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Paleoecology of planktonic foraminifera from the Baden-Sooss section (Middle Miocene, Badenian, Vienna Basin, Austria)

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Abstract: A quantitative analysis was carried out on the planktonic foraminiferal fauna from the scientific Baden-Sooss core, located at the Badenian type locality near Baden (Lower Austria). Counts were performed on groups, mainly on the generic level. Paleoenvironmental reconstruction was based on foraminiferal groups (indicator species) obtained by cluster analysis and on ordination methods. The most important faunal groups are *Globorotalia*, "five-chambered globigerinids" and "four-chambered globigerinids"; *Globigerinoides*, *Globoquadrina*, *Globigerinella*, *Globigerinita*, *Turborotalita*, *Globoturborotalita* and orbulinids are well represented. Detrended Correspondence Analysis resulted in three significant axes. The most explanatory first axis is high positively correlated with the groups "five-chambered globigerinids", "cold and cold-temperate plankton" and abundance; it is thus interpreted as a temperature related factor, indicating cold shallow water masses. Cluster analysis revealed four groups, which are interpreted as clusters indicating cold water- (Cluster 3), temperate water- (Cluster 1) and warm water-faunas (Cluster 2 and partly Cluster 4). The analysis resulted in the reconstruction of sea temperature fluctuations and several cold-water ingressions into the moderately warm Badenian Sea.

Key words: Middle Miocene, Lower Badenian, Central Paratethys, Vienna Basin, multivariate statistics, planktonic foraminifera.

Introduction

The Vienna Basin is part of the Neogene Paratethys basin system (Steininger & Wessely 2000) and is situated at the junction of the Eastern Alps and the Western Carpathians (Fig. 1a). It is a classic pull-apart basin (Strauss et al. 2006) evolved in the Early Miocene and filled by Lower to Middle Miocene (mainly Karpatian to Pannonian) sediments with Badenian sediments as a major constituent (Hohenegger et al. 2008; Wagreich et al. 2008).

The scientific Baden-Sooss core (Fig. 1b) was drilled close to the Badenian stratotype, the former Baden-Sooss brickyard (Rögl et al. 2008) and is made up of bioturbated marls (hemipelagites, "Badener Tegel") with rare intercalations of conglomerates, sand layers (tempestites) and a tuff layer (Wagreich et al. 2008) of Early Badenian (Upper Lagenidae Zone) age (Fig. 2).

Since the 19th century benthic and planktonic foraminifera from the "Badener Tegel" have been of great importance for micropaleotologists (Rögl et al. 2008). In the last century the rich microfaunas from the Baden-Sooss brickyard were biostratigraphically analysed (Papp & Steininger 1978), but no detailed paleoecological studies concerning the Baden-Sooss microfaunas were performed. At the beginning of the new century, more attention was paid to quantitative analyses and paleoecological interpretation of Badenian planktonic foraminiferal faunas from the Austrian Molasse Zone (Mandic et al. 2002; Rögl & Spezzaferri 2003; Spezzaferri 2004).

The goal of the present study is to reconstruct the paleoenvironmental conditions of the Badenian Sea during the Early Badenian within the interval represented by the 102 m deep Baden-Sooss core by means of quantitative planktonic foraminiferal analyses. An important tool to detect changes in environmental parameters and to reconstruct paleoenvironments is the analysis of planktonic foraminiferal distribution patterns. Modern biogeographic patterns show a close relation between planktonic foraminifera and physical, chemical and biological parameters of the different water masses recorded in oceans (Zachariasse & Spaak 1983).

Ecological data, established for recent species and genera, constitute the basis for interpreting fossil assemblages. The most convincing distribution patterns of recent planktonic foraminifera are latitudinal related patterns (Be & Hutson 1977). Therefore temperature preferably controls the distribution of planktonic foraminifera. This idea was confirmed by laboratory experiments (Bijma et al. 1990). Consequently, stenotherm species and genera are thought to be useful for defining water masses of different temperatures.

Various indices and proxies like diversity indices (Buzas 1979) are powerful additional tools for the paleoecological interpretation of planktonic foraminiferal faunas. Multivariate statistical analysis was performed to divide the obtained faunas into groups of higher similarity and to find possible trends and latent gradients.

Material and methods

The intensively bioturbated, marly hemipelagites of the "Badener Tegel" are typical of the Lower Badenian cored by the Baden-Sooss borehole. The conglomeratic and sandy intercalations of tempestitic origin (Wagreich et al. 2008) are rare and not indicative for the sedimentary environment of the "Badener Tegel" and thus not considered in this study. Sam-

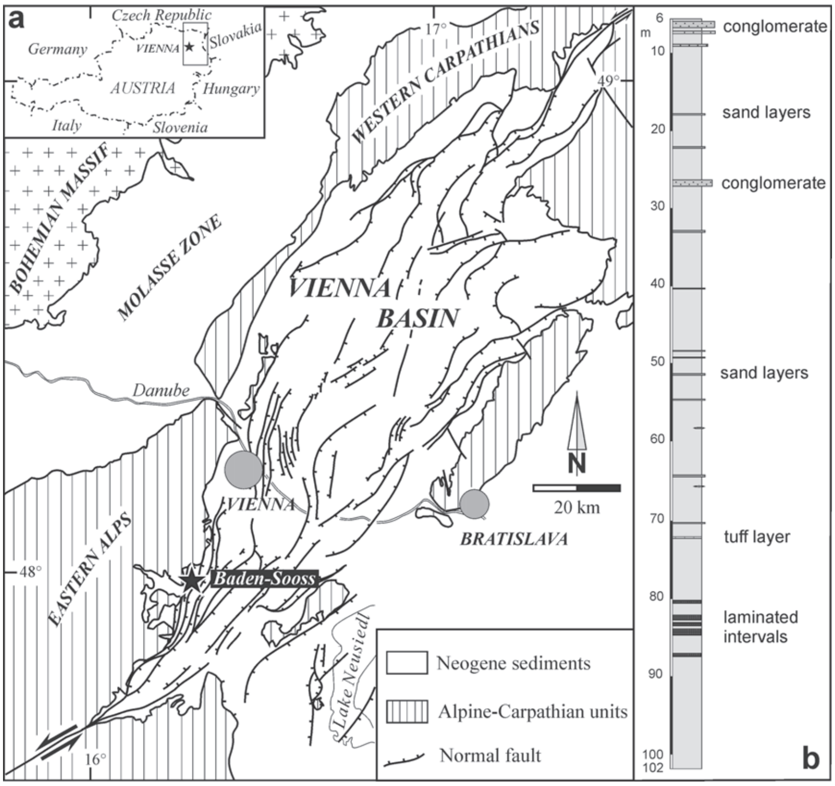

Fig. 1. a — Tectonic sketch map of the Vienna Basin (modified from Decker 1996, and Wagreich & Schmid 2002) and location of the studied borehole Sooss. **b** — Schematic sedimentological log of the borehole Sooss from 6 m to 102 m (Hohenegger et al. 2008).

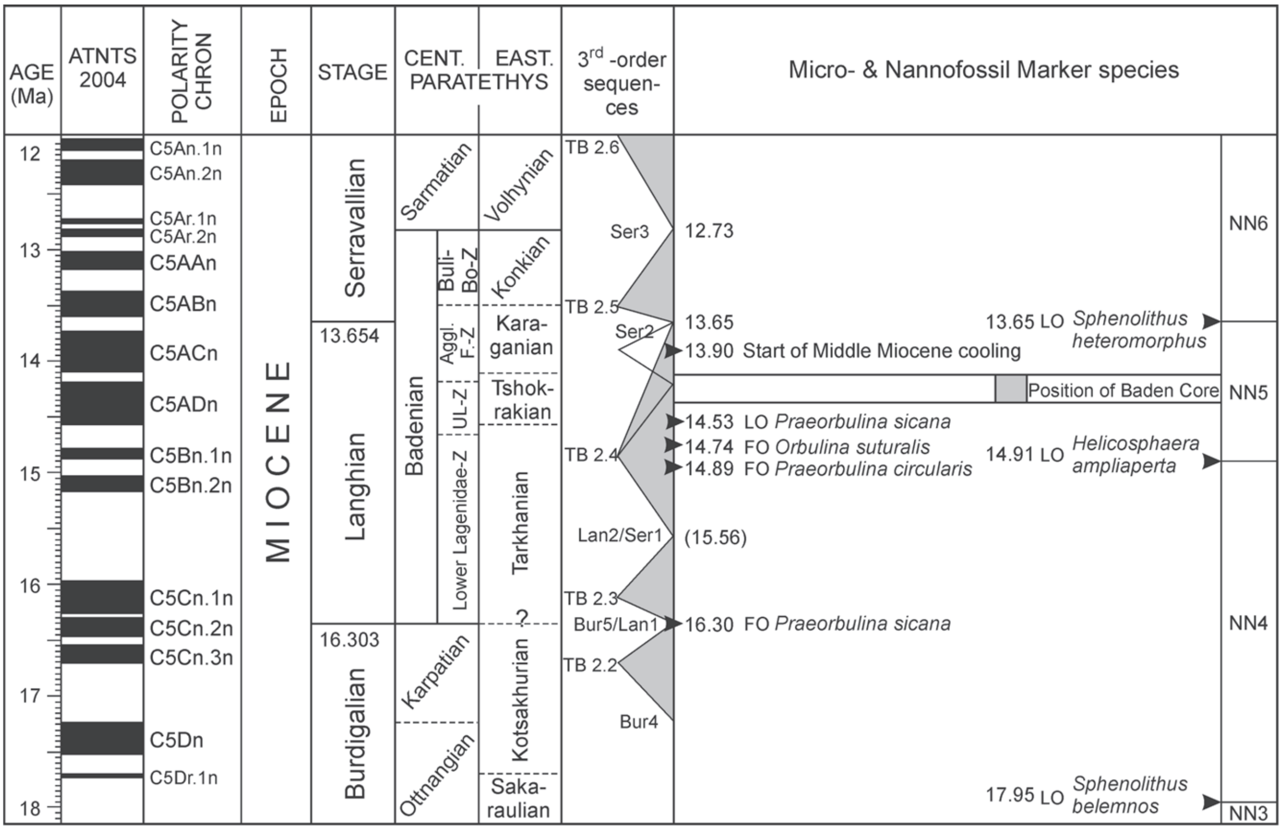

Fig. 2. Lower to Middle Miocene stratigraphic chart, including calibrated planktonic events by Lourens et al. (2004b), based on the time scale of Lourens et al. (2004a); **FO** = first occurrence, **LO** = last occurrence. Base of Langhian according to the FO of *Praeorbulina sicana*, according to EEDEN Project at the base of chron C5Cn.1r. 3[rd]-order sequences of Haq et al. (1988) are re-calculated according to ATNTS (Hohenegger et al. 2008).

ples of the "Badener Tegel" were taken at distances of 2.5 m to 3.6 m along the core. Quantitative analyses of planktonic foraminiferal faunas were carried out on 36 samples from 8.4 m to 101.8 m. The sample treatment is described in Báldi & Hohenegger (2008), the residues > 125 µm were split using a modified Kennard & Smith microsplitter (Rupp 1986) and all planktonic foraminifera of the subsample were picked. Since planktonic foraminifera are highly variable and species definitions are often not adequate to exactly discriminate the different species, the picked specimens were counted on the generic level (Table 1) including some artificial groups like "four-chambered globigerinids" (see taxonomic notes). Additionally, all identified species were noted in order to gain a presence/absence list on specific level (Table 2). Broken specimens with the initial part were counted as "undetermined", if an assignment to any "generic" category was impossible, smaller fragments without the initial part were neglected. Relative abundances of these groups were plotted against core-depth (Figs. 3–4) and provide the basic information for comparing the groups with the requirements and tolerances of their modern equivalents.

