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

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Abstract: A quantitative analysis of benthic foraminifera was carried out on a scientific core from the type locality of the Paratethyan stage Badenian (Middle Miocene) and results were compared to stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) and magnetic susceptibility. Two approaches were applied to reconstruct the paleoenvironment. First, several indices (inbenthics %, oxyphylic %, foraminiferal numbers, diversity) and paleodepth proxies were calculated, second, multivariate statistics (Detrended Correspondence Analysis, cluster analyses combined with the indicator value method) were carried out. High correlations between environmental indices and core-depth manifest some trends. Five **biofacies units** were recognized, and the lowermost **unit I** encompasses a laminated interval coinciding with a biofacies subunit. The most indicative and abundant species is *Uvigerina semiornata*, a dysoxy tolerant inbenthic. The following **unit II** can be characterized as a stable period of improved oxygenation and lowered nutrient supply. **Unit III** is distinguished by *Trifarina angulosa* preferring well-aerated turbulent bottom water and sandy substrate, while accompanied by some low salinity tolerant species. A non-stratified water column with high terrigenous input is accepted for this unit. **Unit IV** is characterized by low diversities and the deep inbenthic indicator species *Bulimina elongata*, *Fursenkoina acuta*, tolerant of oxygen deficiency and benefiting from unlimited food supply in a well-stratified sea. The high foraminiferal numbers are the consequence of low terrigenous input not diluting the highly productive opportunistic species in the sediment. The indicator species of **unit V,** the reticulate *Bolivina viennensis*, has ecological needs similar to the previous unit. Environmental changes from **unit IV** to **V** are the increased terrigenous input and oscillation, indicating less stable conditions. The biofacies unit boundaries always coincide with major shifts of the isotope and susceptibility record. It is concluded, that the physical environmental parameters controlling benthic foraminiferal distribution are primarily influenced by proximity to land.

Key words: Middle Miocene, Paratethys, Vienna Basin, statistics, paleowater proxy, benthic foraminifera, Badenian stratotype.

Introduction

The Badenian of the Vienna Basin has been of great interest for foraminiferal experts since the pioneer monograph of Alcide d'Orbigny (1846). The work of d'Orbigny founding the basis of foraminiferal taxonomy has been revised by Marks (1951) and Papp & Schmid (1985). Since the times of d'Orbigny, two lines of interest have developed among foraminiferal experts. Some wanted to reconstruct the flow of time recorded in the sediments by studying foraminifera, while others wanted to reconstruct the environment of the past. A significant example of this first kind is the benthic foraminiferal zonation of Grill (1941) of the Vienna Basin used for correlation in the entire Central Paratethys. The basic work defining the Badenian, its correlation and stratotypes (Papp et al. 1978) gives proper attention to the foraminifera of the studied area. The most recent summarizing work of similar magnitude is Cicha et al. (1998) focusing on Central Paratethyan foraminifera. There are several works dealing with the correlation of the Central Paratethys based on foraminifera (Rögl 1996). Contributions from a paleoecological point of view applying a fully quantitative approach are of Rupp (1986) on the Vienna Basin, and partly Mandić et al. (2002), while Spezzaferri et al. (2002), Spezzaferri (2004) and Hohenegger (2005) dealt with material from the neighbouring Styrian Basin.

The aim of the present work is the reconstruction of the paleoenvironment based on the recently deepened Baden-Sooss borehole close to the stratotype section (Fig. 1). Fortunately, most benthic species of the Middle Miocene Paratethys have present-day living counterparts, thus paleoenvironmental reconstructions can rely on actualistic principles. Recent contributions to benthic foraminiferal ecology, concerning the in-sediment microhabitat distribution in relation to food availability and bottom water oxygenation (e.g. Jorissen et al. 1995; de Stigter et al. 1998; Kaiho 1999; Den Dulk et al. 2000; Fontanier et al. 2002; Altenbach et al. 2003; Kouwenhoven & Van der Zwaan 2006; Hayward et al. 2007) and statistical methods were employed (Dufrêne & Legendre 1997; McCune & Mefford 1999; Hammer & Harper 2005). In the present work, it is hoped that benthic paleoecology results can be confirmed by independent geochemical and geophysical evidence. The independent records available of the studied section are the oxygen and carbon stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) and magnetic susceptibility. Thus, the samples were prepared in the present work especially for statistical analysis, and the species concept applied here used generalizing, 'lumping' species (Báldi 1999).

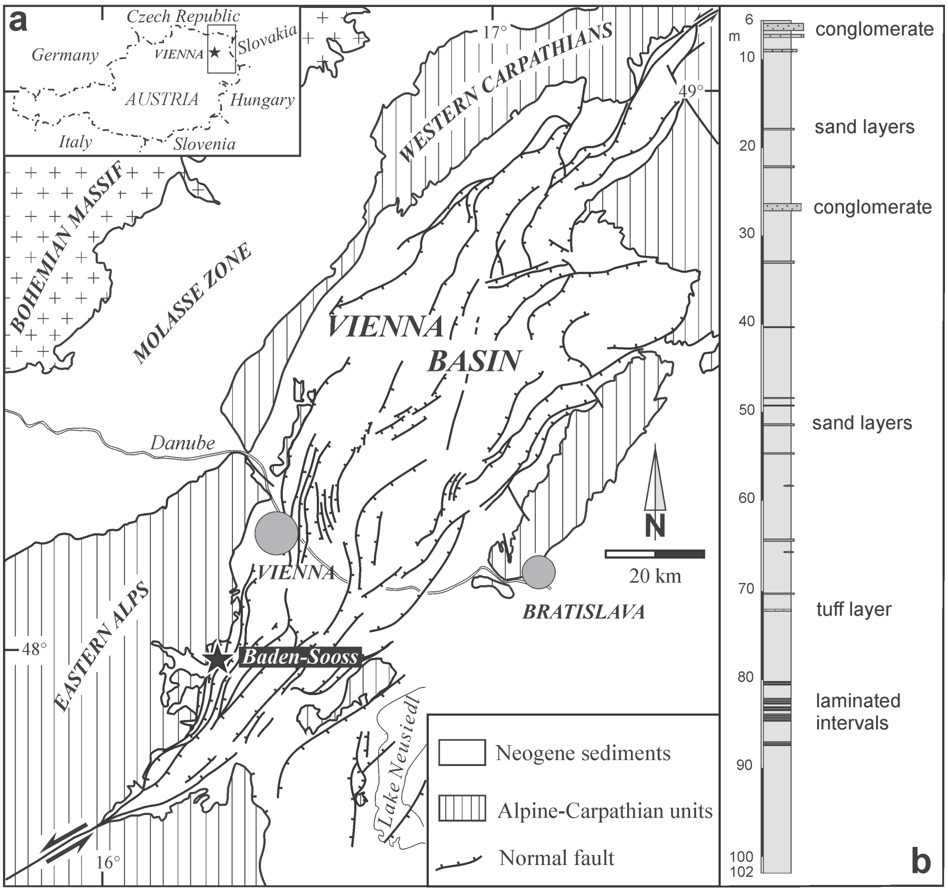


Fig. 1. a — Tectonic map of the Vienna Basin and location of the studied borehole Baden-Sooss. **b** — Schematic sedimentological log of the borehole Baden-Sooss (after Hohenegger et al. 2008).

Methods

Sample processing

Benthic foraminiferal analyses were carried out on a sample-set taken in regular intervals of 1.25 m from the bottom of the core at 102 m to 8 m at the top. The sediments were rather undisturbed in the lower part (40 to 102 m), and tectonically affected in the upper part (8 to 40 m; Hohenegger et al. 2007).

The samples were dissolved in pure water, then sieved through a set of standard sieves. Fractions from sieves were combined to make the 'fine fraction' (63–125 μm), the 'medium fraction' (125 μm–2 mm) and 'coarse fraction' (>2 mm). All fractions were paid a quick look under a binocular microscope to exclude the possibility of missing information by analysing only the medium fraction. The fully quantitative analysis of benthic foraminifera was carried out on the medium fraction (125 μm–2 mm). This fraction was split with a microsplitter to the appropriate size of more than 200 specimens of benthic foraminifera. All benthic foraminifera were picked from the split and mounted on a microslide with a layer of glue (Tragacantha). This glue makes it possible to turn specimens with wet brush to see different, taxonomically important views of foraminifera. Planktonic foraminifera were counted under the microscope in the same split used for the benthic foraminiferal analysis.

The quantitative analyses of benthic foraminifera were carried out on 74 samples eligible for statistics containing more than 200 benthic foraminiferal specimens. Altogether, 102 taxonomic categories were distinguished including 68 on the species level (Table 1; Cicha et al. 1998; Báldi 1999). Strictly all specimens were counted, even broken or badly-preserved. Counting broken specimens resulted in occasional decimals, expressing the picked fragments proportion to the whole test. Sometimes, when determination to the generic level was impossible, the categories of 'undetermined calcareous' or 'agglutinated' specimens were used. These 'undetermined' categories also include the extremely sporadic occurrences of determinable species, that is few specimens in all the material. However, the percentage of 'undetermined calcareous' or 'agglutinated' specimens was kept below 5.99 % of all benthic foraminifera in any particular sample.

The basic lists can be found as an Electronic Supplement of this paper in web version at http://www.geologicacarpathica.sk.

