universität, Kiel, 252 pp.

Szczechura, J. and Aiello, G., 2003. The ostracod genus Nipponocythere Ishizaki, 1971 from the Middle Miocene of the Fore-Carpathian Depression, Central Paratethys; its origin and paleoenvironment. Geologica Carpathica, 54, 9-20.

Van der Zwaan, D.J., Jorissen, F.J. and de Stigter, H.C., 1990. The depth dependency of planktonic/benthic foraminiferal ratios: Constraints and applications. Marine Geology, 95, 1-16.

Van der Zwaan, G.J., Duijnstee, I.A.P., den Dulk, M., Ernst, S.R., Jannink, N.T. and Kouwenhoven, T.J., 1999. Benthic foraminifers: proxies or problems? A review of paleocological concepts. Earth-Science Reviews, 46, 213-236.

Van Morkhoven, F.P.C.M., 1963. Post-Paleozoic Ostracoda. Elsevier, Amsterdam, Part 1: 204 pp., Part 2: 478 pp.

Vetters, H., 1914. Mitteilungen aus dem tertiären Hügellande unter dem Manhartsberge. Verhandlungen der Geologischen Reichsanstalt, 1914, 65–74.

Whatley, R., 1995. Ostracoda and oceanic palaeoxygen levels. Mitteilungen aus dem hamburgischen zoologischen Museum und Institut, 92 (Ergänzungsband), 337-353.

Yanko, V., Ahmad, M. and Kaminski, M., 1998. Morphological deformities of benthic foraminiferal tests in response to pollution by heavy metals: implication for pollution monitoring. Journal of Foraminiferal Research, 28, 177-200.

Yanko, V., Arnold, A.J. and Parker, W.C., 1999. Effects of marine pollution on benthic foraminifera. In: B.K. Sen Gupta (ed.), Modern foraminifera. Kluwer Academic Publishers, Dordrecht, pp. 217-235.

Zelenka, J., 1990. A review of the Sarmatian ostracoda of the Vienna Basin. In: R. Whatley and C. Maybury (eds.), Ostracoda and global events. British Micropalaeontological Society Publiocation Series. Chapman and Hall, London, pp. 263-270.

Zorn, I., 2003. Ostracoda from the Gaindorf Formation (Middle Miocene, Lower Badenian) of Mühlbach (Molasse Basin, Lower Austria). Annalen des Naturhistorischen Museums in Wien, 104 A, 77-84.

Zorn, I., 2004. Ostracoda from the Lower Badenian (Middle Miocene) Grund Formation (Molasse Basin, Lower Austria). Geologica Carpathica, 55, 179-189.

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Holger GEBHARDT*), Irene ZORN & Reinhard ROETZEL
Geologische Bundesanstalt, Neulinggasse 38, 1030 Wien, Austria;
*) Corresponding author, holger.gebhardt@geologie.ac.at

Appendix 1

Simplified lithologic description of the KB5 borehole near Hollabrunn, depth measurements in cm below surface.

Quaternary

0-200 artificial fill-up
-340 peaty silt, sandy
-540 alternation of fine and medium sand, in parts coarse sand to fine gravel, calcareous

Neogene

Ziersdorf Formation (lower Sarmatian)

-580 silt, clayey, calcareous
-600 fine sand, silty, calcareous
-760 silt, clayey, calcareous, bivalves, sample KB5/3 (670 cm)
-820 fine sand, silty, calcareous
-880 silt, fine-sandy, calcareous
-1350 fine-medium gravel, sandy to silty, high matrix-content, calcareous, with boulders (limestones, sandstones, quartzite, quartz) up to 15 cm, sample KB5/4 (1050 cm)
-1360 silt, fine-sandy, calcareous
-1440 fine sand with medium sand, partly fine to medium gravel, calcareous, sample KB5/5 (1420 cm)
-2650 silt, clayey, rarely fine-sandy, calcareous, samples KB5/6 (1560 cm), KB5/7 (2010 cm), KB5/8 (2470 cm)
-2800 fine sand, silty, calcareous
-2830 silt, fine-sandy, calcareous
-2950 fine sand, silty, calcareous, sample KB5/9 (2860 cm)
-2980 silt, clayey, fine-sandy, probably bioturbated, calcareous
-3030 fine sand, silty, calcareous
-3080 silt, fine-sandy, calcareous
-3230 silt, clayey, fine-sandy, calcareous

Grund Formation (lower Badenian)

-3420 alternation of fine sand and silt, partially bioturbated, calcareous, sample KB5/10 (3340 cm)
-3510 silt, clayey, calcareous
-3530 fine sand, calcareous, sample KB511 (3520 cm)
-3710 silt, clayey, with fine sand stringers, calcareous
-3720 fine sand, calcareous
-3780 silt, clayey, calcareous
-3820 fine sand, silty, calcareous
-3880 silt, clayey, calcareous
-3930 fine sand, silty, calcareous
-4000 silt, clayey, calcareous, sample KB5/12 (3960 cm)

Plate 1:

Figure 1-9: Sarmatian foraminifers.