As faunal parameters show additional environmental trends, the following parameters were calculated for characterizing the faunal composition (Fig. 5):

"Abundance" was obtained by standardizing the count of planktonic specimens through the dry weight of the washed sediment. "Diversity" was measured using the Simpson Diversity Index (Hammer & Harper 2005). The number of specimens within every species group was calculated in percentages of the total number and transformed by the arcsine-root transformation (Parker & Arnold 1999) for further linear statistical treatment. Temperature related groups of foraminifera have been established and used as paleotemperature indices (Spezzaferri & Ćorić 2001; Bicchi et al. 2003) in order to detect temperature fluctuations. "Warm and warm-temperate" as well as "cold and cold-temperate" elements were ex-

Table 1: Relative abundances of species groups.

m	Orbulinids	*Globigerinoides*	*Globoquadrina*	*Globoturborotalita*	*Globigerina* four-chamb.	*Globigerina* five-chamb.	*Turborotalita*	*Globigerinella*	*Clavatorella*	*Globigerinita*	*Tenuitellinata*	*Globorotalia*	*Paragloborotalia*	Plankton indet.
8.40	0.00	16.23	0.33	11.26	36.92	0.99	0.17	0.00	0.00	20.20	0.00	13.08	0.00	0.83
11.21	2.05	3.69	0.82	0.00	26.02	5.94	4.30	5.12	0.00	17.83	0.20	31.76	0.00	2.25
14.81	0.33	39.51	0.00	0.00	8.03	3.28	1.80	4.75	0.00	16.56	0.00	25.57	0.00	0.16
17.61	0.00	10.40	0.00	13.37	40.10	0.33	0.66	1.16	0.00	12.54	0.00	14.36	0.00	7.10
20.02	0.79	11.39	0.00	0.79	22.59	0.39	3.34	1.18	0.00	17.09	0.00	40.47	0.00	1.96
23.61	1.48	1.59	0.11	40.11	22.86	2.86	6.88	0.95	0.00	20.95	0.00	1.59	0.00	0.63
26.41	1.12	0.67	0.00	0.07	6.35	85.20	1.12	0.37	0.00	1.94	0.00	0.60	0.00	2.54
30.01	0.23	0.47	0.06	0.00	13.95	40.64	4.24	0.47	0.00	2.62	0.00	35.87	0.00	1.45
34.41	0.19	2.79	0.00	0.00	17.87	34.87	1.15	1.15	0.00	5.19	0.19	35.54	0.00	1.06
37.61	2.39	22.99	7.46	4.48	5.37	9.55	5.37	4.78	0.00	28.96	0.30	8.06	0.00	0.30
40.01	4.15	13.97	8.30	6.77	8.08	9.61	15.07	1.97	0.00	11.79	2.18	17.25	0.00	0.87
42.41	1.32	13.78	8.67	8.05	6.81	22.60	3.64	11.84	0.08	11.92	0.00	10.29	0.00	1.01
45.01	0.00	14.05	1.67	2.34	7.69	32.61	7.53	6.69	0.00	15.55	0.00	10.03	0.00	1.84
47.6	0.19	2.09	19.96	3.99	14.83	32.89	6.46	4.56	0.00	9.51	0.00	2.28	0.00	3.23
50.01	0.00	2.61	17.33	1.16	32.04	12.97	15.30	5.42	0.77	6.20	0.00	5.03	0.00	1.16
52.01	0.00	10.58	6.65	0.55	30.43	10.58	13.30	10.25	0.00	5.02	0.00	4.14	0.00	8.51
55.01	0.00	0.72	16.71	1.45	37.04	11.25	5.20	12.37	0.00	4.14	0.00	6.78	0.00	4.34
57.61	0.15	11.61	0.05	2.38	9.63	40.50	2.58	0.20	0.00	4.37	0.00	28.54	0.00	0.00
60.01	2.29	0.85	2.94	1.57	32.30	20.39	0.69	0.60	0.00	6.33	0.06	30.73	0.00	1.25
62.61	0.33	5.98	6.83	1.04	26.20	0.33	4.94	0.91	0.00	3.38	0.00	49.09	0.00	0.98
65.01	0.30	4.30	1.14	0.72	25.16	0.06	3.23	5.98	0.00	2.87	0.12	55.29	0.00	0.84
67.60	0.10	3.86	1.06	0.00	24.30	0.00	5.59	2.60	0.00	0.68	0.00	61.23	0.00	0.58
70.01	0.12	2.93	3.80	1.62	20.26	0.19	0.94	7.29	0.06	2.43	0.00	59.10	0.00	1.25
72.60	0.00	15.21	5.12	0.25	17.69	0.41	2.23	9.83	0.00	1.49	0.00	46.94	0.00	0.83
75.03	0.00	15.05	12.04	0.65	23.76	0.22	0.43	0.75	0.00	1.29	0.00	45.48	0.00	0.32
77.60	0.09	18.84	8.51	3.44	26.00	0.00	1.09	5.25	0.00	2.36	0.00	32.70	0.00	1.72
80.04	0.00	37.04	2.57	0.12	20.78	0.00	0.12	1.34	0.00	4.89	0.00	33.01	0.00	0.12
82.63	5.95	17.18	5.61	3.57	27.55	0.00	0.51	2.72	0.00	3.40	0.00	32.99	0.00	0.51
85.01	2.73	10.36	12.73	7.09	10.73	4.18	0.55	8.36	0.00	8.73	0.00	32.55	0.00	2.00
87.61	0.19	6.68	19.27	9.16	14.50	0.57	0.76	19.85	0.00	2.86	0.00	24.24	0.00	1.91
90.01	0.52	4.39	5.02	4.28	21.21	0.42	0.52	12.23	0.00	1.78	0.00	49.01	0.00	0.63
92.60	0.00	5.00	4.11	3.23	17.85	35.19	3.23	2.65	0.00	2.06	0.00	26.16	0.00	0.51
95.01	0.00	2.35	10.47	0.84	22.45	43.72	2.68	3.60	0.00	1.93	0.00	11.39	0.08	0.50
97.61	0.00	0.71	3.55	0.71	32.07	36.80	6.46	1.18	0.00	1.42	0.00	16.08	0.00	1.02
100.01	0.00	1.08	0.83	0.47	15.76	26.98	5.41	1.48	0.00	0.36	0.00	47.62	0.00	0.00
101.81	0.00	4.16	16.40	0.12	15.30	12.97	0.61	4.53	0.00	0.49	0.00	44.80	0.00	0.61

Table 2: Presence absence list of species.

m	*Orbulina suturalis*	*Praeorbulina glomerosa circularis*	*Globigerinoides trilobus*	*Globigerinoides bisphericus*	*Globigerinoides quadrilobatus*	*Globigerinoides apertasuturalis*	*Globoquadrina altispira*	*Globoquadrina* cf. *altispira*	*Globoturborotalita woodi*	*Globoturborotalita druryi*	*Globoturborotalita bazieri*	*Globoturborotalita connecta*	*Globigerina praebulloides*	*Globigerina bulloides*	*Globigerina diplostoma*	*Globigerina concinna*	*Globigerina eamesi*	*Globigerina pseudociperoensis*	*Globigerina ottnangiensis*	*Globigerina tarchanensis*	*Globigerina* sp.	*Turborotalita quinqueloba*	*Turborotalita* cf. *quinqueloba*	*Globigerinella regularis*	*Clavatorella sturani*	*Globigerinita glutinata*	*Globigerinita uvula*	*Tenuitellinata angustiumbilicata*	*Globorotalia bykovae*	*Globorotalia transsylvanica*	*Paragloborotalia acrostoma*
8.40			x	x	x	x		x	x	x	x	x	x	x	x	x			x	x	x	x				x	x		x		
11.21	x	x	x	x	x			x					x	x	x	x			x	x	x		x	x		x		x	x	x	
14.81	x	x	x	x	x	x							x	x		x			x	x	x	x	x	x		x	x		x	x	
17.61			x	x	x	x			x		x	x	x	x	x	x					x	x	x	x		x	x		x	x	
20.02	x	x	x	x	x	x			x				x	x	x	x				x		x	x	x		x	x		x	x	
23.61	x	x	x		x			x	x	x	x	x	x	x						x	x	x	x	x		x	x		x		
26.41	x	x	x	x					x				x	x					x	x	x	x	x	x		x	x		x		
30.01	x		x	x	x			x					x	x	x				x	x	x	x	x	x		x	x		x	x	
34.41	x		x	x	x								x	x	x	x			x	x	x	x	x	x		x		x	x	x	
37.61	x	x	x	x	x	x	x	x	x		x	x	x	x					x		x	x		x		x	x	x	x	x	
40.01	x	x	x	x	x	x	x	x	x	x	x	x	x	x					x	x	x	x	x	x		x	x	x	x		
42.41	x	x	x	x	x	x	x	x	x	x	x		x	x					x		x	x	x	x	x	x	x		x		
45.01			x	x	x	x		x	x	x			x	x	x		x		x	x	x	x	x	x		x	x		x		
47.60	x		x	x	x	x	x	x	x				x	x	x	x		x	x	x	x	x	x	x		x	x		x	x	
50.01			x	x	x	x	x	x	x	x			x	x	x	x		x	x		x	x	x	x	x	x			x		
52.01			x	x	x	x		x	x	x	x		x	x	x	x	x		x		x		x	x		x	x		x	x	
55.01			x		x		x	x	x	x		x	x	x	x	x	x		x		x	x	x	x		x	x		x	x	
57.61	x	x	x	x	x	x		x	x	x	x	x	x	x	x				x	x	x	x	x	x		x	x		x	x	
60.01	x	x	x	x				x	x	x	x	x	x	x	x	x			x	x	x	x	x	x		x	x	x	x	x	
62.61	x	x	x	x	x	x		x	x		x	x	x	x	x					x	x	x	x	x		x	x		x		
65.01	x	x	x	x	x	x		x	x	x	x		x	x				x			x		x	x		x		x	x	x	
67.60		x	x	x	x			x					x	x	x		x						x	x		x	x		x	x	
70.01		x	x	x	x			x	x	x	x	x	x	x	x	x					x		x	x	x	x			x	x	
72.60			x	x	x	x	x	x			x	x	x	x	x						x		x	x		x	x		x	x	
75.03			x	x	x	x	x	x	x	x		x	x	x						x		x	x	x		x	x		x	x	
77.60		x	x	x	x	x	x	x	x	x		x	x	x			x					x	x	x		x	x		x	x	
80.04			x	x	x	x	x	x				x	x	x	x							x		x		x			x	x	
82.63	x	x	x	x	x	x	x	x	x	x		x	x	x								x	x	x		x			x	x	
85.01	x	x	x	x	x			x	x	x	x	x	x	x	x		x		x	x		x		x		x			x	x	
87.61		x	x	x	x	x		x	x		x		x	x							x	x	x	x		x			x	x	
90.01	x	x	x	x	x	x	x	x	x	x	x		x	x	x						x		x	x		x	x		x	x	
92.60			x	x	x	x	x	x	x	x			x	x	x		x		x		x		x	x		x			x	x	
95.01			x	x	x	x	x	x	x	x			x	x	x		x		x	x	x		x	x		x	x		x	x	x
97.61				x	x			x	x		x	x	x	x					x	x	x		x	x		x			x	x	
100.01			x	x	x		x	x	x			x	x	x					x	x	x	x	x	x		x			x	x	
101.81			x	x		x	x	x		x			x	x	x				x	x	x	x	x	x		x	x		x	x	

pressed in percentages of the total planktonic foraminiferal fauna, afterwards arcsine-root transformed for further statistical analyses.

Grouping of samples into classes that are homogeneous in their faunal composition was performed by Ward's Method (Figs. 6, 7; Table 3) based on Squared Euclidean Distances (McCune & Mefford 1999) with a subsequent determination of species that are indicative for the obtained clusters (Dufręne & Legendre 1997). To prevent distortion of linear relations normally gained in analyses reducing the multidimensional character space into a few axes, Detrended Correspondence Analyses (DECORANA; Hill & Gauch 1980) were used to represent the configuration of samples and genera in a few-dimensional system of axes (Figs. 6, 8, 9).

Simple statistical analyses were calculated with MS Excell, while for complex analyses the program packages SPSS (2006) and PC-ORD (McCune & Mefford 1999) were used.

Results

Distribution of the species groups

The following species were grouped into the species groups discussed (see also taxonomic notes):

— ***Clavatorella*:** *C. sturanii*.

— **"Four-chambered globigerinids":** *Globigerina bulloides*, *G. concinna*, *G. diplostoma*, *G. eamesi*, *G. prae-*

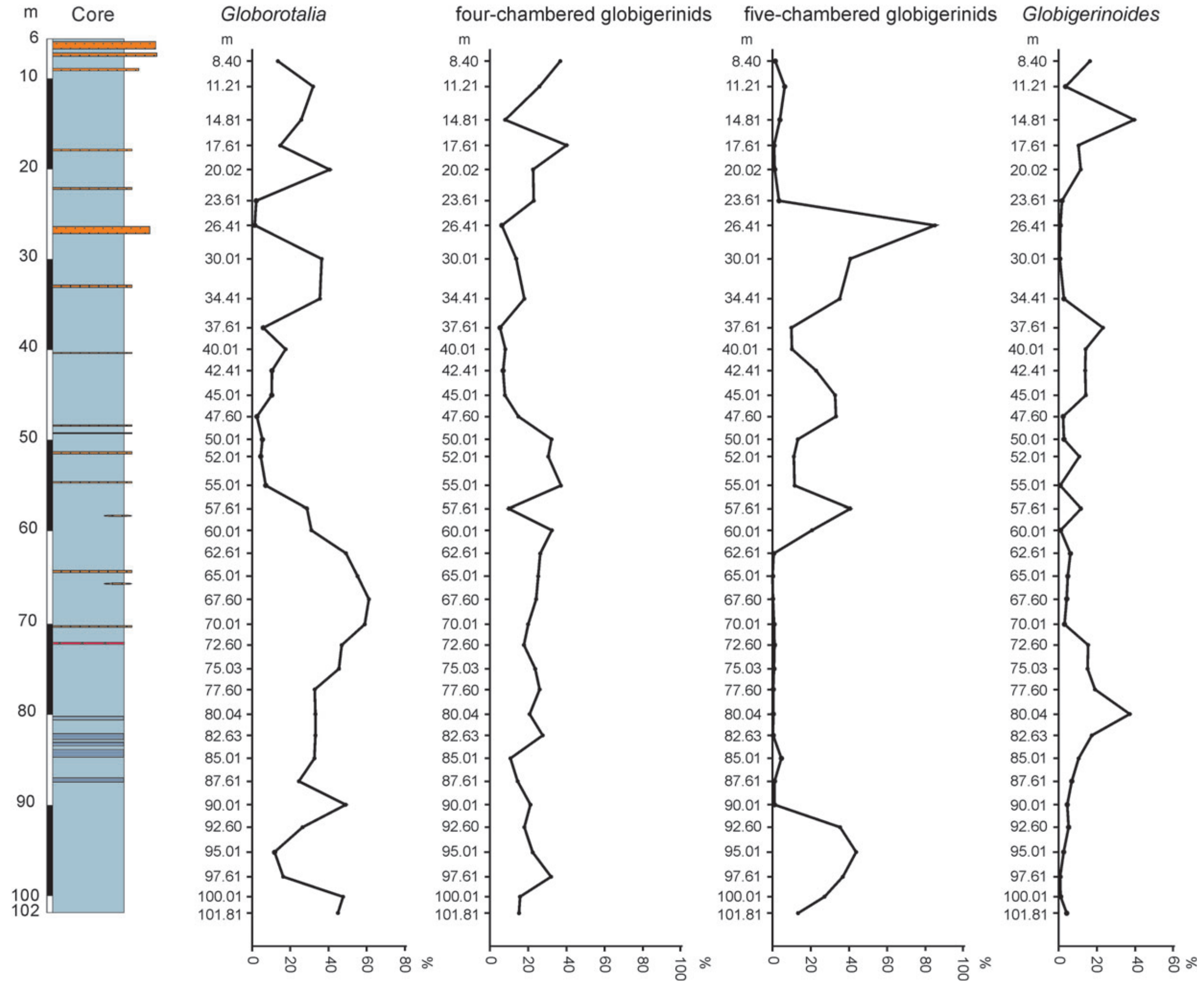

Fig. 3. Species groups *Globorotalia*, "four-chambered globigerinids", "five-chambered globigerinids" and *Globigerinoides*. Relative abundances plotted versus core-depth.

bulloides, *G. pseudociperoensis*.
- **"Five-chambered globigerinids":** *Globigerina ottnangiensis*, *G.* sp., *G. tarchanensis*.
- ***Globigerinella*:** *G. regularis*.
- ***Globigerinita*:** *G. glutinata*, *G. uvula*.
- ***Globigerinoides*:** *G. apertasuturalis*, *G. bisphericus*, *G. quadrilobatus*, *G. trilobus*.
- ***Globoquadrina*:** *G. altispira*, *G.* cf. *altispira*.
- ***Globorotalia*:** *G. bykovae*, *G. transsylvanica*.
- ***Globoturborotalita*:** *G. brazieri*, *G. connecta*, *G. druryi*, *G. woodi*.
- **Orbulinids:** *Orbulina suturalis*, *Praeorbulina glomerosa circularis*.
- ***Paragloborotalia*:** *P. acrostoma*.
- ***Tenuitellinata*:** *T. angustiumbilicata*.
- ***Turborotalita*:** *T. quinqueloba*, *T.* cf. *quinqueloba*.