Quantitative methods

The analyses of benthic foraminifera were directed towards determining the environmental changes, possible trends and underlying gradients in the studied time interval. Two sorts of approach were applied:

1. Indices and proxies were calculated for environmental reconstruction.

2. For multivariate statistics the Detrended Correspondence Analysis (DCA) and cluster analyses were carried out

Table 1: Total count of species and species groups and their presence in samples. Inbenthic taxa are denoted by single asterisks, while oxyphylic taxa are denoted by double asterisks.

Species	Specimen number	Number of samples	Species	Specimen number	Number of samples
Haplophragmoides sp.	4	4	*Cibicides ungerianus* (d'Orbigny)**	229	49
Martinotiella communis (d'Orbigny)	55.8	34	*Dentalina brevis* (d'Orbigny)	4	3
Sigmoilopsis sp.	115	48	*Dentalina communis* (d'Orbigny)	27	15
Spiroplectammina carinata (d'Orbigny)	529	68	*Dentalina elegans* (d'Orbigny)	131	24
Spiroplectammina spp.	43	8	*Ehrenbergia serrata* Reuss	30	10
Textularia cf. *mexicana*	130	41	*Elphidium* spp.	204	62
Textularia sp.	68	19	*Fissurina* spp.	69	41
Textularia spp.	171	58	*Fursenkoina acuta* (d'Orbigny)*	152	47
Vulvulina spp.	104	44	*Gavelinopsis praegeri* (Heron-Allen & Earland)	550	70
			Glandulina sp.	6	5
Adelosina spp.**	49	17	*Globobulimina pyrula* (d'Orbigny)*	239	53
Cornuspira plicata (Czjzek)	13	7	*Guttulina* sp. (d'Orbigny)	10	9
Pyrgo spp.**	34	21	*Gyroidina parva* (Cushman & Renz)	32	14
Quinqeloculina spp.**	144	47	*Gyroidina soldanii* (d'Orbigny)	82	28
Sigmoilinita tenuis (Czjzek)**	163	60	*Gyroidina umbonata* (Silvestri)	271	56
Spiroloculina excavata (d'Orbigny)**	49	25	*Hanzawaia boueana* (d'Orbigny)**	266	65
Triloculina spp.**	21	10	*Heterolepa dutemplei* (d'Orbigny)**	503	70
Miliolid spp.**	119	45	*Hoeglundina elegans* (d'Orbigny)	210	49
			Lagena spp.	89	30
Alabamina sp.	130	36	*Lenticulina arcuata* (d'Orbigny)**	17	9
Allomorphina trigonia (Reuss)*	13	12	*Lenticulina calcar* (Linné)**	34	15
Ammonia beccarii (Linné)	68	34	*Lenticulina* sp.**	245	61
Amphicoryna badenensis (d'Orbigny)	53	30	*Marginulina hirsuta* (d'Orbigny)	29	17
Asterigerinata planorbis (d'Orbigny)	222	59	*Melonis pompilioides* (Fichtel & Moll)*	738	74
Astrononion cf. *italicum* (Cushman & Edwards)	120	46	*Nodosaria raphanistrum* (Linné)	19	12
Biapertorbis biaperturatus Pokorny	145	33	*Nodosaria* sp.1	40	31
Bitubulogenerina reticulata Cushman	22	20	*Nodosaria* sp.2	19	16
Bolivina antiqua (d'Orbigny)*	16	13	*Nonion commune* (d'Orbigny)	1052	60
Bolivina hebes (Macfadyen)	63	21	*Nonionella turgida* (Williamson)	15	13
Bolivina plicatella (Cushman)	325	38	*Oolina* spp.	17	13
Bolivina scalprata var. *Miocenica* (Macfadyen)	246	68	*Oridorsalis umbonatus* (Reuss)	56	29
Bolivina spathulata (Williamson)*	29	6	*Pappina parkeri* (Karrer)*	24	15
Bolivina spp.	67	30	*Pullenia bulloides* (d'Orbigny)*	179	59
Bolivina undetermined (contorted forms)	10	9	*Pullenia quinqueloba* (Reuss)*	35	19
Bolivina viennensis (Marks)*	255	49	*Reussella spinulosa* (Reuss)	18	13
Bulimina aculeata (d'Orbigny)*	797	68	*Rosalina* spp.	40	24
Bulimina costata (d'Orbigny)	694	49	*Siphonina reticulata* (Czjzek)**	13	9
Bulimina elongata (d'Orbigny)*	665	58	*Sphaeroidina bulloides* (d'Orbigny)*	99	33
Cancris auriculus (Fichtel & Moll)	26	15	*Stilostomella adolphina* (d'Orbigny)	109	36
Cassidulina carinata (Silvestri)	73	31	*Trifarina angulosa* (Williamson)	400	57
Cassidulina laevigata (d'Orbigny)	531	67	*Trifarina bradyi* (Cushman)	29	16
Cassidulina oblonga (Reuss)*	231	41	*Uvigerina aculeata* (d'Orbigny)*	235	18
Cassidulina spp.	19	9	*Uvigerina acuminata* (Hosius)*	37	13
Cassidulina subglobosa (Brady)*	468	69	*Uvigerina acuminata* f. *macrocarinata**	8	3
Ceratocancris hauerina (d'Orbigny)	270	52	*Uvigerina semiornata* (d'Orbigny)*	327	33
Cibicides kullenbergi (Parker)**	49	20	*Uvigerina* spp.*	24	10
Cibicides lobatulus (Walker & Jacob)**	1147	74	*Valvulineria complanata* (d'Orbigny)*	803	72
Cibicides spp.	17	10			

to contribute to our understanding of benthic assemblages coupled with environmental shifts or gradients.

Indices and proxies

The inbenthic and oxyphylic indices are based on the different microhabitat preferences of benthic foraminifera in relation to their ecological needs and tolerances (Corliss 1985; Corliss & Chen 1988; Jorissen et al. 1995; Fontanier et al. 2002; Altenbach et al. 2003; Hayward et al. 2007). These indices are the percentages of taxa following an inbenthic mode of life, or needing well aerated bottom water in the case of oxyphylic species. Considering the in-sediment distribution of each recognized taxa, where possible, a decision was made on the inbenthic or oxyphylic nature of the particular species (Corliss 1985; Corliss & Chen 1988; Kaiho 1994, 1999; de Stigter et al. 1998; Den Dulk et al. 2000; Kouwenhoven & Van der Zwaan 2006), see details in Báldi (2006). The selection of taxa considered inbenthic or oxyphylic are to be found denoted by asterisks next to their name in Table 1. Variables based on percentages were transformed using the arcsine-root transformation. The benthic foraminiferal number in 100 g sediments was calculated from the proportion of split size yielding the >200 specimens benthic sample to the total original dry sediment sample weighed on an analytical scale.

Different aspects of diversity were examined in the present work:

— dominance (D) taking values from 0 to 1 (Simpson 1949; Magurran 2004)

$$D = \sum_{j=1}^{m} (n_j / n)^2$$

where n_j indicates abundance of the j^{th} species and m the number of species. When it takes the maximum value 1, one single species dominates the whole assemblage.

— Shannon index (H)

$$H = -\sum_{j=1}^{m} (n_j / n) \ln (n_j / n)$$

reaching maximum values when a few individuals of many taxa are present in a sample, a sort of measure of entropy (Shannon 1948).

— Fisher-α

$m = \alpha \ln (1 + n/\alpha)$

a classical measure of species richness able to compensate for variable sample sizes. Fisher's α diversity is calculated using the formula given by Fisher et al. (1943) with the constants from Williams (1964: fig. 125). All diversity indices were calculated by the program PAST (Hammer & Harper 2005).

Paleowater depth as an essential factor determining the distribution of marine life was estimated by two independent proxies. The first proxy is based on the ratio of planktonic and benthic foraminifera (abbreviated as P/B-ratio in the following) in the sediment (Van der Zwaan et al. 1990, 1999), while the second one is an extension of the transfer equation developed by Hohenegger (2005) including species abundance by

$$depth = \sum_{j=1}^{m} (n_j l_j d_j^{-1}) / \sum_{j=1}^{m} (n_j d_j^{-1})$$

needing the depth ranges of taxa as an input. In this equation, the location parameters l of the j^{th} species is weighted on the one side by abundance n_j and by dispersion d_j on the other.