Figure 1-6: *Aubignyna perlucida* (Heron-Allen and Earland), sample KB5/8; 1-3: normal specimens, 1: umbilical view, 2: spiral view, 3: lateral view, 4-6: abnormal tests, 4: increased and reduced chamber sizes, 5: development of two whorls with different axes of rotation, 6: irregular coiling axis.

Figure 7: *Anomalinoides dividens* Luczkowska, sample KB5/5.

Figure 8: *Nonion bogdanowiczi* Voloshinova, sample KB5/3.

Figure 9: *Elphidium* cf. *incertum* (Williamson), sample KB5/3.

Figure 10-39: Badenian foraminifers.

Figure 10, 11: *Globorotalia bykovae* (Aisenstat), sample KB5/10, 10: spiral view, 11: umbilical view.

Figure 12: *Paragloborotalia siakensis* (Le Roy), sample KB5/12

Figure 13: *Globigerinoides trilobus* (Reuss), sample KB5/12

Figure 14: *Globigerinoides bisphaericus* Todd, sample KB5/12

Figure 15: *Praeorbulina glomerosa circularis* (Blow), sample KB5/12

Figure 16: *Orbulina suturalis* Brönnimann, sample KB5/12

Figure 17: *Globigerina bulloides* d'Orbigny, sample KB5/12

Figure 18: *Globigerina diplostoma* Reuss, sample KB5/12

Figure 19: *Globigerina falconensis* Blow, sample KB5/12

Figure 20: *Globigerina praebulloides* Blow, sample KB5/12

Figure 21: *Globigerina* cf. *tarchanensis* Subbotina and Chutzieva, sample KB5/10

Figure 22: *Globigerinella* obesa (Bolli), sample KB5/10

Figure 23: *Turborotalita quinquelloba* (Natland), sample KB5/10

Figure 24: *Tenuitellinata angustiumbilicata* (Bolli), sample KB5/12

Figure 25: *Tenuitellinata selleyi* Li, Radford and Banner, sample KB5/12

Figure 26: *Spirorutilus carinatus* (d'Orbigny), sample KB5/3

Figure 27: *Semivulvulina pectinata* (Reuss), sample KB5/3

Figure 28: *Martinottiella karreri* (Cushman), sample KB5/11

Figure 29: *Martinottiella communis* (d'Orbigny), sample KB5/3

Figure 30: *Siphotextularia concava* (Karrer), sample KB5/10

Figure 31: *Textularia gramen* d'Orbigny, sample KB5/12

Figure 32: *Sigmoilinita tenuis* (Czjzek), sample KB5/10

Figure 33: *Dentalina acuta* d'Orbigny, sample KB5/3

Figure 34: *Pyramidulina continuicosta* (Schubert), sample KB5/3

Figure 35: *Laevidentalina badensis* (d'Orbigny), sample KB5/10

Figure 36: *Amphimorphina haueriana* Neugeboren, sample KB5/3

Figure 37: *Plectofrondicularia* sp. sample KB5/10

Figure 38: *Dimorphina akneriana* (Neugeboren), sample KB5/3

Figure 39: *Lenticulina inornata* (d'Orbigny), sample KB5/10

All scale bars 0.1 mm, Figs 26, 27, 29, 33, 34, 36, and 38 are reworked specimens gained from Sarmatian sediments.