Three species groups are the most important elements and dominate the planktonic foraminifera of the Baden-Sooss core (Table 1):

***Globorotalia* (Fig. 3; Table 1):**

This is the most abundant genus in the Baden-Sooss core. *Globorotalia* dominates 17 of the 36 samples with relative abundances >50 % between 65.01 m and 70.01 m. Very low abundances are found between 50.01 m and 47.60 m and from 23.61 m to 26.41 m.

"Four-chambered globigerinids" (Fig. 3; Table 1):

The morphological group "four-chambered globigerinids" is the second important constituent in the studied samples. It dominates 6 samples; relative abundances vary considerably reaching >40 % at 17.61 m.

"Five-chambered globigerinids" (Fig. 3; Table 1):

This morphological group is the third in order of important planktonic foraminifera and dominates 9 samples. It is abundant between 90.01 m and 101.81 m and between 26.41 m and 62.61 m, dominating the planktonic foraminiferal fauna with 85 % at 26.41 m.

Seven species groups are subdominant to common; three of them occasionally dominate a planktonic foraminiferal sample (Table 1):

***Globigerinoides* (Fig. 3; Table 1):**

The genus *Globigerinoides* dominates 2 samples and is a common element within the Baden-Sooss assemblages. It reaches high percentages around 14.81 m, 37.61 m and 80 m.

***Globoquadrina* (Fig. 4; Table 1):**

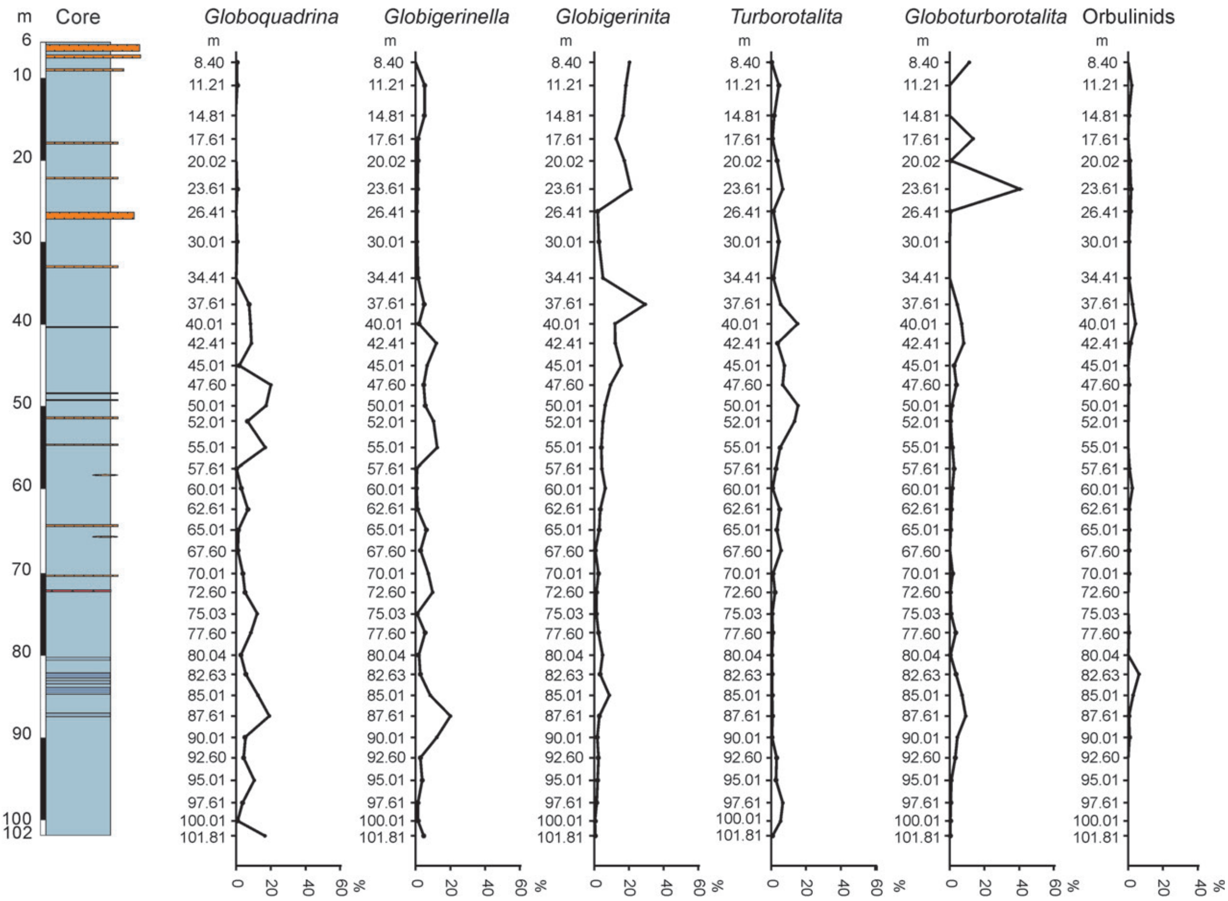

Fig. 4. Species groups *Globoquadrina*, *Globigerinella*, *Globigerinita*, *Turborotalita*, *Globoturborotalita* and orbulinids. Relative abundances plotted versus core-depth.

The genus *Globoquadrina* does not exceed relative frequencies of 20 % reaching maxima at 47.60 m and 87.61 m. It is very rare in the upper part of the core (from 34.41 m upwards).

Globigerinella **(Fig. 4; Table 1):**

This genus is present in almost all samples, often with more than 10 %, reaching nearly 20 % at 87.61 m.

Globigerinita **(Fig. 4; Table 1):**

In the lower part of the Baden-Sooss core this genus is present only in lower numbers. *Globigerinita* becomes more abundant from 47.60 m upwards, reaching a maximum of 29 % at 37.61 m. After a short decline, it again reaches relative frequencies around 20 % between 8.40 m and 23.61 m.

Turborotalita **(Fig. 4; Table 1):**

Except in samples from 40.01 m and 50.01 m with ~15 %, the genus *Turborotalita* is present in low percentages.

Globoturborotalita **(Fig. 4; Table 1):**

This group is sporadically present only in the upper part of the core at percentages of > 10 %, with 40 % (!) at 23.61 m.

Orbulinids (Fig. 4; Table 1):

Orbulinids are known to be rare components of planktonic foraminiferal faunas. They never exceed 6 % (at 82.63 m) within the Baden-Sooss samples.

The groups *Clavatorella*, *Paragloborotalia* and *Tenuitellinata* are not discussed, being represented only by a few specimens.

Faunal parameters and paleoclimatic indices

Abundance (Fig. 5):

The well-preserved planktonic foraminiferal faunas of the Baden-Sooss core show extreme fluctuations in abundance measured in tests per gram. Remarkably low abundances below 200 tests per gram are found from 80.04 m to 85.01 m, 45.01 m to 47.60 m, 37.61 m to 40.01 m, at 20.02 m and from 8.40 m to 14.81 m.

Diversity (Fig. 5):

Since counts were taken on genera, diversity is lowered compared to the species level. Consequently, diversity measures stressing the number of variables (species) like the Margalef Index will be less informative. Therefore, the Simpson Index, which rather stresses the "evenness" of a population, was used. Along the core, the Simpson Index is high where abundance is low, which can be seen around 85.01 m, 40.01 m and 11.21 m. In contrast, it is low where abundance is high, as is best seen at 26.41 m.

Paleoclimatic indices:

According to Spezzaferri (1992) and Bicchi et al. (2003), planktonic foraminifera were grouped by their paleoclimatic significance as follows: warm water indicators are orbulinids, *Globigerinoides* and *Globoquadrina*, with *Globigerinella* as a warm-temperate indicator. Indicators for cold-temperate waters are *Globoturborotalita* and *Globorotalia* while "four-

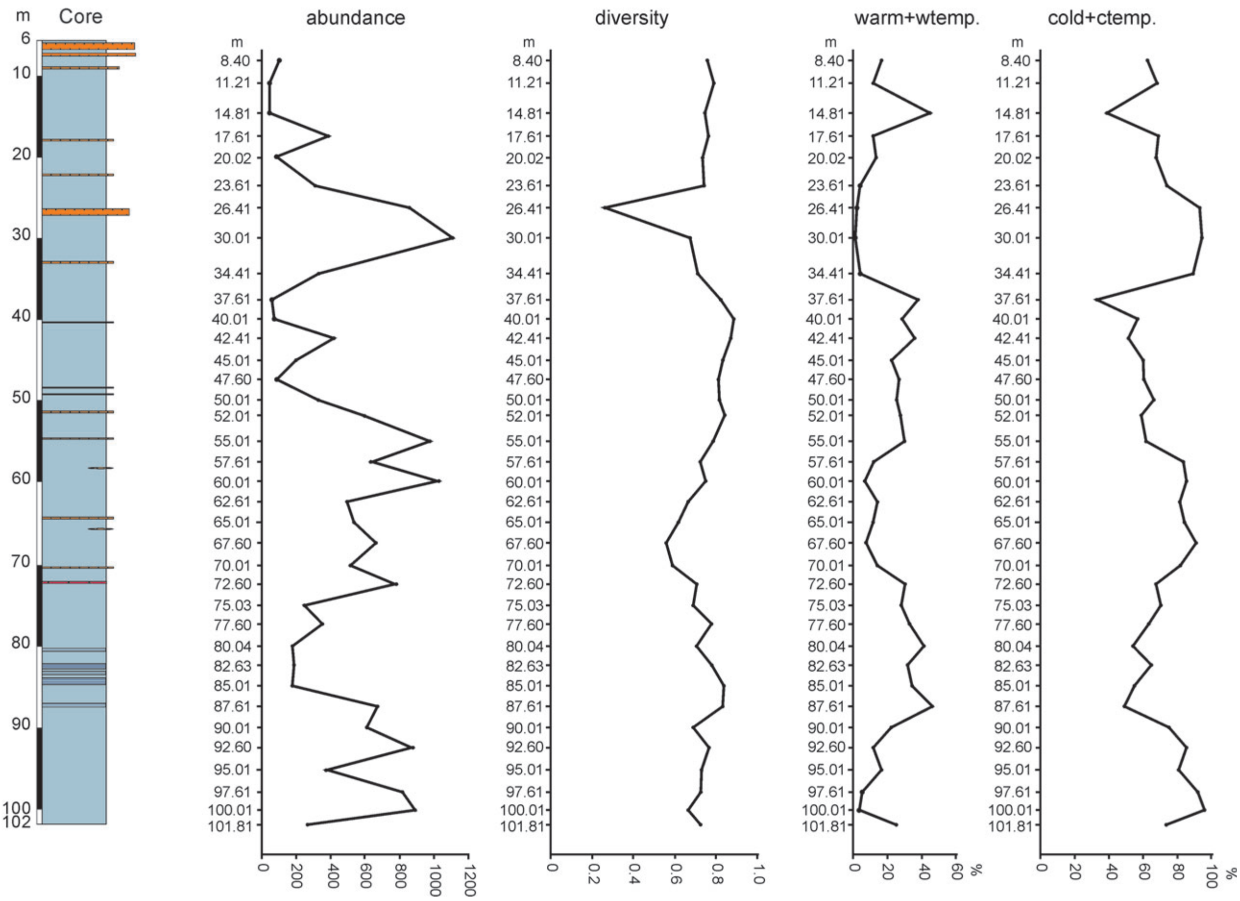

Fig. 5. Abundance, diversity, relative abundances of the groups "warm and warm-temperate plankton" and "cold and cold-temperate plankton" plotted versus core-depth.

chambered globigerinids", *Turborotalita* and "five-chambered globigerinids", which are lumped together with *Turborotalita* in most ecological and paleoecological studies (e.g. Kroon et al. 1988), hint at cold water. *Globigerinita* is considered tolerant to temperature (Hilbrecht 1996; Li et al. 1999).

— **"Warm and warm-temperate plankton"** group (Fig. 5): This faunal group reaches values of >20 % between 72.60 m and 90.01 m, 37.61 m and 55.01 m and at 40.81 m.