Multivariate analyses

First, Detrended Correspondence Analysis (DCA) was used to find relations between samples and species to support environmental interpretation (program PAST, Hammer & Harper 2005). Second, samples were clustered into non-overlapping classes by Ward's Method based on relative Euclidean distances (program PC-ORD — McCune & Mefford 1999). Since species normally cannot be grouped into non-overlapping clusters, the indicator value method (Dufręne & Legendre 1997) has been used for finding characteristic spe-

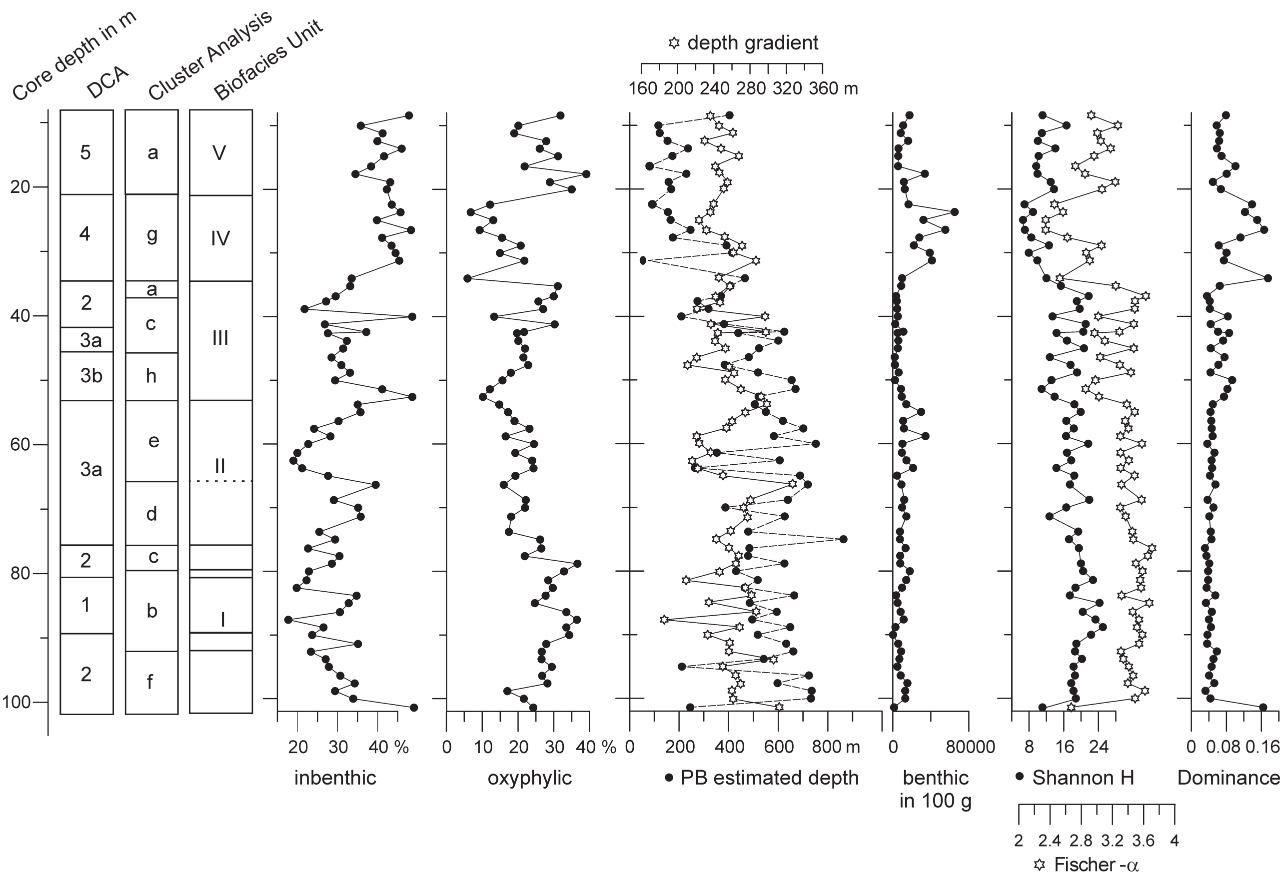


Fig. 2. Benthic foraminiferal indices and proxies plotted against depth in core with biofacies units on the left. From left to right cumulative percentages of inbenthic taxa, oxyphylic taxa, paleowater depth proxies with planktonic/benthic (PB) ratio and depth gradient analysis, benthic foraminiferal number calculated in 100 g dry sediments, species diversities of Fischer-α and of Shannon (H) and Dominance.

Table 2: Calculated indices and proxies against core depth in Fig. 2.

Depth in core (m)	Number of benthic foraminifera 125 μm to 2 mm in 100 g sediment	Percentage of inbenthic taxa on total benthic foraminifera	Percentage of oxyphylic taxa on total benthic foraminifera	Percentage of planktonic foraminifera	Number of benthic species inclusive undetermined groups
8.41	17532	47.8	31.9	52.9	35
10.02	10880	35.8	20.1	24.2	45
11.21	8285	41.2	19.0	23.6	33
12.44	16121	39.9	27.9	29.4	33
13.62	5936	46.0	26.1	37.9	41
14.81	5641	41.6	31.2	31.8	33
16.41	5493	38.3	21.8	15.6	30
17.61	33639	34.5	39.1	41.8	33
18.88	11616	43.1	28.9	29.0	37
20.02	12585	42.3	35.0	30.8	40
22.41	16486	43.5	12.2	16.9	25
23.61	65030	45.7	6.8	27.5	30
24.86	32156	39.8	13.1	31.3	23
26.41	55242	48.3	9.3	38.1	25
27.62	27858	41.1	15.5	32.2	28
28.86	22135	43.5	20.8	53.9	41
30.01	38847	44.4	14.9	55.3	30
31.22	41189	45.4	21.8	12.6	32
34.01	9762	33.5	5.9	63.5	39
35.21	8758	33.2	31.1	59.3	47
36.81	3398	29.5	30.0	57.5	56
37.61	4205	27.1	25.7	49.5	54
38.81	4533	21.8	27.0	55.7	56
40.01	5277	48.6	13.3	33.7	43
41.21	2528	26.8	30.2	59.4	51
42.41	11084	37.2	21.7	72.3	53
42.61	5065	27.6	19.7	63.6	39
43.81	5747	32.3	20.1	72.4	45
45.01	5257	31.4	22.0	68.0	60
46.41	1939	28.5	21.5	66.2	44
47.61	2199	31.0	22.9	58.3	50
48.81	6121	33.1	18.0	67.2	50
50.01	2205	29.4	15.6	76.2	44
51.41	8648	41.1	12.1	73.7	37
52.61	9356	48.6	10.2	61.3	43
53.81	14171	35.0	14.7	65.7	52
55.01	29757	35.7	17.2	68.4	56
56.41	10877	30.2	19.0	74.1	47
57.61	11711	24.2	23.2	79.8	46
58.81	34384	28.2	16.5	72.6	48
60.01	10073	22.7	24.5	82.5	58
61.41	9509	20.0	19.2	59.2	52
62.61	14295	19.0	24.0	76.2	54
63.82	21333	21.2	24.3	50.4	46
65.01	4422	27.6	19.3	78.4	53
66.42	8975	39.5	16.0	76.9	49
67.61	8812	31.5	25.0	75.0	50
68.81	12030	29.1	22.2	75.5	57
70.01	9719	35.1	22.0	56.9	46
71.42	14222	35.8	18.1	72.9	40
72.61	10628	34.6	17.3	77.3	55
73.81	7538	25.5	17.5	67.0	52
75.01	7487	29.4	26.2	86.1	49
76.41	13392	22.7	26.5	68.1	68
77.61	7697	30.5	21.9	65.4	55
78.81	7754	28.6	36.6	74.9	54
80.01	18988	22.9	32.9	64.4	60
81.41	14122	22.3	28.4	70.3	62
82.61	9691	19.8	29.7	67.6	54
83.83	3408	34.7	27.7	75.3	52
85.01	4967	32.8	24.7	65.1	60
86.41	8163	30.6	33.5	72.6	50
87.61	11396	17.7	36.5	70.1	61
88.81	2709	26.5	33.5	76.6	59
90.01	189	23.7	34.3	70.0	57
91.41	5653	35.1	27.9	73.4	51
92.63	8696	23.4	26.6	78.0	53
93.81	6838	27.1	26.6	70.5	55
95.01	4724	27.8	29.4	41.9	55
96.41	8234	30.7	26.7	79.5	52
97.61	15298	34.3	28.2	71.7	51
98.81	13022	29.4	17.0	80.3	55
100.01	13077	33.9	21.6	79.1	53
101.41	1292	49.0	24.3	37.6	35

cies determining the sample clusters. This method has hardly ever been used in paleontology, though it was successfully employed in biology (Dai et al. 2006; Nahmani et al. 2006). It combines information on the concentration (A_{jk}) of species j in a particular cluster k and the faithfulness of occurrence of a species in a particular cluster (B_{jk}), where

$$A_{jk} = \sum_{i=1}^{r} (n_{ijk}/r) / \sum_{k=1}^{g} \sum_{i=1}^{r} (n_{ijk}/r),$$

with r representing the number of samples in cluster k and g representing the number of clusters. Transforming relative abundance A_{jk} of species j in cluster k into presence/absence values yields B_{jk}. This method produces indicator values ($IndVal_{jk}$) for each species j in each cluster k by

$$IndVal_{jk} = A_{jk} \cdot B_{jk} \cdot 100,$$

which are tested for statistical significance using the Monte Carlo technique. The indicator value reaches its maximum (i.e. 100 %), when all individuals are found in a single cluster and when the species is present in all samples of that particular cluster.