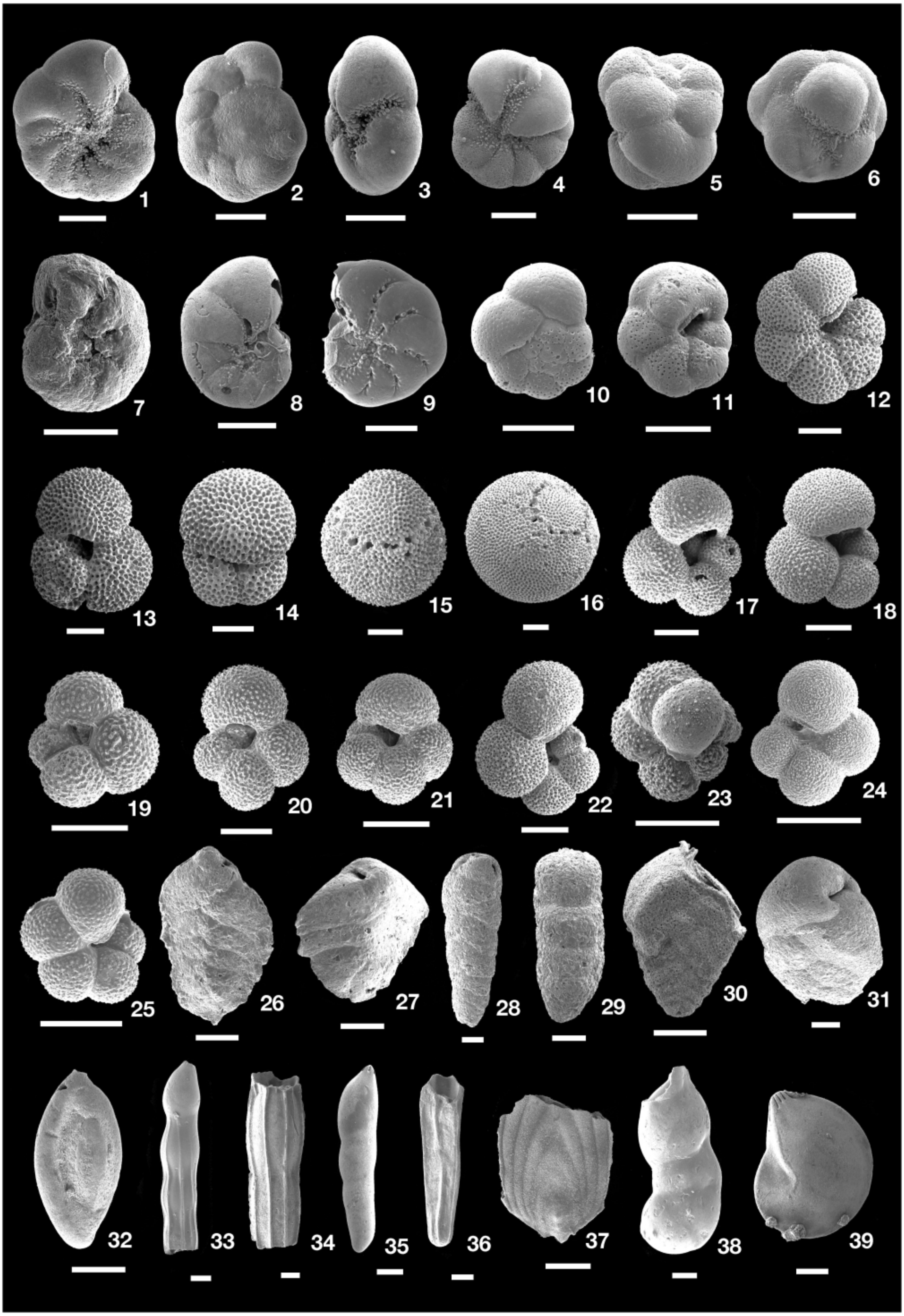
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Plate 2:

Badenian foraminifers.