— **"Cold and cold-temperate plankton"** group (Fig. 5): This group shows high values with more than 80 % between 92.60 m and 100.01 m, 57.61 m and 70.01 m and between 26.41 m and 43.41 m.

Detrended Correspondence Analysis (DECORANA)

According to results of the DECORANA (Figs. 6, 8, 9) there are three gradients characterizing the faunal succession along the Baden-Sooss core.

DECORANA axis 1 (Fig. 6):

This axis has a coefficient of determination of 0.492 and is the most explanatory axis. It shows positive values from 92.60 m to 101.81 m, from 40.01 m to 60.01 m and from 26.41 to 34.41 m.

DECORANA axis 2 (Fig. 6):

This axis has a coefficient of determination of 0.195. With a few exceptions (85.01 m, 82.63 m, 57.61 m) this gradient shows negative values in the lower part of the core. Positive values can be detected between 37.61 m to 47.60 m, while axis values are almost positive to highly positive in the uppermost core, with an exception at 11.21 m.

DECORANA axis 3 (Fig. 6):

This axis has a coefficient of determination of 0.096. It shows positive values almost in the lower (at 101.81 m, from 85.01 m to 97.61 m and from 70.01 m to 77.60 m) and middle parts (between 47.60 m and 55.01 m and at 42.41 m) of the core. With the exception of 23.61 m, it is negative from 40.01 m upwards.

Correlations (Table 4)

Correlations (Pearson's correlation coefficient) were calculated between species groups, faunal parameters and paleoclimatic indices. Furthermore, correspondence of species groups, faunal parameters and paleoclimatic indices to DECORANA gradients were calculated.

Globorotalia:

Being the most abundant genus in our material, high proportions of *Globorotalia* influence the diversity as expressed in a

Table 3: Faunal groups and clusters, including indicator values.

m	**Orbulinids**	***Globigerinoides***	***Globoquadrina***	***Globoturborotalita***	***Globigerina* four-chamb.**	***Globigerina* five-chamb.**	***Turborotalita***	***Globigerinella***	***Clavatorella***	***Globigerinita***	***Tenuitellinata***	***Globorotalia***	***Paragloborotalia***
Cluster 1:													
8.40	0.00	16.23	0.33	11.26	36.92	0.99	0.17	0.00	0.00	20.20	0.00	13.08	0.00
17.61	0.00	10.40	0.00	13.37	40.10	0.33	0.66	1.16	0.00	12.54	0.00	14.36	0.00
23.61	1.48	1.59	0.11	40.11	22.86	2.86	6.88	0.95	0.00	20.95	0.00	1.59	0.00
Ind. value	4	14	1	38	19	6	10	3	0	23	0	9	0
Cluster 2a:													
37.61	2.39	22.99	7.46	4.48	5.37	9.55	5.37	4.78	0.00	28.96	0.30	8.06	0.00
40.01	4.15	13.97	8.30	6.77	8.08	9.61	15.07	1.97	0.00	11.79	2.18	17.25	0.00
42.41	1.32	13.78	8.67	8.05	6.81	22.60	3.64	11.84	0.08	11.92	0.00	10.29	0.00
45.01	0.00	14.05	1.67	2.34	7.69	32.61	7.53	6.69	0.00	15.55	0.00	10.03	0.00
47.6	0.19	2.09	19.96	3.99	14.83	32.89	6.46	4.56	0.00	9.51	0.00	2.28	0.00
Ind. value	22	18	19	18	9	24	21	17	3	21	25	9	0
Cluster 2b:													
50.01	0.00	2.61	17.33	1.16	32.04	12.97	15.30	5.42	0.77	6.20	0.00	5.03	0.00
52.01	0.00	10.58	6.65	0.55	30.43	10.58	13.30	10.25	0.00	5.02	0.00	4.14	0.00
55.01	0.00	0.72	16.71	1.45	37.04	11.25	5.20	12.37	0.00	4.14	0.00	6.78	0.00
Ind. value	0	10	24	8	19	18	26	21	26	12	0	7	0
Cluster 3a:													
30.01	0.23	0.47	0.06	0.00	13.95	40.64	4.24	0.47	0.00	2.62	0.00	35.87	0.00
34.41	0.19	2.79	0.00	0.00	17.87	34.87	1.15	1.15	0.00	5.19	0.19	35.54	0.00
57.61	0.15	11.61	0.05	2.38	9.63	40.50	2.58	0.20	0.00	4.37	0.00	28.54	0.00
60.01	2.29	0.85	2.94	1.57	32.30	20.39	0.69	0.60	0.00	6.33	0.06	30.73	0.00
92.60	0.00	5.00	4.11	3.23	17.85	35.19	3.23	2.65	0.00	2.06	0.00	26.16	0.00
95.01	0.00	2.35	10.47	0.84	22.45	43.72	2.68	3.60	0.00	1.93	0.00	11.39	0.08
97.61	0.00	0.71	3.55	0.71	32.07	36.80	6.46	1.18	0.00	1.42	0.00	16.08	0.00
100.01	0.00	1.08	0.83	0.47	15.76	26.98	5.41	1.48	0.00	0.36	0.00	47.62	0.00
Ind. value	5	8	7	5	14	33	14	8	0	9	3	17	13
Cluster 3b:													
26.41	1.12	0.67	0.00	0.07	6.35	85.20	1.12	0.37	0.00	1.94	0.00	0.60	0.00
Cluster 4a:													
11.21	2.05	3.69	0.82	0.00	26.02	5.94	4.30	5.12	0.00	17.83	0.20	31.76	0.00
14.81	0.33	39.51	0.00	0.00	8.03	3.28	1.80	4.75	0.00	16.56	0.00	25.57	0.00
20.02	0.79	11.39	0.00	0.79	22.59	0.39	3.34	1.18	0.00	17.09	0.00	40.47	0.00
80.04	0.00	37.04	2.57	0.12	20.78	0.00	0.12	1.34	0.00	4.89	0.00	33.01	0.00
Ind. value	14	23	2	1	14	5	11	12	0	20	4	18	0
Cluster 4b:													
62.61	0.33	5.98	6.83	1.04	26.20	0.33	4.94	0.91	0.00	3.38	0.00	49.09	0.00
65.01	0.30	4.30	1.14	0.72	25.16	0.06	3.23	5.98	0.00	2.87	0.12	55.29	0.00
67.60	0.10	3.86	1.06	0.00	24.30	0.00	5.59	2.60	0.00	0.68	0.00	61.23	0.00
70.01	0.12	2.93	3.80	1.62	20.26	0.19	0.94	7.29	0.06	2.43	0.00	59.10	0.00
72.60	0.00	15.21	5.12	0.25	17.69	0.41	2.23	9.83	0.00	1.49	0.00	46.94	0.00
75.03	0.00	15.05	12.04	0.65	23.76	0.22	0.43	0.75	0.00	1.29	0.00	45.48	0.00
77.60	0.09	18.84	8.51	3.44	26.00	0.00	1.09	5.25	0.00	2.36	0.00	32.70	0.00
82.63	5.95	17.18	5.61	3.57	27.55	0.00	0.51	2.72	0.00	3.40	0.00	32.99	0.00
90.01	0.52	4.39	5.02	4.28	21.21	0.42	0.52	12.23	0.00	1.78	0.00	49.01	0.00
Ind. value	12	15	15	8	15	1	11	15	1	8	1	23	0
Cluster 4c:													
85.01	2.73	10.36	12.73	7.09	10.73	4.18	0.55	8.36	0.00	8.73	0.00	32.55	0.00
87.61	0.19	6.68	19.27	9.16	14.50	0.57	0.76	19.85	0.00	2.86	0.00	24.24	0.00
101.81	0.00	4.16	16.40	0.12	15.30	12.97	0.61	4.53	0.00	0.49	0.00	44.80	0.00
Ind. value	12	13	27	17	11	11	6	23	0	9	0	18	0

negative correlation with diversity indices. This species group is also high negatively correlated with the group "five-chambered globigerinids", *Globigerinita* and *Turborotalita*. It is also significantly negatively correlated with the three DECORANA axes.

"Four-chambered globigerinids":

This group does not significantly correlate with any of the herein considered groups, except the significant negative correlation with "five-chambered globigerinids".

Table 4: Table of correlation (Pearson correlation coefficient).

0.389 = highly correlated **0.292 = correlated** ***0.051* = not correlated**	**DECORANA 1**	**DECORANA 2**	**DECORANA 3**	**abundance**	**diversity**	**Orbulinids**	***Globigerinoides***	***Globoquadrina***	***Globoturborotalita***	***Globigerina* 4 chamb.**	***Globigerina* 5 chamb.**	***Turborotalita***	***Globigerinella***	***Clavatorella***	***Globigerinita***	***Tenuitellinata***	***Globorotalia***	**warm+wtemp.**	**cold+ctemp.**
abundance	**0.389**	−0.351	*0.111*		**−0.391**	−0.299	**−0.530**	*−0.108*	*−0.185*	*0.149*	**0.391**	*−0.060*	***0.097***	*−0.065*	**−0.620**	*−0.250*	*−0.150*	**−0.440**	**0.630**
diversity	−0.328	0.292	0.337	**−0.391**		*0.223*	*0.254*	**0.403**	*0.203*	*0.063*	**−0.399**	0.326	0.335	*0.128*	**0.392**	*0.244*	−0.312	**0.521**	**−0.621**
Orbulinids	*−0.094*	*0.269*	*−0.136*	−0.299	*0.223*		*0.130*	*−0.011*	*0.176*	*−0.160*	*−0.126*	*−0.069*	*−0.085*	*−0.095*	0.281	**0.477**	*−0.091*	*0.164*	*−0.253*
Globigerinoides	**−0.458**	*0.137*	−0.312	**−0.530**	*0.254*	*0.130*		*−0.135*	*−0.063*	*−0.239*	−0.377	*−0.172*	*−0.013*	*−0.122*	0.363	*0.089*	*−0.025*	**0.681**	**−0.696**
Globoquadrina	*−0.071*	*−0.140*	**0.850**	*−0.108*	**0.403**	*−0.011*	*−0.135*		*−0.066*	*−0.006*	*−0.120*	*0.186*	**0.533**	0.324	*−0.202*	*0.038*	*−0.225*	**0.568**	−0.384
Globoturborotalita	*−0.158*	**0.823**	*0.206*	*−0.185*	*0.203*	*0.176*	*−0.063*	*−0.066*		*0.079*	*−0.212*	*0.057*	*−0.013*	*−0.056*	**0.460**	*0.053*	−0.370	*0.065*	*−0.161*
***Globigerina* 4 chamb.**	−0.316	*0.051*	*0.144*	*0.149*	*0.063*	*−0.160*	*−0.239*	*−0.006*	*0.079*		−0.369	*0.007*	*−0.112*	*0.181*	*−0.137*	*−0.248*	*0.022*	*−0.235*	*0.211*
***Globigerina* 5 chamb.**	**0.972**	*−0.018*	*−0.070*	**0.391**	**−0.399**	*−0.126*	−0.377	*−0.120*	*−0.212*	−0.369		*0.065*	*−0.276*	*−0.021*	*−0.204*	*−0.052*	**−0.405**	**−0.446**	**0.454**
Turborotalita	*0.212*	*0.129*	*0.201*	*−0.060*	0.326	*−0.069*	*−0.172*	*0.186*	*0.057*	*0.007*	*0.065*		*0.024*	**0.485**	*0.164*	**0.479**	**−0.408**	*−0.022*	*−0.099*
Globigerinella	*−0.246*	*−0.130*	**0.612**	***0.097***	0.335	*−0.085*	*−0.013*	**0.533**	*−0.013*	*−0.112*	*−0.276*	*0.024*		*0.069*	*−0.103*	*−0.107*	*−0.050*	**0.590**	**−0.455**
Clavatorella	*0.061*	*−0.006*	0.315	*−0.065*	*0.128*	*−0.095*	*−0.122*	0.324	*−0.056*	*0.181*	*−0.021*	**0.485**	*0.069*		*−0.023*	*−0.047*	*−0.209*	*0.080*	*−0.056*
Globigerinita	*−0.124*	**0.728**	*−0.243*	**−0.620**	**0.392**	0.281	0.363	*−0.202*	**0.460**	*−0.137*	*−0.204*	*0.164*	*−0.103*	*−0.023*		*0.192*	**−0.457**	*0.163*	**−0.592**
Tenuitellinata	*0.007*	*0.114*	*−0.147*	*−0.250*	*0.244*	**0.477**	*0.089*	*0.038*	*0.053*	*−0.248*	*−0.052*	**0.479**	*−0.107*	*−0.047*	*0.192*		*−0.098*	*0.096*	*−0.177*
Globorotalia	**−0.484**	**−0.691**	−0.325	*−0.150*	−0.312	*−0.091*	*−0.025*	*−0.225*	−0.370	*0.022*	**−0.405**	**−0.408**	*−0.050*	*−0.209*	**−0.457**	*−0.098*		*−0.153*	**0.378**
warm+wtemp.	**−0.468**	*0.015*	0.380	**−0.440**	**0.521**	*0.164*	**0.681**	**0.568**	*0.065*	*−0.235*	**−0.446**	*−0.022*	**0.590**	*0.080*	*0.163*	*0.096*	*−0.153*		**−0.884**
cold+ctemp.	**0.424**	−0.366	*−0.220*	**0.630**	**−0.621**	*−0.253*	**−0.696**	−0.384	*−0.161*	*0.211*	**0.454**	*−0.099*	**−0.455**	*−0.056*	**−0.592**	*−0.177*	**0.378**	**−0.884**	

"Five-chambered globigerinids":

This group significantly correlates with total abundance and the DECORANA axis 1. Significant negative correlations are to diversity, *Globigerinoides*, "four-chambered globigerinids" and extremely negative to *Globorotalia* and the group "warm and warm-temperate plankton".