Results

Indices and proxies

The indices and proxies (Fig. 2) are based on the counting results and percentages (Table 2, Fig. 3). Correlations were

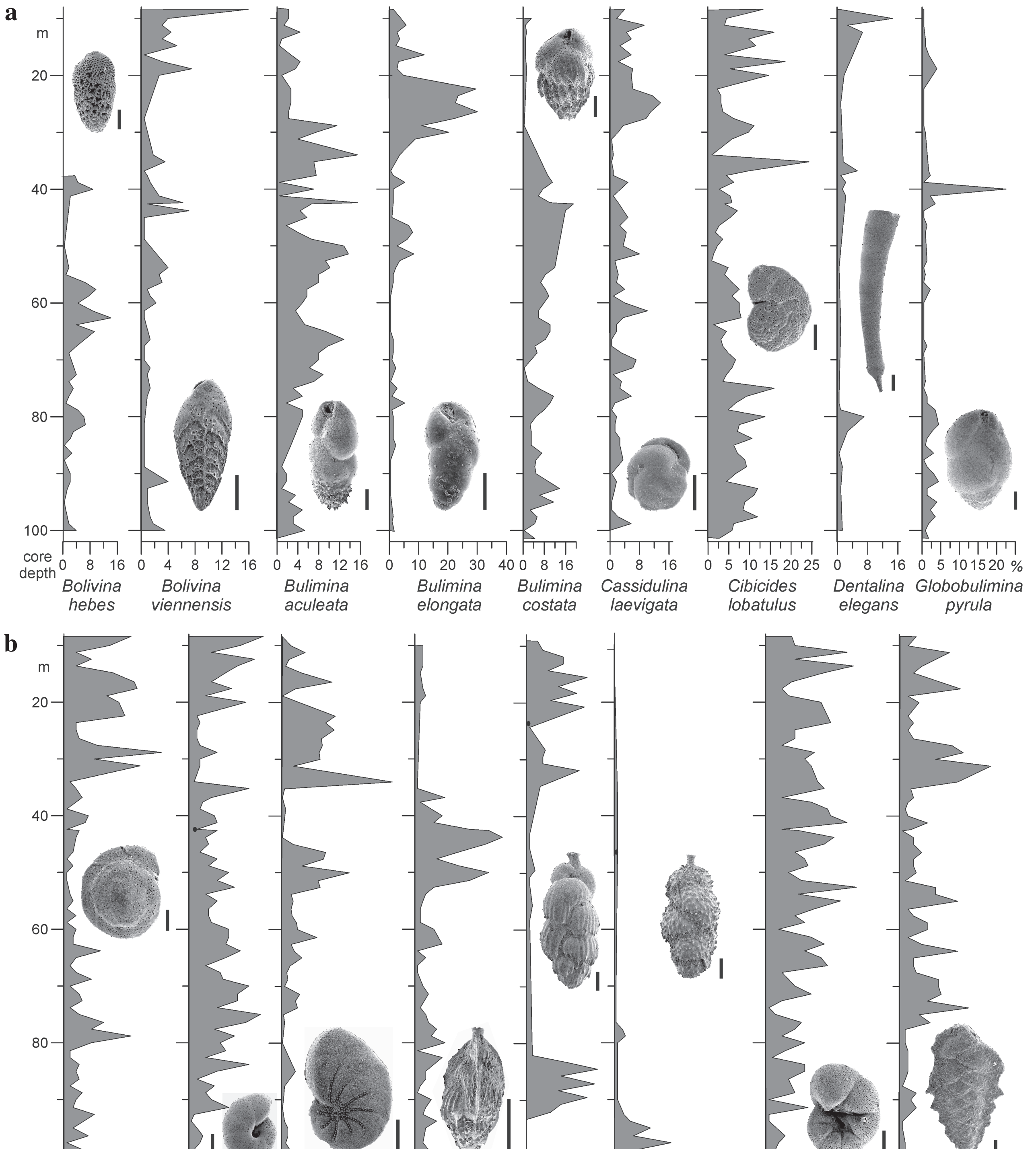


Fig. 3. a — The relative frequencies (percentages) of the most common taxa (>10 %) plotted against depth in core and illustrated by SEM; bar length = 100 μm. *Bolivina hebes* (Macfadyen) from 95.01 m, *Bolivina viennensis* Marks from 42.41 m, *Bulimina aculeata* (d'Orbigny) from 95.01 m, *Bulimina elongata* (d'Orbigny) from 28.81 m, *B. costata* (d'Orbigny) from 95.01 m, *Cassidulina laevigata* (d'Orbigny) from 8.41 m, *Cibicides lobatulus* (Walker & Jacobs) from 95.01 m, *Dentalina elegans* (d'Orbigny) from 8.41 m, *Globobulimina pyrula* (d'Orbigny) 95.01 m. **b** — bar length = 100 μm. *Heterolepa dutemplei* (d'Orbigny) from 16.41 m, *Melonis pompilioides* (Fichtel & Moll) from 42.41 m, *Nonion commune* (d'Orbigny) from 95.01 m, *Trifarina angulosa* (Williamson) from 95.01 m, *Uvigerina semiornata* (d'Orbigny) from 8.41 m, *Uvigerina aculeata* (d'Orbigny) from 95.01 m, *Valvulineria complanata* (d'Orbigny) from 95.01 m, *Spiroplectammina carinata* (d'Orbigny) from 42.41 m.

Table 3: Correlation matrix, where in lower triangle Pearson's r to be found, while in upper triangle the probability of uncorrelated columns. Calculated in PAST (Hammer & Harper 2005).

	Depth (m)	inbenthic (%)	oxyphylic (%)	P/B paleowater depth	No. of benthic in 100 g	Dominance	Shannon	Fischer-α	Depth gradient analyses
Depth (m)		0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.07
inbenthic (%)	0.53		0.00	0.00	0.00	0.00	0.00	0.00	0.00
oxyphylic (%)	−0.25	−0.40		0.68	0.00	0.00	0.00	0.00	0.24
P/B paleowater depth	−0.66	−0.44	0.05		0.01	0.00	0.00	0.00	0.08
No. of benthic in 100 g	0.32	0.35	−0.38	−0.31		0.00	0.00	0.00	0.29
Dominance	0.44	0.57	−0.54	−0.47	0.40		0.00	0.00	0.81
Shannon	−0.61	−0.67	0.52	0.57	−0.49	−0.94		0.00	0.72
Fischer-α	−0.65	−0.68	0.45	0.60	−0.50	−0.76	0.91		0.80
Depth gradient analyses	−0.21	0.39	−0.14	0.20	−0.12	−0.03	0.04	0.03	

calculated among environmentally significant indices and proxies (inbenthics %, oxyphylic %, paleowater depth proxies, benthic foraminiferal number in 100 g sediment and different diversity indices and core depth; Table 3). Calculating correlation with core depth makes it possible to verify upward trends. Generally, the indices showed significant correlation with core depth meaning definite trends through the studied interval. An increase of inbenthic (r=0.53) and a slightly decreasing oxyphylic (r=–0.25) trend was observed up the core. Both paleowater proxies demonstrated a significant shallowing trend (P/B: r=–0.66, depth gradient: r=–0.21) through the examined time interval, also the number of benthic specimens in 100 g sediment increased (r=0.32). The highest correlations are found, not surprisingly, among the different diversity indices. Nevertheless, diversities showed very strong trends up the core (Dominance: r=0.44, Shannon: r=–0.61, Fisher-α: r=–0.65), meaning enhancing dominance and declining diversity with time. The oxyphylic and inbenthic taxa (r=–0.4) show significant negative correlation, as expected. The inbenthic index has high values when diversity is low and dominance is high (inbenthic to Dominance: r=0.57, inbenthic to Shannon: r=–0.67, inbenthic to Fisher-α: r=–0.68) while oxyphylic taxa show the opposite correlation to inbenthics (oxyphylic to Dominance: r=–0.54, oxyphylic to Shannon: r=0.52, oxyphylic to Fisher-α: r=0. 45). The two depth proxies behave differently to diversity. Depth estimation based on the P/B-ratio highly correlates with diversity (with Dominance r=–0.47, Shannon r=0.57, Fisher-α r=0.60), while the depth gradient analysis based estimations shows negligible correlation with diversity (with Dominance r=–0.03, Shannon r=0.04, Fisher-α r=0.03; see results in Table 3).

Multivariate statistics

Detrended Correspondence Analyses (DCA)

This analysis was carried out on specimen counting. In the present study, the first two axes were considered and plotted against each other. These plots (Fig. 4) showed five clouds or sample groups (1, 2, 3, 4, 5), where each group contains samples of a rather distinct core depth.

Group **1)** consists of all samples between 82.6 and 88.8 m with the exception of the sample from 85.01 m. Group **2)** comprises samples from three distinct intervals. These are the lowermost samples of the core between 90.0 and 101.4 m, then between 76.4 and 81.4 m, and between 35.2 and 41.2 m. Group **3)** contains most samples between 42.4 and 75.0 m, and an occasional occurrence of this group expressed in sample 34.0 m above the mentioned interval. Group **4)** has samples from the interval 22.4 to 30.0 m. Samples from the upper part of the core belong to group **5)** between 8.4 and 20.0 m, with a few additional samples below 85.0 m and at 31.2 m (Fig. 4).