Figure 1: *Lenticulina serpens* (Seguenza), sample KB5/10
Figure 2: *Lenticulina calcar* (Linné), sample KB5/10
Figure 3: *Saracenaria arcuata* (d'Orbigny), sample KB5/10
Figure 4: *Amphicoryna badensis* (d'Orbigny), sample KB5/12
Figure 5: *Amphicoryna hispida* (d'Orbigny), sample KB5/3
Figure 6: *Vagulinopsis pedum* (d'Orbigny), sample KB5/11
Figure 7: *Lagena striata* (d'Orbigny), sample KB5/10
Figure 8: *Guttulina communis* d'Orbigny, sample KB5/10
Figure 9: *Glandulina aequalis* (Reuss), sample KB5/12
Figure 10: *Pseudosolenia lateralis carinata* (Buchner), sample KB5/10
Figure 11: *Lagenonodosaria sublineata* (Brady), sample KB5/12
Figure 12: *Bolivina antiqua* d'Orbigny, sample KB5/3
Figure 13: *Bolivina dilatata* Reuss, sample KB5/10
Figure 14: *Bolivina hebes* Macfadyen, sample KB5/10
Figure 15: *Bolivina vienensis Marks, sample KB5/10*
Figure 16: *Cassidulina laevigata* d'Orbigny, sample KB5/12
Figure 17: *Evolvocassidulina* cf. *brevis* (Aoki), sample KB5/12
Figure 18: *Globocassidulina oblonga* (Reuss), sample KB5/3
Figure 19: *Caucasina elongata* (d'Orbigny), sample KB5/11
Figure 20: *Caucasina subulata* (Cushman and Parker) sample KB5/10
Figure 21: *Bulimina striata* d'Orbigny, sample KB5/3
Figure 22: *Globobulimina pupoides* (d'Orbigny), sample KB5/3
Figure 23: *Uvigerina grilli* Schmid, sample KB5/12
Figure 24: *Uvigerina macrocarinata* Papp and Turnowsky, sample KB5/3
Figure 25: *Uvigerina semiornata* d'Orbigny, sample KB5/12
Figure 26: *Angulogerina angulosa* (Williamson), sample KB5/3
Figure 27: *Fursenkoina acuta* (d'Orbigny), sample KB5/3
Figure 28: *Neugeborina irregularis* (d'Orbigny), sample KB5/10
Figure 29: *Neugeborina longiscata* (d'Orbigny), sample KB5/12
Figure 30: *Stilostomella adolphina* (d'Orbigny), sample KB5/10
Figure 31: *Siphonodosaria consobrina* (d'Orbigny) sample KB5/10
Figure 32: *Siphonodosaria pyrula* (d'Orbigny), sample KB5/10
Figure 33: *Myllostomella advena* (Cushman and Laiming), sample KB5/3
Figure 34: *Myllostomella recta* (Palmer and Bermudez), sample KB5/3
Figure 35: *Baggina* cf. *arenaria* (Karrer), sample KB5/10
Figure 36: *Valvulineria complanata* (d'Orbigny), sample KB5/12
Figure 37: *Cibicidoides pachyderma* (Rzehak), sample KB5/10
Figure 38: *Cibicidoides ungerianus* (d'Orbigny), sample KB5/10
Figure 39: *Nonion commune* (d'Orbigny), sample KB5/12
Figure 40: *Nonionoides karaganicus* (Krasheninnikow) sample KB5/10
Figure 41: *Melonis pompilioides* (Fichtel and Moll), sample KB5/10
Figure 42: *Pullenia bulloides* (d'Orbigny), sample KB5/10
Figure 43: *Asterigerinata planorbis* (d'Orbigny), sample KB5/3
Figure 44: *Hanzawaia boueana* (d'Orbigny), sample KB5/10
Figure 45: *Heterolepa dutemplei* (d'Orbigny), sample KB5/11
Figure 46: *Gavelinopsis praegeri* (Heron-Allen and Earland), sample KB5/12
Figure 47: *Gyroidinoides soldanii* (d'Orbigny), sample KB5/3
Figure 48: *Gyroidinoides umbonatus* (Silvestri), sample KB5/10

All scale bars 0.1 mm, Figs 5, 12, 18, 21, 22, 24, 26, 27, 33, 34, 43, and 47 are reworked specimens gained from Sarmatian sediments.