Globigerinoides:

This genus correlates highly positively with the group "warm and warm-temperate plankton", positively with *Globigerinita*, but highly negatively with the group "cold and cold-temperate plankton", abundance and the DECORANA axis 1, and weaker negatively with "four-chambered globigerinids" and the DECORANA axis 3.

Globoquadrina:

This genus is highly positively correlated with *Globigerinella*, diversity, the group "warm and warm-temperate plankton" and the DECORANA axis 3. The positive correlation with *Clavatorella* is meaningless because of the low numbers of the latter genus. It is negatively correlated with the group "cold and cold-temperate plankton".

Globigerinella:

Globigerinella is highly positively correlated with *Globoquadrina*, the group "warm and warm-temperate plankton" and the DECORANA axis 3. It is more weakly positively correlated with diversity and highly negatively with the group "cold and cold-temperate plankton".

Globigerinita:

This genus is highly positively correlated with *Globoturborotalia*, diversity and the DECORANA axis 2 and more weakly positively correlated with *Globigerinoides* and orbulinids. It is high negatively correlated with *Globorotalia*, the group "cold and cold-temperate plankton" and abundance.

Turborotalita:

Turborotalita is highly positively correlated with the very rare *Clavatorella* and *Tenuitellinata*, more weakly positively correlated with diversity and high negatively correlated with *Globorotalia*.

Globoturborotalita:

This genus is highly positively correlated with *Globigerinita* and the DECORANA axis 2, and negatively correlated with *Globorotalia*.

Orbulinids:

This group is highly positively correlated with the very rare *Tenuitellinata* and more weakly positively with *Globigerinita*. It is negatively correlated with abundance.

Abundance:

This faunal parameter correlates highly positively with the groups "cold and cold-temperate plankton" and "five-chambered globigerinids" and the DECORANA axis 1,

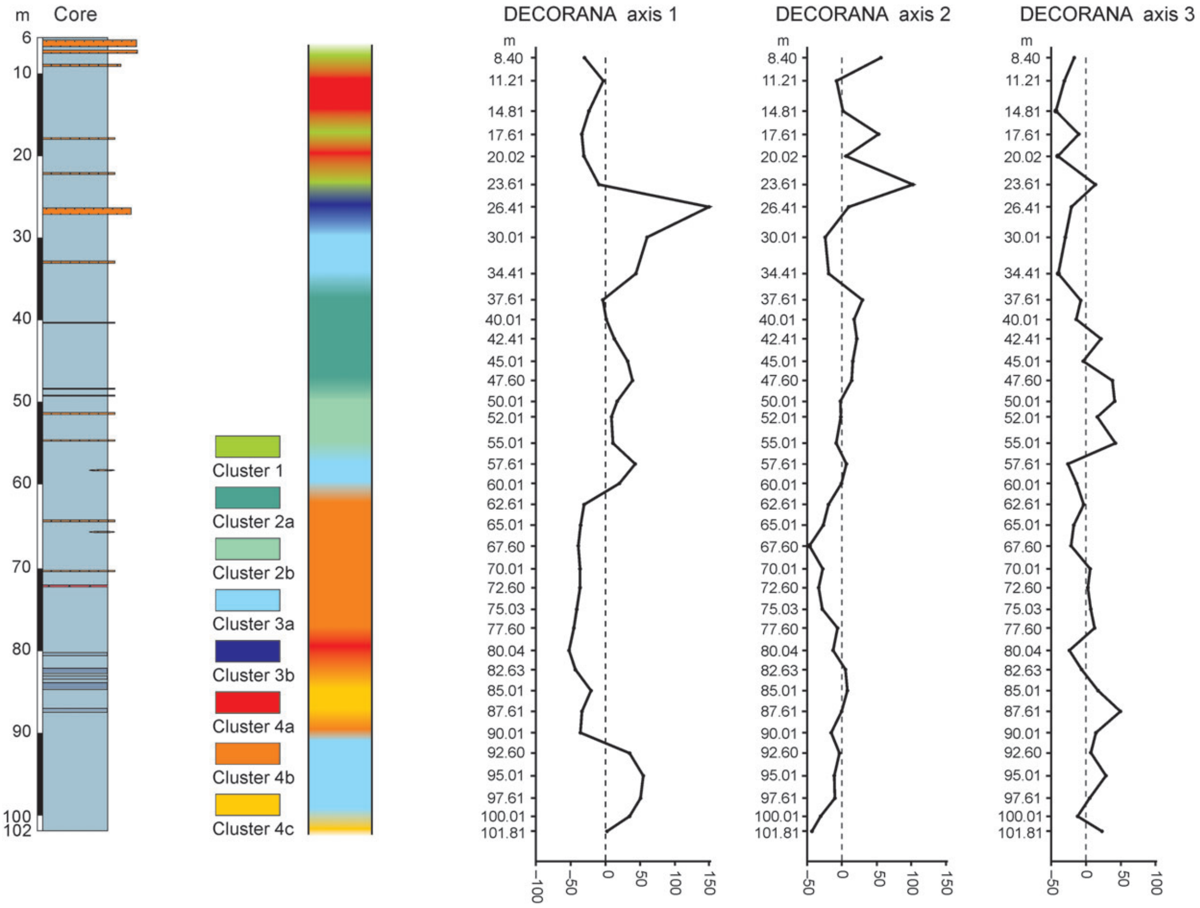

Fig. 6. Clusters 1 to 4 and DECORANA axis 1 to 3 plotted versus core-depth.

high negatively with *Globigerinoides*, *Globigerinita*, the group "warm and warm-temperate plankton" and diversity, more weakly negatively with orbulinids and the DECORANA axis 2.

Diversity:

Diversity correlates highly negatively with abundance, but also with the groups "cold and cold-temperate plankton" and "five-chambered globigerinids". It correlates negatively with *Globorotalia*. Diversity correlates highly positively with the group "warm and warm-temperate plankton", *Globoquadrina* and *Globigerinita*, positively with *Globigerinella* and *Turborotalita*.

"Warm and warm-temperate plankton" group:

On the one hand, this faunal group is highly positively correlated with *Globigerinoides*, *Globigerinella*, *Globoquadrina* and diversity and more weakly positively correlated with the DECORANA axis 3. On the other hand, it correlates high negatively with the "cold and cold-temperate plankton" group, the DECORANA axis 1, "five-chambered globigerinids" and abundance.

"Cold and cold-temperate plankton" group:

This group correlates highly positively with abundance, "five-chambered globigerinids", DECORANA axis 1 and more weakly positively with *Globorotalia*. Negative correlation is found with *Globoquadrina* and the DECORANA axis 2. Correlation is highly negative with the "warm and warm-temperate plankton" group, *Globigerinoides*, *Globigerinita*, *Globigerinella* and diversity; a negative correlation also exists with *Globoquadrina* and the DECORANA axis 2.

DECORANA axis 1:

This axis is highly positively correlated with the groups "five-chambered globigerinids", and "cold and cold-temperate plankton" and with abundance. Highly negative correlations exist with *Globorotalia*, *Globigerinoides* and the "warm and warm-temperate plankton" group; it is also negatively correlated with "four-chambered globigerinids" and diversity.

DECORANA axis 2:

This axis is correlated highly positively with *Globoturborotalita* and *Globigerinita*, more weakly positively with diversity, more weakly negatively with abundance and the "cold and cold-temperate plankton" group and highly negatively with *Globorotalia*.

DECORANA axis 3:

This axis is correlated highly positively with *Globoquadrina* and *Globigerinella*, positively with diversity, *Clavatorella* and with the group "warm and warm-temperate

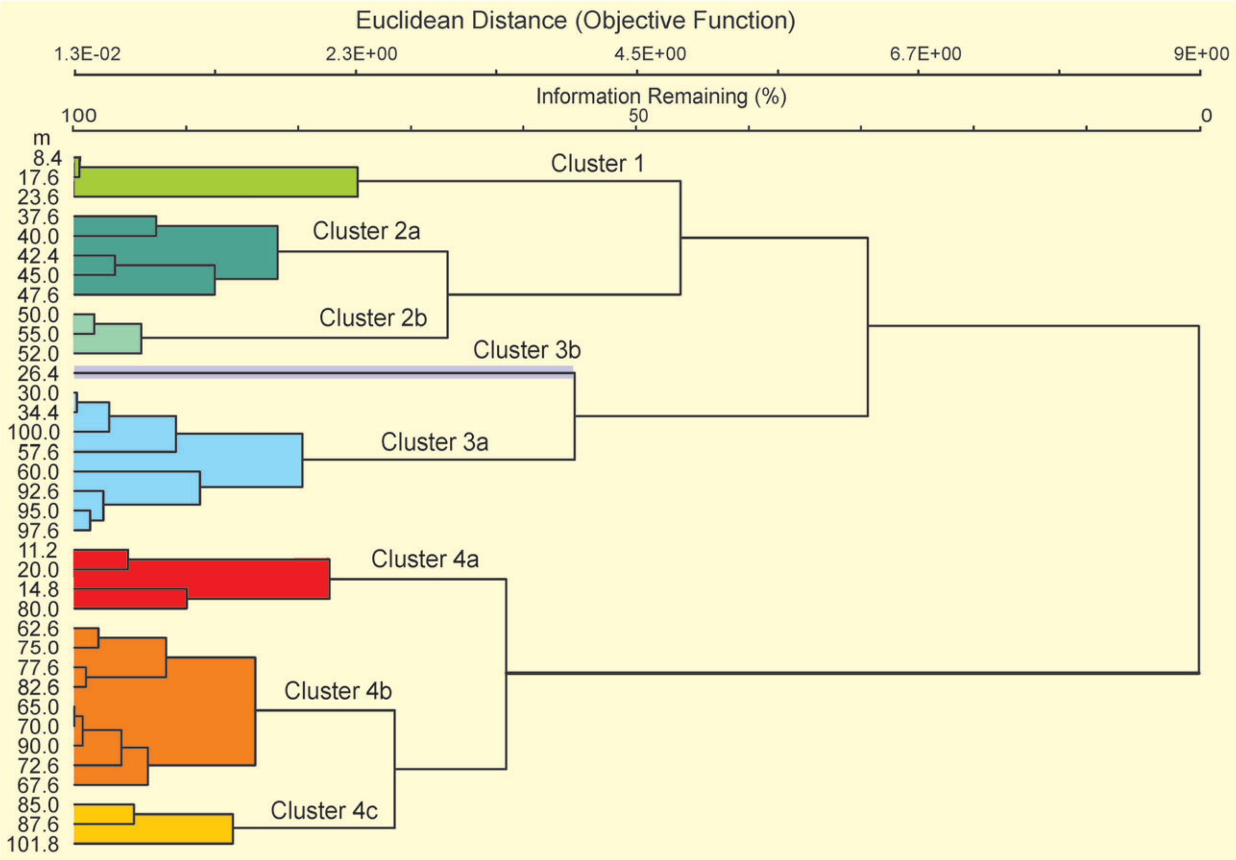

Fig. 7. Cluster analysis: Dendrogram of sample clusters (Ward's Method, based on Squared Euclidean Distances).

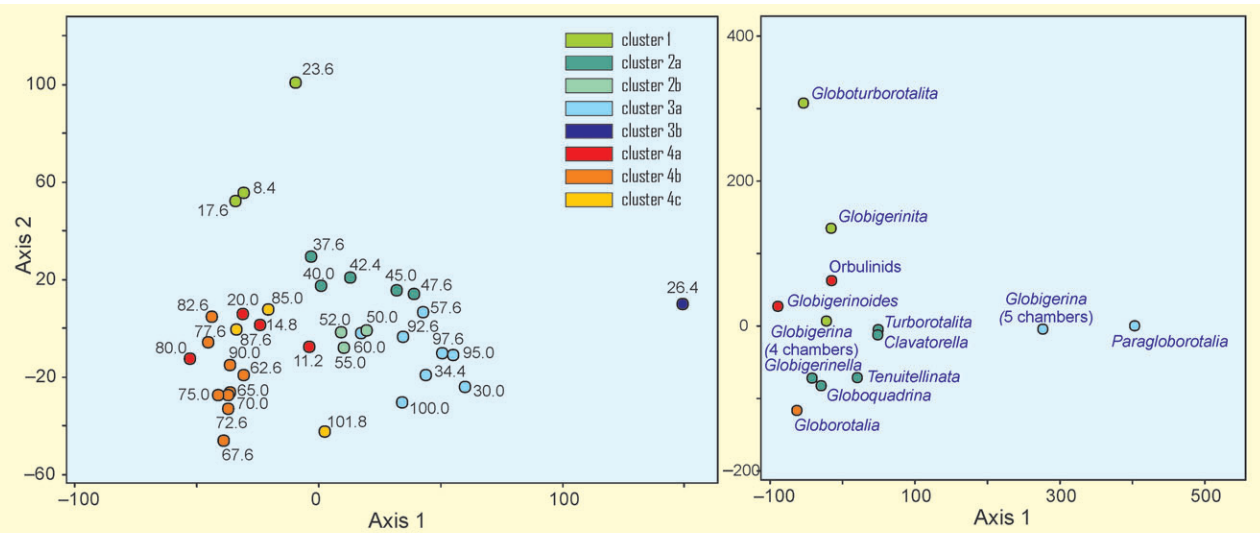

Fig. 8. Detrended Correspondence Analysis: Samples and species groups scaled by DECORANA axis 1 versus DECORANA axis 2.

plankton". It is correlated negatively with *Globigerinoides* and *Globorotalia*.

Cluster analysis

The obtained clusters order the samples with respect to the most abundant groups involved in this study (Figs. 6, 7; Table 3):

Cluster 1:

Cluster 1 groups the samples 8.40 m, 17.61 m and 23.61 m. High indicator values are given for *Globoturborotalita*, *Globigerinita* and "four-chambered globigerinids", they are the most abundant elements within this cluster. The faunas of this cluster are positively stressed by the DECORANA axis 2 (Fig. 8).