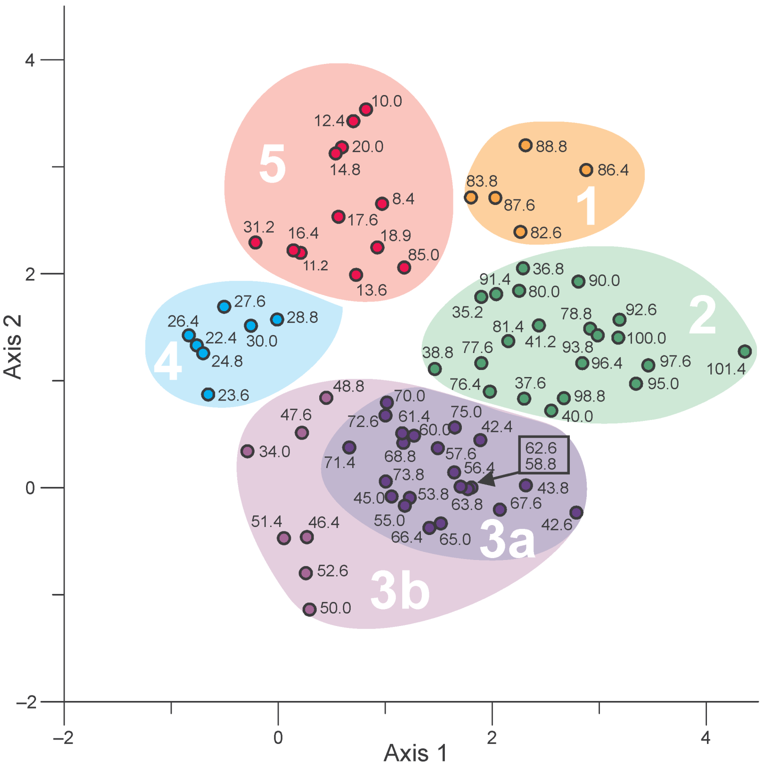


Fig. 4. Presentation of samples by the first and second axes of DCA (Detrended Correspondence Analysis) and subjective clustering into 5 groups marked by colours.

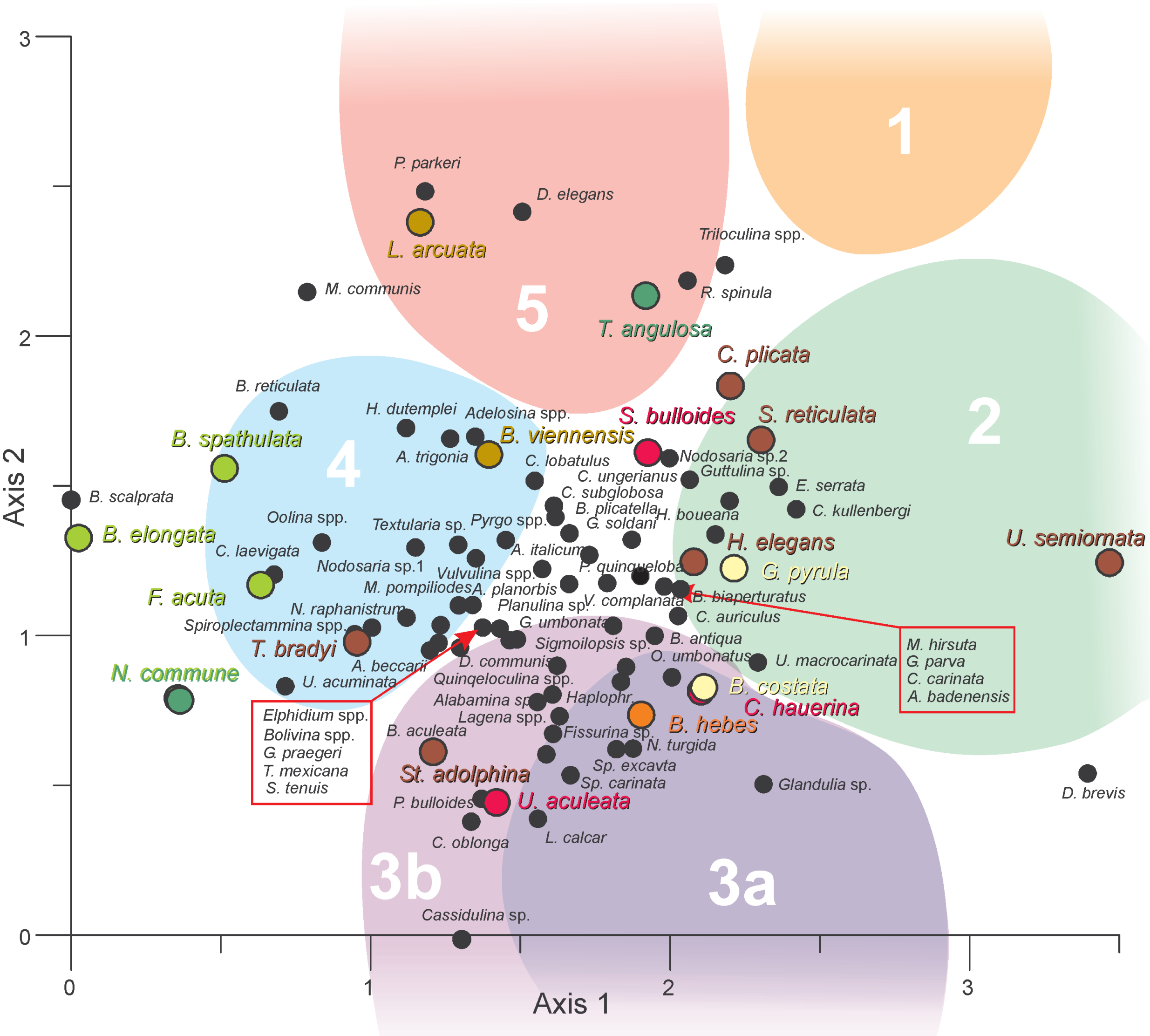


Fig. 5. Presentation of species by the first and second axes of DCA (Detrended Correspondence Analysis) and their position related to sample groups. Position of indicator species of clusters gained by Ward's method (Table 4; Fig. 6) are accentuated by size and cluster colours related to Fig. 6.

Detrended Correspondence Analyses (DCA) were also applied to recognize species groups, but there were no distinct well-defined groups because of overlapping clusters in R-mode classification analysis.

However, looking at the bivariate plot of the first two axis (Fig. 5), species on the left are deep inbenthic, low oxygen tolerant forms (*Bulimina elongata*, *Fursenkoina acuta*, *B. spathulata*), while oxyphylic species of epibenthic, or even epiphytic habitat *(Hanzawaia boueana*, *Cibicides lobatulus*, *Cibicides* spp.*)* tend to appear on the right side of the plot. Several species suspected to be deepwater markers appear on the right upper side of the plot *(Siphonina reticulata*, *Cibicides ungerianus*, *Cibicides kullenbergi)* as expected of oxyphylic deep dwelling taxa (Fig. 5).

Cluster Analyses (CA)

The first step to attain indicator values of species according to the method described in Dufrêne & Legendre (1997) is to carry out a cluster analysis. Ward's method based on the arcsine-root transformed percentage database without cut-off levels to ignore rare species was used. Generally, the recognizable clusters (Fig. 6) appear to include samples from particular intervals of core depth. Eight clusters (a, b, c, d, e, f, g, h) can be separated with the cut-off level 49 % of information remaining. The uppermost samples of the borehole belong to cluster **a)** from 8.4 to 20.0 m (except — 16.4 m) and to another interval from 35.21 to 37.61 m and two additional samples at 45.0 m and 75.0 m. Cluster **b)** samples fall into one single distinct interval from 80.0 to 91.4 m. The cluster **c)** is to be found from 76.4 to 78.8 m and from 38.8 to 43.8 m. Clusters **d)** and **e)** are closely related and both scatter in the depth interval from 53.8 to 73.8 m, where cluster **d)** consists of 11 samples (53.8 m, 55.0 m, 60.0 m, 63.8 m, 66.4 m, 67.61 m, 68.81 m, 70.01 m, 71.415 m, 72.61 m, 73.81 m), while cluster **e)** comprises six samples (56.4 m, 57.6 m, 58.8 m, 61.4 m, 62.6 m, 65.0 m). The samples of cluster **f)** are the lowermost samples of the borehole from the interval of