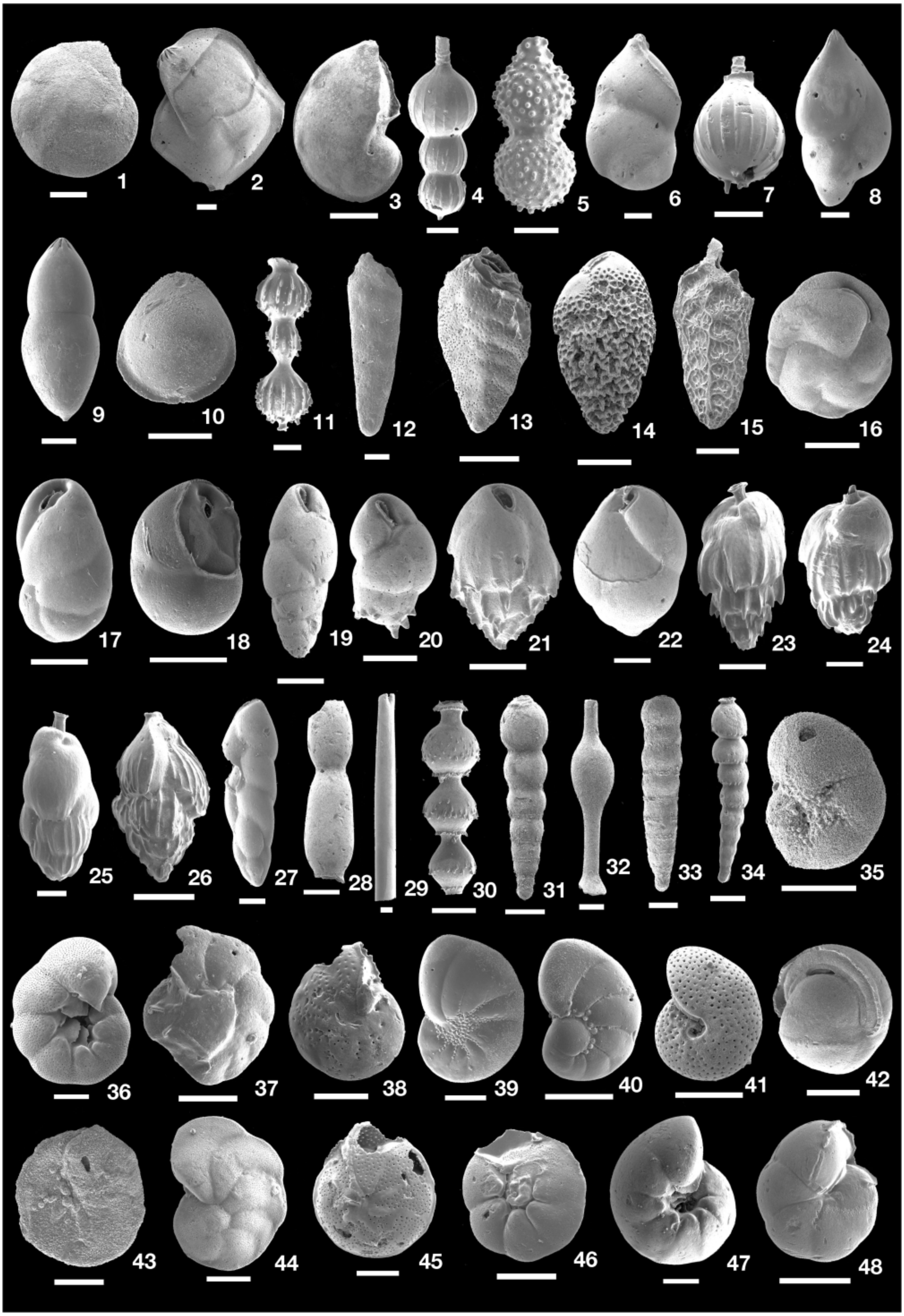
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Plate 3:

Figure 1-6: Badenian foraminifers

Figure 1: *Ammonia pseudobeccarii* (Putrja), sample KB5/3

Figure 2: *Ammonia viennensis* (d'Orbigny), sample KB5/3

Figure 3: *Elphidiella minuta* (Reuss) sample KB5/11

Figure 4: *Elphidium fichtelianum* (d'Orbigny), sample KB5/3

Figure 5: *Elphidium* cf. *grilli* Papp, sample KB5/12

Figure 6: *Elphidium reussi* Marks, sample KB5/3

Figure 7-10: Sarmatian ostracods

Figure 7: *Ilyocypris* cf. *expansa* (Reuss), left valve, sample KB5/7

Figure 8: *Darwinula* ? sp., left valve, sample KB5/7

Figure 9: *Fabaeformiscandona* cf. *pokornyi* (Kheil), right valve, juvenile, sample KB5/6

Figure 10: *Hemicyprideis dacica* (Héjjas), left valve, sample KB5/8

Figure 11-25: *Badenian ostracods*

Figure 11: *Henryhowella asperrima* (Reuss), right valve, sample KB5/10

Figure 12: *Argilloecia fatua* Barra et al., right valve, sample KB5/12

Figure 13-15: *Cytherella cercinata* Aiello et al., left valve of carapace with predator borehole, sample KB5/12; Fig. 14: anterior part of left valve, Fig. 15: posterior part of left valve

Figure 16: *Pseudopsammocythere* cf. *kollmanni* Carbonnel, left valve, sample KB5/10

Figure 17: *Parakrithe rotundata* Aiello et al., right valve, sample KB5/10

Figure 18: *Buntonia subulata* (Ruggieri), right valve, sample KB5/12

Figure 19: *Nipponocythere karsyensis* Szczechura and Aiello, right valve, sample KB5/10