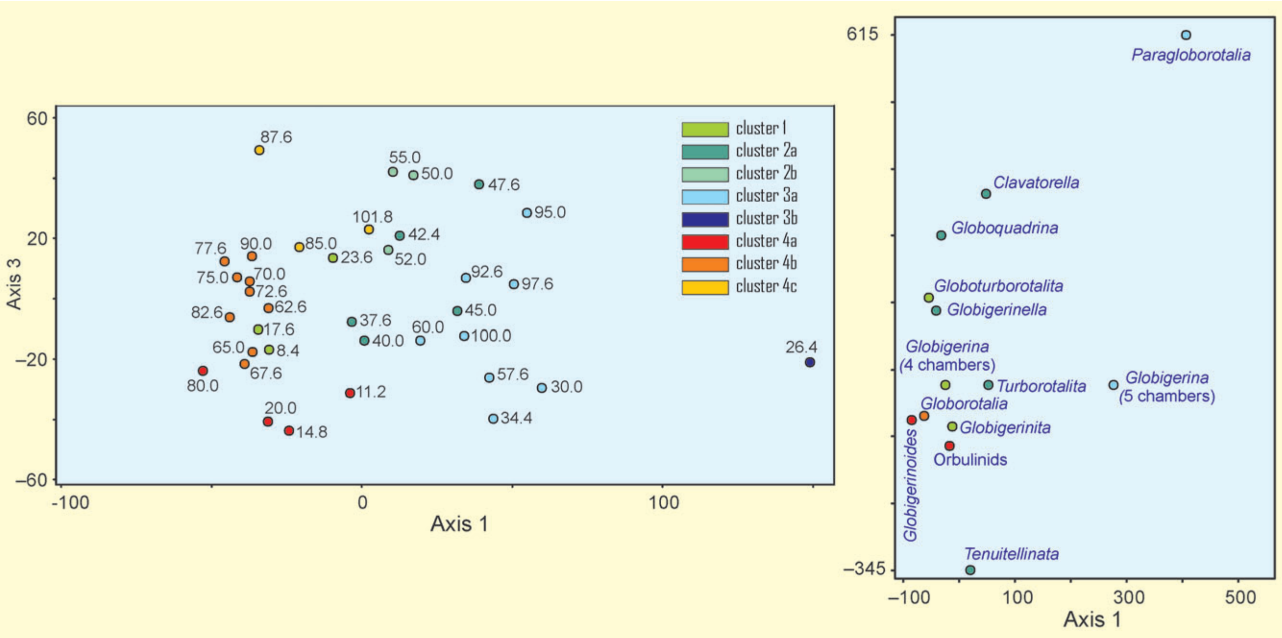

Fig. 9. Detrended Correspondence Analysis: Samples and species groups scaled by DECORANA axis 1 versus DECORANA axis 3.

Cluster 2 is divided into two subclusters (Fig. 7):

Subcluster 2a contains the samples from 37.61 m, 40.01 m, 42.41 m, 45.01 m, and 47.60 m. High indicator values are found for "five-chambered globigerinids", orbulinids, *Globigerinita* and *Turborotalita*. The faunas are dominated either by the group "five-chambered globigerinids" or by *Globigerinoides*, which also possesses a moderately high indicator value.

Subcluster 2b contains the samples 50.01 m, 52.01 m and 55.01 m. High indicator values are given for *Turborotalita*, *Globoquadrina*, *Globigerinella* and the group "four-chambered globigerinids", which dominates the samples of this subcluster. The faunas of this cluster are highly diverse. Most of them are loaded weakly positive by DECORANA axis 1 (Fig. 8), some by DECORANA axis 2 (Fig. 8) and even some by DECORANA axis 3 (Fig. 9).

Cluster 3 is also divided into two subclusters (Fig. 7):

Subcluster 3a comprise samples 30.01 m, 34.41 m, 57.61 m, 60.01 m, 92.60 m, 95.01 m, 97.61 m and 100.01 m. These faunas are dominated by the group "five-chambered globigerinids", which also has the highest indicator value. Besides this group, *Globorotalia* and the group "four-chambered globigerinids" are important elements of these faunas.

Subcluster 3b yields the outstanding sample 26.41 m. This fauna is highly dominated by the group "five-chambered globigerinids". Cluster 3 is partly highly positively loaded by the DECORANA axis 1 (Fig. 8).

Cluster 4 is subdivided into three subclusters (Fig. 7):

Subcluster 4a groups the samples 11.21 m, 14.81 m, 20.02 m and 80.04 m. *Globigerinoides*, *Globigerinita* and *Globorotalia* possess high indicator values; together with the "four-chambered globigerinids" they constitute the most important groups within these faunas.

Subcluster 4b is made up of the samples 62.61 m, 65.01 m, 67.60 m, 70.01 m, 72.60 m, 75.03 m, 77.60 m, 82.63 m and 90.01 m. These faunas are highly dominated by *Globorotalia*, which also has the highest indicator value. The group "four-chambered globigerinids" and, to a lesser extent, *Globigerinoides* are important elements of these faunas.

Subcluster 4c comprises the samples 85.01 m, 87.61 m, and 101.81 m. Here, *Globoquadrina* and *Globigerinella* have the highest indicator values, although *Globorotalia* is once again the most important element of these faunas. *Globorotalia* dominates almost all Cluster 4 faunas. Most of the faunas are negatively loaded by the DECORANA axis 1 (Fig. 8). Many of them, especially those of Subcluster 4b, are loaded negatively by the DECORANA axis 2 (Fig. 8) and many of them, especially those of Subcluster 4c, are loaded positively by the DECORANA axis 3 (Fig. 9).

Discussion

The foraminiferal groups

Globorotalia, mainly represented by *G. bykovae*, shows negative correlations to almost all the other variables. This might be due to a different habitat preferred by this group. Since *G. scitula*, related to *G. bykovae* (Cicha et al. 1998), is not only associated with cold water (Be & Hutson 1977) but also a deep-water element (Hilbrecht 1996; Itou et al. 2001), the group of Badenian *Globorotalia* probably dwelled in deeper waters compared to most of the other groups involved in this study. This might explain the negative correlation with all other groups and parameters discussed. The overall trend, that *Globorotalia* is less abundant in the upper part of the core compared to the lower part, is probably a result of a slight basin shallowing observed by Báldi & Hohenegger (2008).

The group “four-chambered globigerinids” shows high fluctuations but remains an important faunal constituent in most of the core samples. This group does not demonstrate any significant correlation to the other groups involved. The reason might be found in different ecological preferences of the species incorporated in this group. According to the literature, *Globigerina bulloides* prefers productive environments being rather tolerant in respect to temperature and salinity, whereas *G. praebulloides*, similar to *G. falconensis*, might rather be sensitive to temperature (Hilbrecht 1996).

The group “five-chambered globigerinids” shows a very significant distribution along the lithological succession. Small, “five-chambered globigerinids” are represented in high numbers even within shallow water environments (e.g. Middle Ottnangian foraminiferal faunas; Rupp & Van Husen 2007) and should be considered as living in shallow water layers. In addition, they are supposed to be related to cool water (Rögl & Spezzaferri 2003). High relative abundance of “five-chambered globigerinids”, therefore, might signalize the presence of a cold, shallow water layer. This corresponds to the negative correlation to the groups “warm and warm-temperate plankton”, *Globigerinoides* and diversity, since high diversities are expected in warm rather than in cold oceans. The positive correlation with abundance also supports this assumption as cold waters are often highly productive (Arnold & Parker 1999).

Globigerinoides is almost represented by *G. trilobus* and related species, which prefer tropical and warm temperate environments (Li et al. 1999). Its membership of a warm-water group is also confirmed by the highly positive correlation with the group “warm and warm-temperate plankton”.

Globoquadrina is represented in the Baden-Sooss material by *G. altispira* and variants. Heavy cancellate species of *Globoquadrina* are typical warm water elements found in tropical and subtropical oceans (*G. hexagona*; Be & Hutson 1977) which corresponds to the correlations presented above. *Globoquadrina altispira* is thought to prefer intermediate water depth (Nikolaev et al. 1998).

Globigerinella regularis is similar to the recent *G. siphonifera*, which prefers low to mid latitudes, shows a correlation with high temperature around 200 m and is suggested to be a “deeper water element” (Hilbrecht 1996; Nikolaev et al. 1998: *G. obesa*).

Globigerinita is reported to be a “shallow water” element (Hemleben et al. 1989) and most abundant in areas adjacent to upwelling zones (Brummer & Kroon 1988; Hilbrecht 1996).

Turborotalita (*T. quinqueloba* and variants) is common in temperate and cold water (Hilbrecht 1996) and dwells in “shallow” to “intermediate water masses” (Hemleben et al. 1989). The highly positive correlation to *Clavatorella* and *Tenuitellinata* is probably artificial due to the low numbers of the latter groups.

Globoturborotalita is supposed to be a faunal element preferring deeper water layers (*G. woodi*; Nikolaev et al. 1998). Rögl & Spezzaferri (2003) found *Globoturborotalita* associated with globigerinids preferring highly productive environments corresponding to a high input of continental material. A preference for higher productivity might give an explanation for the high correlation with *Globigerinita*, which is related to upwelling.

Orbulina (and *Praeorbulina*) is a temperate to tropical element. The high correlation to *Tenuitellinata* is unimportant because of the low numbers of the latter.

Faunal parameters and paleoclimatic indices

Abundance shows extreme fluctuations along the core. In modern oceans planktonic foraminiferal abundances result from fertility of the water masses and physical parameters (Hemleben et al. 1989). In the fossil realm, sedimentation rates, bioturbation and other factors additionally influence planktonic foraminiferal abundance. Despite the highly differing values, a general decrease of abundance towards the top of the core, probably due to higher sedimentation rates, is noticed.

In modern oceans, the diversity of planktonic foraminiferal faunas is higher in warm than in cold waters (Boltovskoy & Wright 1976). In the Baden-Sooss core, diversity is positively correlated with warm water elements (group “warm and warm-temperate plankton”, *Globoquadrina*, *Globigerinella*); high values are thought to be an expression of warm water conditions. A dramatic decrease in diversity takes place at 26.41 m, where high numbers of “five-chambered globigerinids” signalize a drastic lowering of surface water temperatures.

The groups “warm and warm-temperate plankton” and “cold and cold-temperate plankton” are indices estimating general temperature fluctuations along the Baden-Sooss core. Significantly low temperatures are once again expressed by extremely low values for the group “warm and warm-temperate plankton” around 26.41 m.

Detrended correspondence analysis

DECORANA axis 1: According to the high positive correlations with the groups “five-chambered globigerinids”, “cold and cold-temperate plankton” and abundance and the high negative correlations with *Globigerinoides* and the group “warm and warm-temperate plankton”, this axis points towards a temperature related factor. The group “five-chambered globigerinids” was supposed to be related to cold and shallow water (see above). Negative correlation with diversity and highly positive correlation with abundance fits the picture, as cold-water masses are often highly productive and exhibit planktonic foraminiferal faunas of low diversity (Arnold & Parker 1999). Negative correlations with warm water elements like *Globigerinoides* strengthen this interpretation. High positive values of this axis hint at the presence of cold, shallow water masses. Along the Baden-Sooss core, such cold water bodies should have been developed between 92.60 m and 100.01 m and between 26.41 m and 60.01 m, but were best developed at 26.41 m.

DECORANA axis 2: *Globoturborotalita* and *Globigerinita* inhabit different water masses but are probably both related to production (see above); such a proposed preference for high productivity is the only overlap found between these two genera. Therefore this axis might point towards a productivity factor not correlated with the expected high productivity combined with cold water ingressions (see DECORANA axis 1). The circumstance, that the group "four-chambered globigerinids" does not show correlation to such a productivity factor, as might be expected, is declared by different ecological preferences of the species involved within this group (see above). The weak positive correlation with diversity and negative correlation with the group "cold and cold-temperate plankton" suggests temperate sea water. Sticking to such an interpretation, the DECORANA axis 2 shows that productivity under temperate conditions was slightly raised in the Baden-Sooss Sea to the uppermost part of the core with drastic fluctuations between 8.40 m and 26.41 m.

DECORANA axis 3: *Globoquadrina* and *Globigerinella* are highly positively correlated with this axis. Both species are "deeper water elements" preferring warm water conditions. This axis seems to be assigned to high temperature in a deeper water layer. According to this interpretation, temperature in deeper water decreased upwards in the Baden-Sooss core.

Cluster analysis

Cluster 1 faunas do not show high amounts of warm water groups. They are positively loaded by DECORANA axis 2 (see discussion above) and are interpreted as temperate water faunas of a nutrient enriched sea.

Cluster 2 faunas are highly diverse and exhibit strong abundance shifts. They show considerable amounts of "warm-water elements" but positive values of the DECORANA axis 1 also hint at minor ingressions of cold superficial water, obviously not that strong to affect the faunas drastically. Variable loadings of the DECORANA axis 2 and 3 show changes in productivity and deeper water temperatures. These faunas are interpreted as warm water faunas influenced by moderately changing conditions in temperature and productivity.

Cluster 3 comprises samples with high numbers of the group "five-chambered globigerinids". Diversity is moderate to very low, abundance is extremely high and the group "warm and warm-temperate plankton" is almost lacking. All the faunas are positively or high positively loaded by DECORANA axis 1 and show a strong influence of cold, high productive superficial water masses.