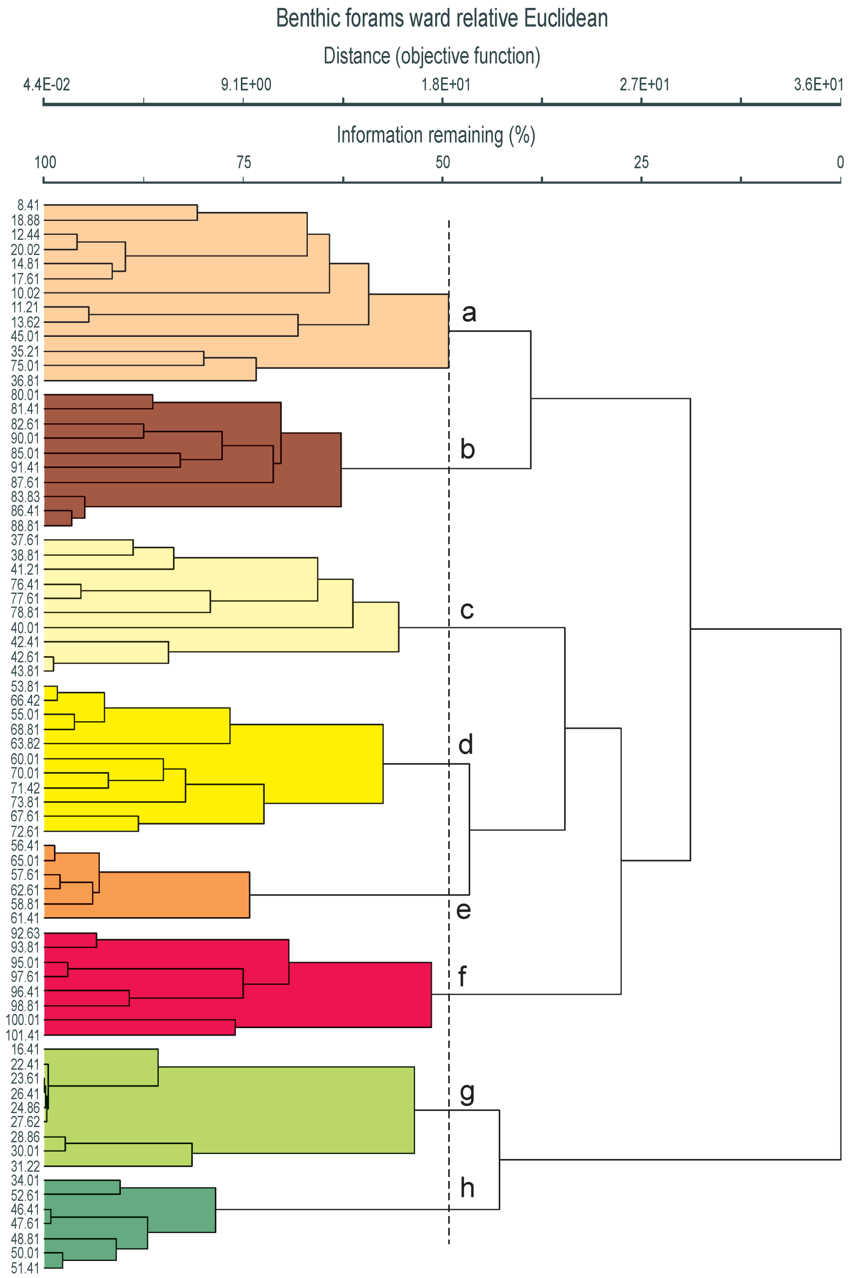


Fig. 6. Cluster analyses of samples by Ward's method based on relative Euclidean distances.

92.6 to 101.4 m. Cluster **g)** samples are from 22.4 to 31.2 m and the additional sample of 16.4 m. The 7 samples of cluster **h)** are from 46.4 to 52.6 m with the extra sample of 34.0 m (Fig. 6).

Combining methods — Ecofacies units

The most indicative species of each group with an indicator value higher then 20 % are listed in Table 4. Based on the multivariate methods (DCA and indicator values) five main benthic foraminiferal ecofacies units (I–V) can be distinguished. Sample groupings of both methods seem to depend on core depth, thus these groupings were translated to intervals along the borehole, referred in meters. The boundaries of these main units are chosen, where sample groupings of both methods coincide suggesting a distinct boundary. However, the main units contain smaller subunits found by DCA and cluster analysis (Fig. 7).

Unit I: This biofacies unit ranges from 81.41 to 101.4 m containing the lowermost part of the core. Both multivariate techniques (DCA and Cluster Analyses) indicate a shorter interval encompassed in the subunit from 80.0 to 91.4 m (Cluster **b)**) or from 81.4 to 88.81 m (DCA group **1)**). In this encompassed interval, indicated by darker shades in Fig. 7 the species *Uvigerina semiornata* has a high indicator value (Table 4) and high abundance (Fig. 3), while *Siphonina reticulata*, in spite of the identically high indicator value, has only a few specimens in the whole core (Fig. 3). The number of inbenthic species is relatively high in this subinterval accompanied by a decrease in the abundance of oxyphylic taxa, but oxyphylic forms are rather abundant (>30 %) in the whole unit. Therefore, the diversity indices Fisher-α and Shannon are slightly high (Fig. 2).

Unit II: This biofacies unit is recognized between 53.8 and 75.0 m. The only indicator species of this period is *Bolivina hebes* from the upper part (Table 4). Generally, the inbenthic index is higher in the lower than in the upper part, while oxyphylic percentages are rather stable. Depth estimations are fluctuating, particularly the P/B ratio tends to oscillate. Both diversity indices are moderately high, indicating low dominance (Fig. 2).

Unit III: The biofacies unit ranges from 35.2 to 52.6 m. The species of *Nonion commune* and *Trifarina angulosa* have high indicator values in the lower part (cluster **h)**) accompanied by the ecologically important, otherwise rare taxa of *Ammonia beccarii, Quinqueloculina* spp., div. miliolids. The indicator species of the upper part (cluster **c)**) are *Bulimina costata, Globobulimina pyrula* and *Trifarina angulosa* (Table 4). The last mentioned *T. angulosa* as an indicator species of both clusters has special significance in this ecofacies unit. It is not just indicative of the whole period, but it is also common in this interval reaching even 10 % of the assemblage. The inbenthic index fluctuates in this interval showing two maxima at 52.6 and 40.0 m, and these peaks have corresponding oxyphylic minima. The number of benthic foraminifera is generally low. Diversity indices are oscillating, slightly lower than before, and higher dominance characterizes this interval (Fig. 2).

Table 4: List of species with higher then 20 indicator values in their cluster groups. Indicator values are calculated according to Dufrêne & Legendre (1997). Species with high indicator values (>30) are indicated by darker shades.

Indicator values of clusters		Indicator values of clusters	
Cluster **a**		Cluster **e**	
Bolivina viennensis (Marks)*	40	*Bolivina hebes* (Macfadyen)	52
Lenticulina arcuata (d'Orbigny)**	34	*Spiroloculina excavata* (d'Orbigny)**	29
Dentalina elegans (d'Orbigny)	27	*Textularia* sp.	29
Cibicides lobatulus (Walker & Jacob)**	23	*Ceratocancris hauerina* (d'Orbigny)	26
Uvigerina semiornata (d'Orbigny)*	23	*Nonionella turgida* (Williamson)	25
Bitubulogenerina reticulata Cushman	22	*Bulimina costata* (d'Orbigny)	23
Melonis pompilioides (Fichtel & Moll)*	21		
Textularia spp.	21	Cluster **f**	
Heterolepa dutemplei (d'Orbigny)**	20	*Uvigerina aculeata* (d'Orbigny)*	92
		Sphaeroidina bulloides (d'Orbigny)*	35
Cluster **b**		*Ceratocancris hauerina* (d'Orbigny)	33
Siphonina reticulata (Czjzek)**	41	*Cibicides ungerianus* (d'Orbigny)**	25
Uvigerina semiornata (d'Orbigny)*	41	*Textularia* cf. *mexicana*	24
Trifarina bradyi (Cushman)	36	*Vulvulina* spp.	21
Hoeglundina elegans (d'Orbigny)	35	*Biapertorbis biaperturatus* Pokorny	20
Cornuspira plicata (Czjzek)	33		
Stilostomella adolphina (d'Orbigny)	32	Cluster **g**	
Cibicides spp.	27	*Bulimina elongata* (d'Orbigny)*	62
Bolivina plicatella (Cushman)	26	*Fursenkoina acuta* (d'Orbigny)*	35
Triloculina spp.**	26	*Bolivina spathulata* (Williamson)*	33
Hansawaia boueana (d'Orbigny)**	24	*Nonion commune* (d'Orbigny)	30
Globobulimina pyrula (d'Orbigny)*	23	*Heterolepa dutemplei* (d'Orbigny)**	29
Rosalina	22	*Cassidulina laevigata* (d'Orbigny)	28
Bolivina undetermined (contorted forms)	21	*Asterigerinata planorbis* (d'Orbigny)	22
Undetermined calcareous specimens	21		
		Cluster **h**	
Cluster **c**		*Nonion commune* (d'Orbigny)	38
Bulimina costata (d'Orbigny)	32	*Trifarina angulosa* (Williamson)	31
Globobulimina pyrula (d'Orbigny)*	30	*Lenticulina calcar* (Linné)**	26
Trifarina angulosa (Williamson)	28	*Cassidulina oblonga* (Reuss)*	25
		Bulimina aculeata (d'Orbigny)*	23
Cluster **d**		*Quinqeloculina* spp.**	22
Alabamina sp.	25	*Ammonia beccarii* (Linné)	21
Lenticulina sp.**	25	Miliolid spp.**	20
Spiroplectammina carinata (d'Orbigny)	24		
Pullenia bulloides (d'Orbigny)*	23		
Textularia cf. *mexicana*	23		
Cassidulina oblonga (Reuss)*	21		
Gyroidina umbonata (Silvestri)	21		
Bulimina aculeata (d'Orbigny)*	20		

Unit IV: This biofacies unit ranges from 22.4 to 34.0 m. The species *Bulimina elongata* (Indicator Value = 62), *Fursenkoina acuta (I.V. = 35), Bolivina spathulata (I.V. = 33)*, *Nonion commune (I.V. = 30)* are highly indicative in this interval as reflected in the high cumulative abundance of these species on the inbenthic curve. The species *Cassidulina laevigata* has a slightly lower indicator value, but reaches maximum abundance in this interval (Fig. 3). This biofacies is rather distinct in many respects compared to other units. It is characterized by high inbenthic and very low oxyphylic percentages. In this interval, the P/B-ratio estimates depths shallower than the gradient method. The number of benthic foraminifera is particularly high in this biofacies unit. This interval is similarly distinctive in respect to diversity. The Fisher-α and Shannon diversity indices are low revealing low species richness, thus high dominance is characteristic in this biofacies unit (Fig. 2).