Figure 20: *Sagmatocythere tenuis* (Ciampo), left valve, sample KB5/10

Figure 21: *Bosquetina carinella* (Reuss), left valve, sample KB5/12

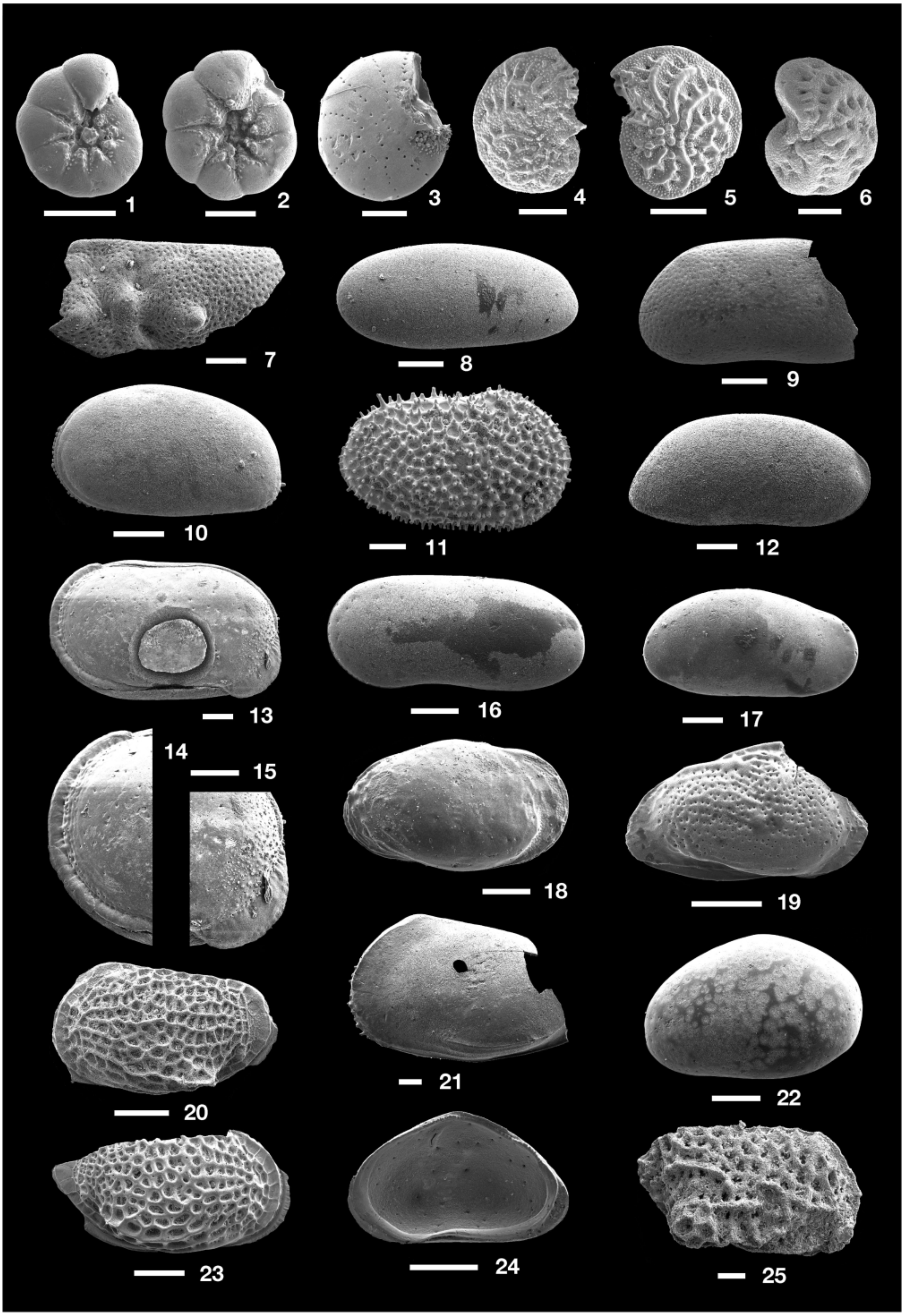
Figure 22: *Xestoleberis glabrescens* (Reuss), left valve, sample KB5/12

Figure 23: *Sagmatocythere* ? sp., right valve, sample KB5/12

Figure 24: *Xestoleberis* sp., right valve, sample KB5/12

Figure 25: *Eucytherura* sp., left valve, sample KB5/7

All scale bars 0.1 mm, Figs 1, 2, 4, 6, and 25 are reworked specimens gained from Sarmatian sediments.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