Cluster 4: *Globorotalia* dominates most of the faunas of this cluster. It is represented by "cold-temperate water" species probably preferring a deeper habitat than most of the other planktonic foraminifera involved in this study. High numbers of this genus hint at cold deep water. On the other hand the group "warm and warm-temperate plankton" reaches the highest values within these faunas, some of them are even dominated by warm water elements like *Globigerinoides*. Just a few faunas of this cluster are poor in "warm to warm-temperate plankton". Diversity is moderate to high and abundance is rather low within these faunas. Negatively loaded by the DECORANA axis 1, faunas of Cluster 4 do not exhibit any cold shallow water ingressions. Negative loadings by the DECORANA axis 2 might point towards rather oligotrophic conditions. The faunas of Subcluster 4c are positively loaded by DECORANA axis 3 and signalize rather warm deeper water masses. So faunas of this cluster are assigned to partly warm, partly temperate, almost well stratified water masses not influenced by any cold shallow water ingressions.

Conclusion

Considering all the variables discussed, the following scenario might give a proper conception about the local paleoenvironment of the Badenian Sea and changing conditions characterizing the environment as a result of the analysed planktonic foraminiferal faunas.

Starting at 101.81 m a rather warm, oligotrophic sea ("warm and warm-temperate plankton", diversity, DECORANA axis 2) with warm "deeper water masses" (*Globoquadrina*, Cluster 4c, DECORANA axis 3) and cold deep water (*Globorotalia*) was affected by a first ingression of cool shallow water masses around 95.01 m ("five-chambered globigerinids", Cluster 3a, DECORANA axis 1). Deeper water masses were not strongly affected during this period (DECORANA axis 3, *Globoquadrina*) and productivity was not drastically raised (abundance, DECORANA axis 2).

The cold water influence ended around 92 m, from 70.01 to 90.01 m a rather stable period, not influenced by any cold shallow water ingressions (negative DECORANA axis 1), followed (Cluster 4a,b,c) and warm and rather oligotrophic, well stratified water masses were formed (*Globigerinoides*, *Globoquadrina*, *Globigerinella*, diversity, "warm and warm-temperate plankton", *Globorotalia*).

Between 62.61 m and 70.01 m a cooling trend could be observed (group "warm and warm-temperate plankton"), although no shallow cold water ingressions were observed (DECORANA axis 1).

A new ingression of superficial cold water started at 60.01 m retaining to 57.61 m (DECORANA axis 1, Cluster 3) without forcing the observed cooling trend seriously. On the contrary, a new warming was observed between 37.61 and 55.01 m ("warm and warm-temperate plankton"). The next ingression of cold shallow water at 47.60 m (to 45.01 m) did not affect shallow (*Globigerinoides*) and deeper water layers (*Globoquadrina*, *Globigerinella*, DECORANA axis 3) too much, but resulted in less stable conditions in shallow water layers with minor temperature fluctuations and changes in productivity ("five-chambered globigerinids", *Globigerinita*, DECORANA axis 1 and 2, Cluster 2).

The next cold water ingression, starting at 34.41 m, was strong ("five-chambered globigerinids", DECORANA axis 1, Cluster 3) and cumulated in an absence of warm water species (*Globigerinoides*, *Globoquadrina*, *Globigerinella*, "warm and warm-temperate plankton") at 30.01 m and 26.41 m and an extraordinary dominance of cold water species ("five-chambered globigerinids", DECORANA axis 1) at 26.41 m.

This drastic ingression abruptly ended and was followed by a rather temperate to warm but unstable and productive period between 8.40 m to 23.61 m (*Globigerinoides*, *Globigerinita*, *Globoturborotalita*, DECORANA axis 2).

Since the approximate age of the Baden-Sooss core was dated to −14.379 to −14.142 Myr (Hohenegger et al. 2008), the sediments were deposited before the Middle Miocene cooling event (−13.9 Myr; Holbourn et al. 2005). This leads to correlation of the observed temperature oscillations with the oscillations reported from the Lower Badenian of the Skawina Formation, Poland (interval P2; Bicchi et al. 2003) immediately before the cooling event.

Taxonomic notes

In addition to the generic groups, all identified species were noted in a presence/absence list and plotted against the core-depth (Table 2).

The taxonomical concept of Cicha et al. (1998) was applied and combined with that of Bolli & Saunders (1985) and Jenkins (1985) in some cases.

Clavatorella

Clavatorella sturanii (Gianelli & Salvatorini)

1976 *Globorotalia sturanii* Gianelli & Salvatorini: 168, pl. 1, fig. 1
1985 *Clavatorella sturanii* (Gianelli & Salvatorini) — Bolli & Saunders: 255, pl. 45, fig. 3

Remarks: Very few specimens.

Globigerina

"Four-chambered globigerinids":

Globigerina bulloides d'Orbigny
(Fig. 10.1)

1826 *Globigerina bulloides* d'Orbigny: 277, no. 1
1846 *Globigerina bulloides* d'Orbigny — d'Orbigny: 163, pl. 9, figs. 4–6, no. 116
1998 *Globigerina bulloides* d'Orbigny — Cicha et al.: 99, pl. 34, figs. 24–26

Remarks: Visual discrimination of *G. bulloides* from *G. praebulloides* is somehow artificial (as it is to *G. falconensis*, see Malmgren & Kennett 1977). Especially juvenile tests are difficult to assign to one of these two species. Here a rather broad species concept was applied, including dwarfed, heavily calcified specimens. The main discriminating feature to *G. praebulloides* is thought to be the increase in chamber size.

Globigerina concinna Reuss

1850 *Globigerina concinna* Reuss: 373, pl. 47, fig. 8
1998 *Globigerina concinna* Reuss — Cicha et al.: 99, pl. 32, figs. 15–17

Remarks: This species was rarely found. Only big adult specimens are five-chambered. Dissecting the youngest chambers typical *G. diplostoma* are revealed. It is interpreted as an ecovariant of *G. diplostoma* and therefore is included in the group "four-chambered globigerinids".

Globigerina diplostoma Reuss

1850 *Globigerina diplostoma* Reuss: 373, pl. 47, fig. 9; pl. 48, fig. 1
1998 *Globigerina diplostoma* Reuss — Cicha et al.: 99, pl. 35, figs. 1–3

Remarks: See *G. concinna*.

Globigerina eamesi Blow

1959 *Globigerina eamesi* Blow: 176, pl. 9, fig. 39
1998 *Globigerina eamesi* Blow — Cicha et al.: 99, pl. 35, figs. 9–11

Globigerina praebulloides Blow
(Fig. 10.2, Fig. 11.3)

1959 *Globigerina praebulloides* Blow: 180, pl. 8, fig. 47; pl. 9, fig. 48
1998 *Globigerina praebulloides* Blow — Cicha et al.: 100, pl. 34, figs. 13–16

Remarks: A broad species concept was applied including almost three chambered specimens and dubious juvenile tests with an almost smooth chamber wall and very small pores. Also few specimens with a fine lip resembling *G. falconensis* were included. See also *G. bulloides*.

Globigerina pseudociperoensis Blow

1969 *Globigerina praebulloides pseudociperoensis* Blow: 381, pl. 17, fig. 8–9

Remarks: Only a few specimens were recorded. The penultimate whorl shows four-chambers; this species is interpreted as an ecovariant of *G. praebulloides* and is included in the group "four-chambered globigerinids".

"Five-chambered globigerinids":

Globigerina ottnangiensis Rögl

1969 *Globigerina ciperoensis ottnangiensis* Rögl: 221, pl. 2, figs. 7–10; pl. 4, 1–7
1998 *Globigerina ottnangiensis* Rögl — Cicha et al.: 100, pl. 32, figs. 9–14

Remarks: Typical *G. ottnangensis* are not common in the Baden-Sooss material. Specimens with typical lobate outline of *G. ottnangensis* but with a smaller umbilicus were also assigned to this species as a very few, rather high-spired specimens resembling *G. dubia* Egger.

Globigerina sp.
(Figs. 10.3,4)

Remarks: Small five-chambered globigerinids, low trochospiral, outline weakly lobate, often with a heavy calcified test and a very small umbilicus. The last chamber is often small ("Kummerkammer"). Related to *G. tarchanensis*, the typical form shows a more compact test, a smaller aperture and a very small umbilicus. This species makes up the great bulk of the group "five-chambered globigerinids".

Globigerina tarchanensis Subbotina & Chutzieva

1950 *Globigerina tarchanensis* Subbotina & Chutzieva in Bogdanowicz: 173, pl. 10, fig. 5
1998 *Globigerina tarchanensis* Subbotina & Chutzieva — Cicha et al.: 101, pl. 32, figs. 18–22

Remarks: present in low numbers in many samples.

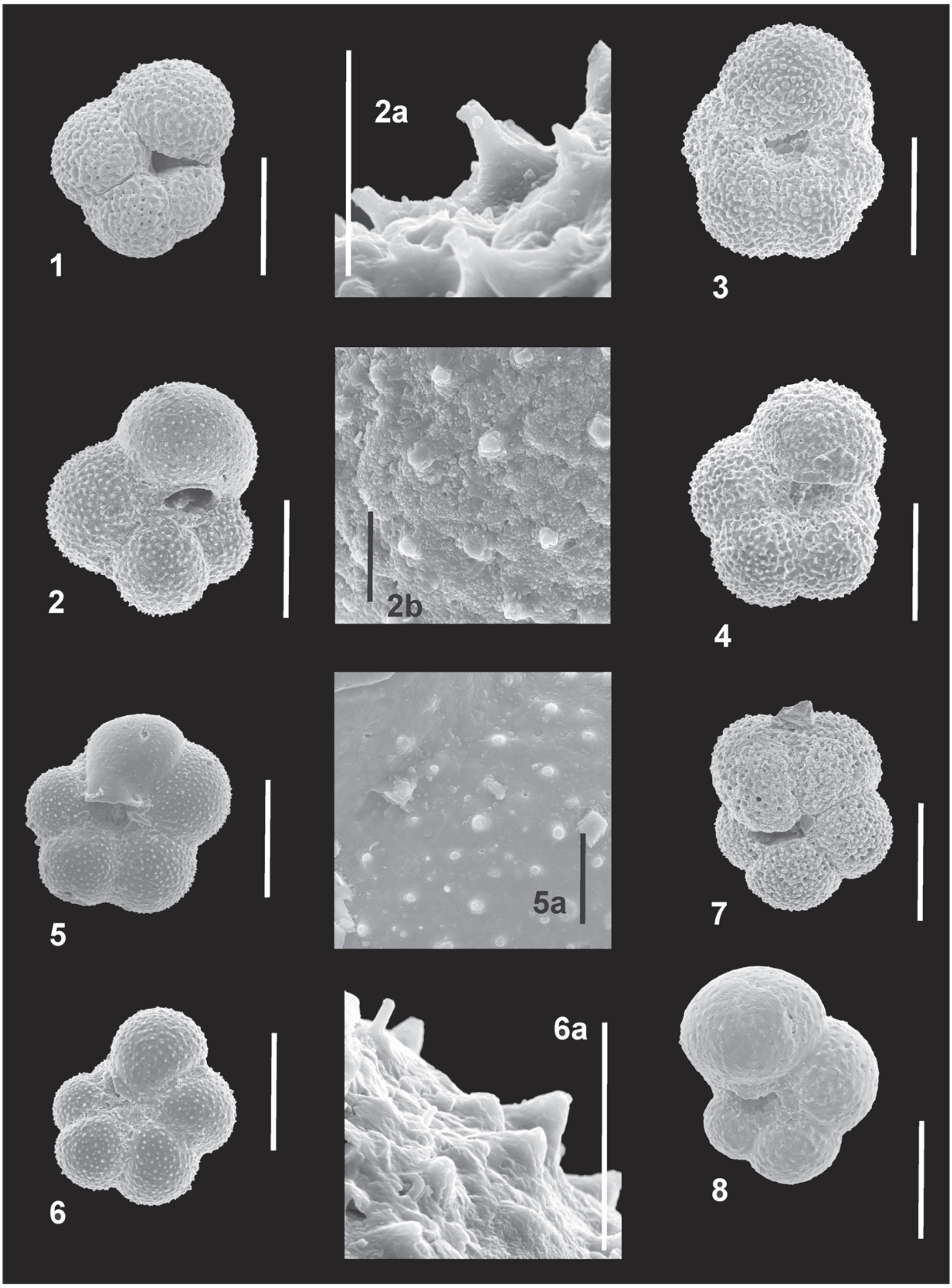

Fig. 10. **1** — *Globigerina bulloides* d'Orbigny, dwarfed specimen; **2** — *Globigerina praebulloides* Blow, juvenile specimen, weakly ornamented chamber wall and very small pores; 2a — spines on 4th chamber; 2b — small pores on 1st chamber; **3** — *Globigerina* sp. with large last chamber; **4** — *Globigerina* sp. typical form; **5** — *Turborotalita* cf. *quinqueloba* (Natland), visually smooth; 5a — pores 2nd chamber; **6** — *Turborotalita* cf. *quinqueloba* (Natland) $5^{1/2}$ chambers with strong incised sutures; 6a — spines 2nd chamber; **7** — *Turborotalita quinqueloba* (Natland); **8** — *Globoquadrina* cf. *altispira* (Cushman & Jarvis), juvenile specimen. **Scale-bars:** 1, 2, 3, 4, 5, 6, 7, 8 = 100 μm; 2a, 2b, 5a, 6a = 10 μm. **Specimens:** 1 to 8: Baden-Sooss core (Lower Badenian).

Globigerinella

Globigerinella regularis (d'Orbigny)

1846 *Globigerina regularis* d'Orbigny: 162, pl. 9, figs. 1–3
1998 *Globigerinella regularis* (d'Orbigny) — Cicha et al.: 101, pl. 38, figs. 4–6

Remarks: This species is highly variable. A very few problematic specimens of *G. obesa* were lumped together with *G. regularis*.