Unit V: This biofacies unit is found in the uppermost part of the core from 20.0 m to the top at 8.4 m. The most indicative species of this interval is the reticulate bolivinid species *Bolivina viennensis*, endemic to the Paratethys and, secondly, the species *Lenticulina arcuata.* The latter species has low abundances in the material, thus it could be ignored for ecological interpretation (Table 4). This unit is characterized by rather high percentages of inbenthic and oxyphylic species. The P/B ratio is similar to the biofacies unit IV below in estimating shallower paleowater depth than the gradient analyses. This interval has moderately high diversity and thus low dominance (Fig. 2).

Discussion

Trends, proxies and correlation

The correlation of indices and proxies with core-depth is generally significant, indicating a changing environmental scenery during deposition (Table 3). The growing number of inbenthic forms and decreasing number of oxyphylic taxa upward in the section points to a eutrophication trend coupled with the stress of low oxygen content in the bottom water. Species richness measured by the Fisher-α and Shannon index decreased, while dominance increased with time (Fig. 2). These trends in diversity are interpreted as enhancing stress through the studied time interval, and can probably be related to the general eutrophication trend throughout the Badenian described in Báldi (2006).

Paleowater depth estimations are based on two different proxies, independent of each other (Van der Zwaan et al. 1990; Hohenegger 2005). The proxy of Van der Zwaan et al. (1990) is based on the P/B ratio, while the proxy of Hohenegger (2005) is based on depth ranges of Recent benthic foraminifera, thus strongly depending on an actualistic approach. Both proxies showed a shallowing trend, however a much stronger trend is postulated according to the planktonic/benthic method. The general trend of shallowing through time in the Badenian is in accordance with Filipescu & Girbacea (1997) and Báldi et al. (2002). Both proxies behaved also differently concerning diversity. The P/B-ratio showed deep water when diversity was high and dominance low, while the gradient analyses showed no significant correlation to these indices (Table 3). Thus accepting diversity changes as a measure of stress, the low diversity means high stress, most likely to happen near-shore rather than in an open marine environment. The P/B method is sensitive for eutrophy causing high productivity surface water (meaning a high

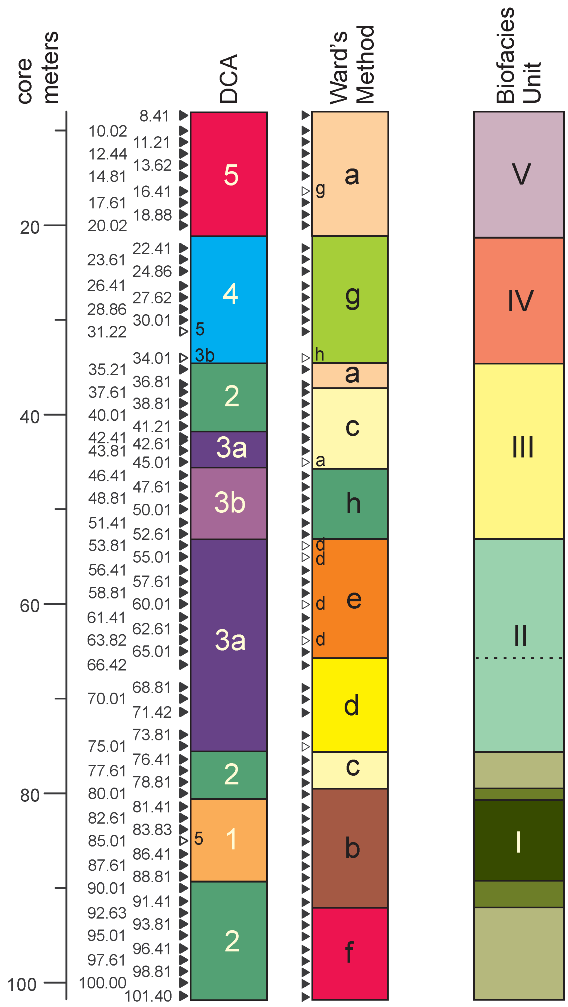


Fig. 7. The recognized biofacies units (I–V) based on groups obtained by DCA (1–5) and Cluster Analysis (a–f). Samples are denoted by black triangles if an actual sample belongs the sample group. When a sample belongs to a different group, then the triangle is empty and the group's assignment is given next to the triangle.

number of planktonic foraminifera) and oxygen deficiency at the bottom culling benthic life (Van der Zwaan et al. 1990). In the studied material, episodic lamination and the high number of planktonic foraminifera (>50 % of all foraminifera) without the occurrence of deep water marker benthic taxa suggests, that paleowater depth is overestimated by the P/B-ratio method. This overestimation is most likely to be pronounced in the deeper part of the core. However, underestimation of paleowater depth by the P/B ratio through reworked foraminiferal tests from shallower parts of the basin is a possibility, while gradient analyses excludes the depth ranges of shallow living species (Hohenegger 2005).

The number of benthic foraminifera correlated to core depth shows an increasing number of benthic foraminifera with time (Table 3). The foraminiferal number is determined by two processes, where the one is dilution in sediment depending on sedimentation rates, while the other is benthic standing stocks and turn over controlling benthic productivity. Here it is assumed that the latter mentioned benthic productivity is responsible of this weak trend through time, as the number of highly productive inbenthic taxa also increase with time. The observed eutrophication and shallowing trends are in accordance with the general trends described throughout the whole Badenian (Báldi 2006). However, the high number of benthic foraminifera from 22.4 to 34.0 m — discussed later as biofacies unit IV — is also related to changes in sedimentation rates.

Ecofacies and geochemistry

Unit I: Periods of stronger lamination are observed in this interval between 82 m and 92 m. This lamination coincides with shorter subunits encompassed by the biofacies as documented by both multivariate methods (Cluster **b)** and DCA group **1)**). An inbenthic maximum coupled with a relatively low number of oxyphylic taxa (from 82.6 to 87.6 m) also exists in this interval (Fig. 2). According to benthic foraminifera, episodic dysoxy or anoxy combined with high food availability conditions (organic matter) is highly probable during deposition. These are optimal conditions for the dominating (Fig. 5) and indicative (Table 4) inbenthic species *Uvigerina semiornata*. According to the stable isotope record in this interval, the δ^{18}O values are more negative measured both in the planktonic and benthic forms, supposedly from higher freshwater influx from land (Fig. 8). This fact is supported by the magnetic susceptibility data showing higher terrigenous influence (Fig. 9). The relatively high number of oxyphylic taxa (>30 %), contributing to the relatively high diversity in the laminated part needs further explanation (Fig. 3). There are two alternatives:

1. well oxygenated periods were sampled, missing the perhaps barren laminated layers;
2. oxyphylic forms were reworked from shallower parts of the basin.

Signs of reworking were not visible on the foraminiferal tests, yet it cannot be excluded that marine sediments from shallower parts of the basin arrived (Holcová 1999). Based on the benthic foraminiferal results accomplished with the geophysical and geochemical parameters, we can suppose the episodic dysoxy and/or anoxy of this period is related to increased terrigenous influence in the form of lowered salinity surface water.

Unit II: The only indicative species *Bolivina hebes* is an endemic species with still unknown ecological demands (Table 4). Concerning isotope results, this biofacies unit marked a rather stable period with slightly increasing δ^{18}O values measured in planktonic foraminifera and high values measured in the benthic forms, indicating normal marine salinities (Fig. 8). This refers to a period of stability, lowered food supply, and better-oxygenated bottom water conditions than in the previous period. Concerning magnetic susceptibility, it was also a stable period of moderate terrestrial input (Fig. 9). Generally, stable conditions and lowered food supply of this period resulted in relatively high diversities. However, the oscillations in the P/B paleowater depth proxies have no plausible explanation at the moment (Fig. 2).