Globigerinita

Globigerinita glutinata (Egger)
(Fig. 11.2)

1893 *Globigerina glutinata* Egger: 371, pl. 13, figs. 19–21
1988 *Globigerinita glutinata* (Egger) — Brummer: 77–100, pl. 1, figs. 1–2, pl. 2, figs. 1–18, pl. 3, figs. 1–16

Remarks: A rather broad species concept was applied, including *G. parkerae* (Bermudez) and *G. juvenilis* (Bolli). The latter is the most frequent form in the Baden-Sooss material. Visual discrimination of microperforate planktonic foraminifera and juvenile globigerinids is sometimes impossible (Zachariasse 1978). Test shape, aperture and the character of the chamber wall often seem to be identical. Only under SEM is it possible to identify the spinose and the non-spinose characters. A very helpful feature for distinguishing microperforate planktonic foraminifera is not only the pore diameter but also the pore concentration, which is much higher than in finely macroperforate taxa (Brummer 1988). Compared to *Globigerinita* and *Tenuitellinata*, juvenile *Globigerina* also exhibit very fine but less densely arranged pores. Occasionally recovered spines and spineholes on tests of juvenile *Globigerina* specimens ascertain the designation (Fig. 11.2a).

Globigerinita uvula (Ehrenberg)
(Fig. 11.1)

1862 *Polydexia uvula* Ehrenberg: 308; 1873: 241, pl. 2, figs. 24–25
1998 *Globigerinita uvula* (Ehrenberg) — Cicha et al.: 102, pl. 30, figs. 16–18

Remarks: Very rare in the Baden-Sooss material.

Globigerinoides

Globigerinoides apertasuturalis Jenkins

1960 *Globigerinoides apertasuturalis* Jenkins: 352, pl. 2, fig. 3
1998 *Globigerinoides apertasuturalis* Jenkins — Cicha et al.: 102, pl. 36, figs. 11–13

Remarks: Typical *G. apertasuturalis* are very rare. This species is easily distinguished from the following species by its more delicate test and the finer cancellation.

Globigerinoides bisphericus Todd

1954 *Globigerinoides bispherica* Todd: 681, pl. 1, fig. 1
1998 *Globigerinoides bisphericus* Todd — Cicha et al.: 102, pl. 36, figs. 4–7

Globigerinoides quadrilobatus (d'Orbigny)

1846 *Globigerina quadrilobata* d'Orbigny: 164, pl. 9, figs. 7–10
1998 *Globigerinoides quadrilobatus* (d'Orbigny) — Cicha et al.: 102, pl. 36, figs. 8–10

Globigerinoides trilobus (Reuss)

1850 *Globigerina triloba* Reuss: 374, pl. 47, fig. 11
1998 *Globigerinoides trilobus* (Reuss) — Cicha et al.: 102, pl. 36, figs. 1–3

Globoquadrina

Globoquadrina altispira (Cushman & Jarvis)

1936 *Globigerina altispira* Cushman & Jarvis: 5, pl. 1, figs. 13–14
1998 *Globoquadrina altispira* (Cushman & Jarvis) — Cicha et al.: 103, pl. 41, figs. 3–5

Globoquadrina cf. *altispira* (Cushman & Jarvis)
(Fig. 10.8)

1998 *Globoquadrina* cf. *altispira* (Cushman & Jarvis) — Cicha et al.: 103, pl. 41, figs. 1–2

Remarks: Size and chamber form are remarkably variable. The cancellation also differs from fine to heavily cancellate, even within one specimen. Juvenile forms are 4- to 5-chambered, often look smooth and are recognized either by the presence of a tooth (Fig. 10.8) or by heavy pustulation around the umbilicus.

Globorotalia

Globorotalia bykovae (Aisenstat)

1960 *Turborotalia bykovae* Aisenstat in Subbotina et al.: 69, pl. 13, fig. 7
1998 *Globorotalia* (*Obandyella*) *bykovae* (Aisenstat) — Cicha et al.: 104, pl. 39, figs. 33–35

Remarks: This species is highly variable (see http://rin.hiroba.org/foraminifera/bykovae.html; 2008.01.18) and intergrades with *G. transsylvanica*. The variability in chamber wall thickness was surprising. Normally, the tests of *G. bykovae* are delicate, smooth and often transparent. In some cases heavy chamber wall thickening and deep depressed pore cones were observed, simulating a cancellate test (see *G. transsylvanica*).

Globorotalia transsylvanica Popescu
(Fig. 11.5)

1970 *Globorotalia transsylvanica* Popescu: 200, pl. 7, figs. 28–30

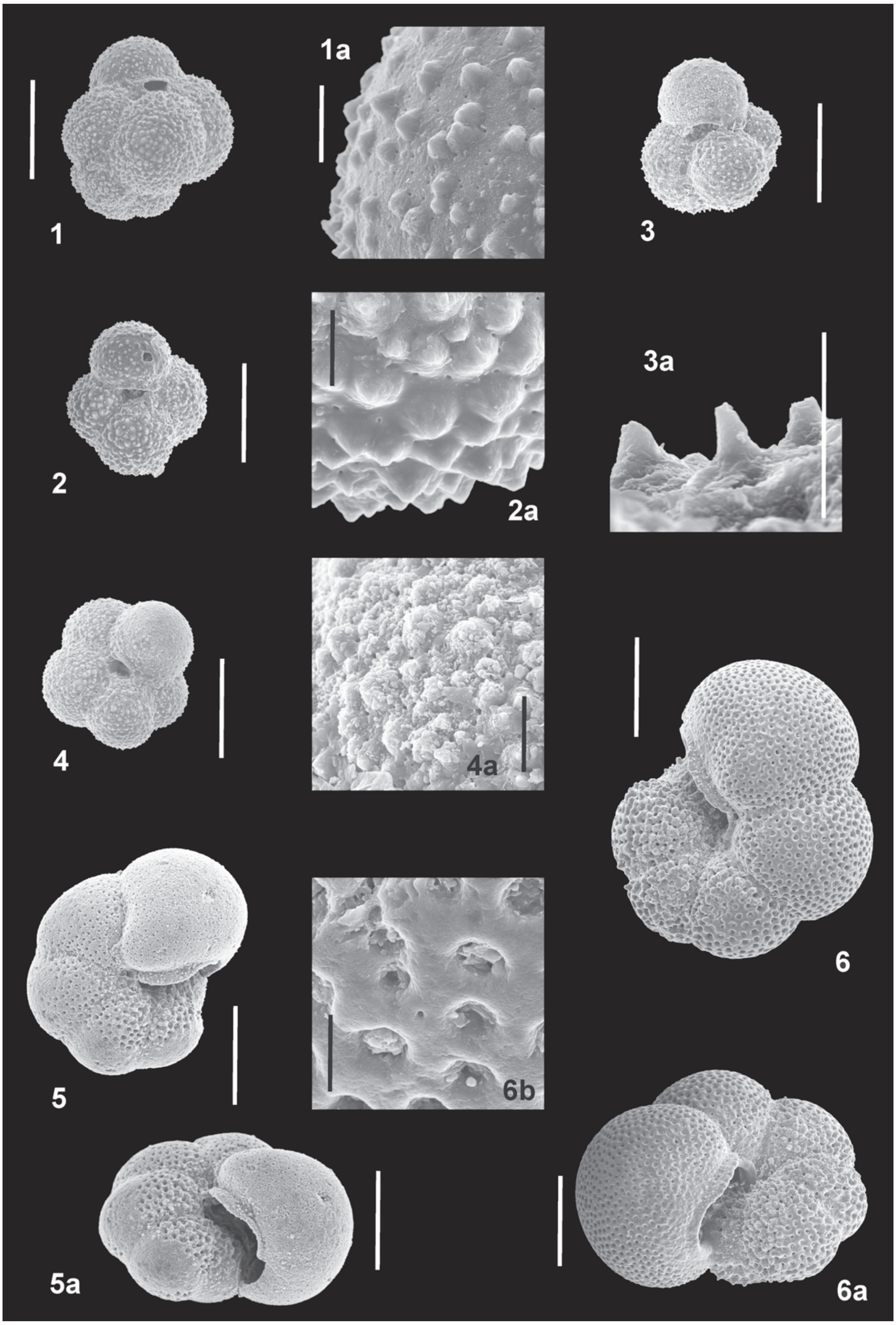

Fig. 11. **1** — *Globigerinita uvula* (Ehrenberg); 1a — 1st chamber, note conical pustules and the great number of micropores, compare pore density with Fig. 10.2b,5a; **2** — *Globigerinita glutinata* (Egger); 2a — 4th chamber, note conical pustules and the great number of micropores; **3** — *Globigerina praebulloides* Blow, visually very similar to *Globigerinita*; 3a — 3rd chamber, spines; **4** — *Tenuitellinata angustiumbilicata* (Bolli); 4a — 1st chamber, note the high number of micropores; **5** — *Globorotalia transsylvanica* Popescu, umbilical view; 5a — *Globorotalia transsylvanica* Popescu, lateral view; **6** — *Paragloborotalia mayeri* (Cushman & Ellisor), umbilical view; 6a — lateral view; 6b — 3rd chamber, cancellation and spine hole. **Scale bars:** 1, 2, 3, 4, 5, 5a, 6, 6a = 100 µm; 1a, 2a, 3a, 4a, 6b = 10 µm. **Specimens:** 1 to 5 — Baden-Sooss core (Lower Badenian); 6 — Trinidad, Cipero Fm, *C. dissimilis* Zone (Lower Miocene).

1998 *Globorotalia* (*Obandyella*) *transsylvanica* Popescu — Cicha et al.: 104, pl. 39, figs. 30–32

Remarks: This species was discriminated from *G. bykovae* by its inflated chambers and rounded periphery. However, some intergradations with *G. bykovae* were observed. As with *G. bykovae*, delicate tests and tests with heavy shell thickening were present. Extremely inflated forms with large apertures, heavily thickened chamber walls and deeply depressed pore cones simulating a cancellate test can be mixed up with *Paragloborotalia mayeri* (Cushman & Ellisor). Scanning microscope analyses clearly demonstrated the difference between the noncancellate and nonspinose *G. transsylvanica* and the throughout cancellate and spinose *P. mayeri* (Fig. 11.6).

Globoturborotalita

Globoturborotalita brazieri (Jenkins)

1966 *Globigerina brazieri* Jenkins: 1098, fig. 7, no. 58–63

Globoturborotalita connecta (Jenkins)

1964 *Globigerina woodi* Jenkins subsp. *connecta* Jenkins: 72, text-fig. 1
1998 *Globoturborotalita connecta* (Jenkins) — Cicha et al.: 104, pl. 35, figs. 16–18

Globoturborotalita druryi (Akers)

1955 *Globigerina druryi* Akers: 654, pl. 65, fig. 1
1998 *Globoturborotalita druryi* (Akers) — Cicha et al.: 104, pl. 35, figs. 17–19

Globoturborotalita woodi (Jenkins)

1960 *Globigerina woodi* Jenkins: 352, pl. 2, fig. 2
1998 *Globoturborotalita woodi* (Jenkins) — Cicha et al.: 104, pl. 35, figs. 14–16

Remarks: By far the most abundant species of *Globoturborotalita* in the Baden-Sooss material.

Orbulinids

Orbulina suturalis Brönnimann

1951 *Orbulina suturalis* Brönnimann: 135, text-figs. 2–4
1998 *Orbulina suturalis* Brönnimann — Cicha et al.: 114, pl. 37, figs. 3–4

Remarks: Very few problematic specimens were included.

Praeorbulina glomerosa circularis (Blow)

1956 *Globigerinoides glomerosa circularis* Blow: 65, text-figs. 2.3–2.4
1998 *Praeorbulina glomerosa circularis* (Blow) — Cicha et al.: 120, pl. 37, figs. 1–2

Remarks: Very few problematic specimens were included.

Paragloborotalia

Paragloborotalia acrostoma Wezel

1966 *Globorotalia acrostoma* Wezel: 1298, pl. 101, figs. 1–12, text-fig. 1
1998 *Paragloborotalia* ? *acrostoma* Wezel — Cicha et al.: 115, pl. 39, figs. 21–23

Remarks: One single specimen was found.

Tenuitellinata

Tenuitellinata angustiumbilicata (Bolli)
(Fig. 11.4)

1957 *Globigerina angustiumbilicata* Bolli: 109, pl. 22, figs. 12-13
1998 *Tenuitellinata angustiumbilicata* (Bolli) — Cicha et al.: 131, pl. 31, figs. 1–4

Remarks: *T. angustiumbilicata* is difficult to discriminate from juvenile *T.* cf. *quinqueloba* (see also *G. glutinata*). Extremely rare.

Turborotalita

Turborotalita quinqueloba (Natland)
(Fig. 10.7)

1938 *Globigerina quinqueloba* Natland: 149, pl. 6, fig. 7
1998 *Turborotalita quinqueloba* (Natland) — Cicha et al.: 132, pl. 31, figs. 7–10

Remarks: Small five-chambered globigerinids, low trochospiral, lobate in outline, sutures not deeply incised, with the last chamber covering almost the umbilicus. Only specimens with the typical turborotalid last chamber were assigned to this species. Relation to "five-chambered globigerinids" is not clear. If the last chamber is damaged or even lacking, no clear discrimination, especially to *G. tarchanensis*, is possible.

Very few specimens, resembling *T. neominutissima* (Bermudez & Bolli) were included. Present in many samples in rather low numbers.

Turborotalita cf. *quinqueloba* (Natland)
(Fig. 10.5,6)

1938 *Globigerina quinqueloba* Natland: 149, pl. 6, fig. 7

Small "five-chambered globigerinids", delicate and visually often smooth tests, low to slightly higher trochospiral, lobate in outline, sutures deeply incised. Visually chambers often looking smooth, with fine pores; small specimens are difficult to discriminate from tenuitellinids. This species is rather variable; very few specimens have up to six chambers. Large specimens are sometimes hard to discriminate from *T. quinqueloba*. More frequent than *T. quinqueloba*.

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