Unit III: A general negative trend of δ^{18}O reaching a minimum in the upper part at 36.8 m, especially pronounced in

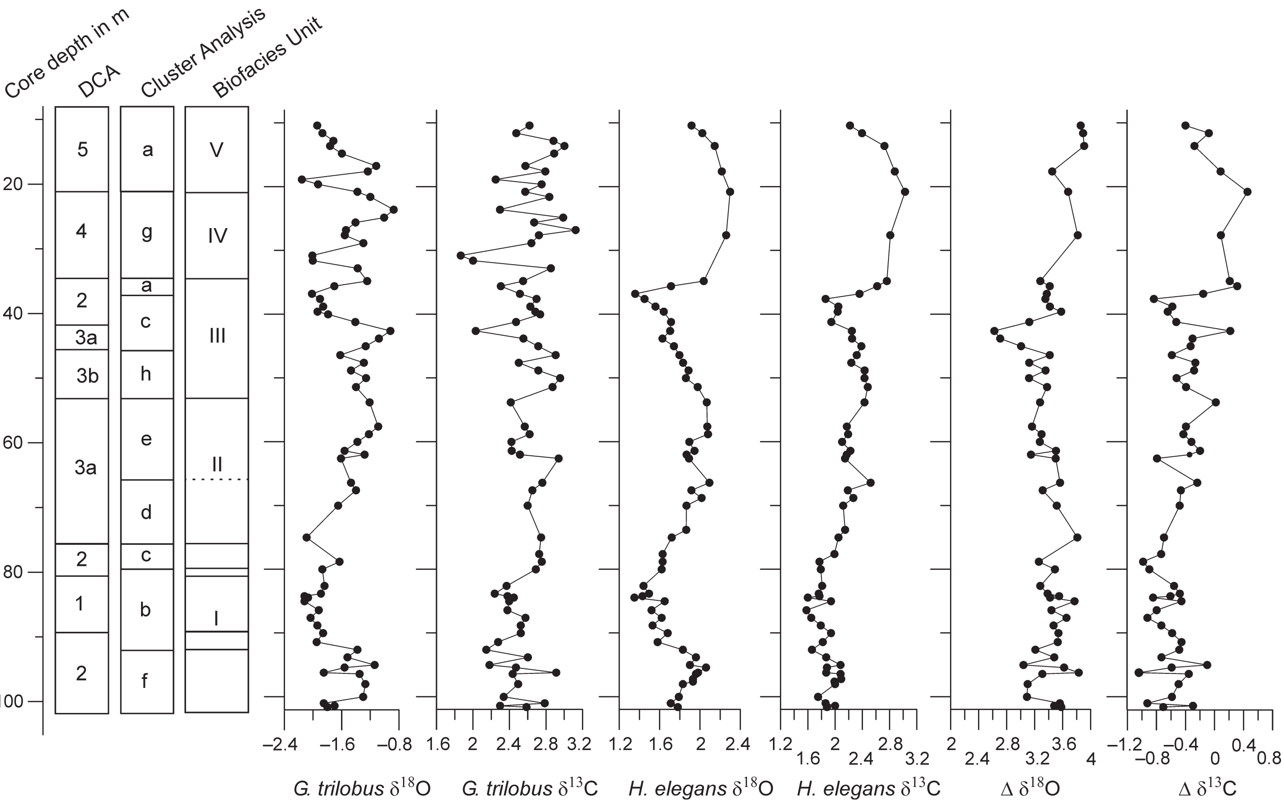
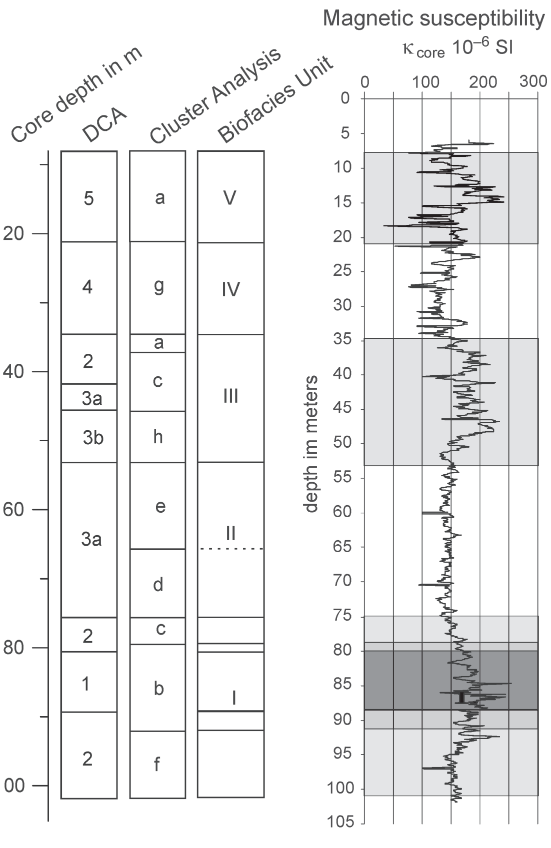


Fig. 8. Stable isotope record plotted against depth in core and the recognized biofacies units on the left. From left to right: The stable isotope record of $\delta^{18}O$ and $\delta^{13}C$ measured in *Globigerinoides trilobus* and in *Hoeglundina elegans*. The delta-delta record was calculated to express differences of surface and bottom water, where the $\Delta\delta^{18}O = \delta^{18}O_{benthic} - \delta^{18}O_{planktonic}$, while $\Delta\delta^{13}C = \delta^{13}C_{benthic} - \delta^{13}C_{planktonic}$.



the benthic $\delta^{18}O$, with a corresponding $\delta^{13}C$ record, characterizes this interval. Extracting the planktonic $\delta^{18}O$ from the benthic $\delta^{18}O$ as a measure of water column stratification is created here, referred to as $\Delta\delta^{18}O$. This difference shows a definite minimum of the entire studied section at 42.6 m, meaning minimal density stratification during deposition of this biofacies (Fig. 8). The magnetic susceptibility shows maximum terrestrial input throughout the whole core, with the highest values in the lower part of the unit (Fig. 9). Some — not too common indicator species (Table 4; Fig. 3) of the lower part (cluster **h)**) such as *Ammonia beccarii*, *Quinqueloculina* spp. and div. miliolids are low salinity tolerant taxa. The species *Trifarina angulosa*, indicative for most of this unit (cluster **h)** and **c)**), is associated with lower salinities sometimes, however, more consequently with coarser substrates, well oxygenated, high energy bottom waters (Harloff & Mackensen 1997; Hayward et al. 2002, 2004; Klitgaard-Kristensen et al. 2002). On the basis of the peak of *Trifarina angulosa*, we suppose well-aerated, turbulent bottom waters at the time of deposition. This is in accordance with the reduced stratification of the period revealed by the $\Delta\delta^{18}O$ minimum. The rather low benthic foraminiferal numbers characterizing this period are due to dilution in sediment by

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Fig. 9. Magnetic susceptibility record plotted against depth in core and the recognized biofacies units on the left.

terrigenous input, also providing the coarse substrate necessary for *Trifarina angulosa.*

Unit IV: The indicator species *Bulimina elongata* and *Fursenkoina acuta* (Table 4) are typical deep inbenthic species possessing elongate tests (Corliss 1985; Corliss & Chen 1988; de Stigter et al. 1998), which are tolerant for episodic dysoxy, while profiting from high food availability living close to the redox front in the sediment. *Bolivina spathulata* (synonym to *Bolivina dilatata* in de Stigter et al. 1998 and Den Dulk et al. 2000) is also a deep inbenthic, while *Cassidulina laevigata* is observed to be tolerant for reduced oxygen and enhanced organic carbon content in muddy sediments (Rogerson et al. 2006). The other indices like oxyphylic percentages are low, confirming lowered oxygen levels. The diversity indices Shannon (H) and Fisher-α are low, while dominance is high due to the low oxygen levels at the bottom causing stress for benthic life. The number of benthic foraminifera is raised ten folds in this biofacies unit (Fig. 2). This could be the combined result of r-strategist highly productive inbenthic forms *(Bulimina elongata*, *Fursenkoina acuta* and *Bolivina spathulata)* and the low terrigenous input shown by magnetic susceptibility not diluting the foraminiferal stock in the sediment (Fig. 9).

The stable isotope results (Fig. 8) provide additional information about how the highly eutrophic bottom water conditions developed in this biofacies. The carbon isotope record measured in the planktonic foraminifera (*Globigerinoides trilobus)* indicates rather highly productive surface water conditions sustaining food for the benthic community. The only available $\Delta\delta^{18}O$ data point of this interval shows a highly stratified water column, which contributed to oxygen deficiency at the bottom by restricting vertical circulation.

Unit V: The indicator species, the reticulate *Bolivina viennensis,* is abundant enough to contribute significant information about the environment. Reticulate bolivinids prefer oxygen depleted bottom water with sustained food supply and sluggish circulation (Hayward et al. 2002). The stable isotopes and magnetic susceptibility highly oscillate during this period (Figs. 8, 9). The $\Delta\delta^{18}O$ is rather high, thus we can suppose that the intensive stratification of the water column characterizing the previous unit had persisted. However, the faunal turnover from biofacies unit IV to V is probably due to less stable conditions reflected as oscillations and intensified terrigenous input according to susceptibility. The relatively high percentages of oxyphylic taxa are due to reworking and intensified transport from land similarly to the anoxic event in biofacies unit I (Fig. 2).

Conclusion

1. The benthic foraminifera of the Baden-Sooss borehole were found to be a sufficient tool for paleoenvironmental reconstructions. Results based on foraminifera were confirmed by stable isotope records ($\delta^{18}O$ and $\delta^{13}C$) and magnetic susceptibility (Figs. 8, 9), thus the actualistic approach combined with the applied species concept worked.

2. The different indices and proxies (Fig. 2) showed strong correlation with core depth, meaning apparent trends (Table 3). The applied multivariate techniques resulted in sample groupings or species assemblages that also characterize distinct depth intervals of the section (Figs. 4, 6, 7). These observations suggest that a succession of changing environmental regimes is manifested in the benthic foraminiferal record.

3. The correlation to core depth revealed an increasing inbenthic percentages coupled with a slightly decreasing oxyphylic number and declining diversity (Table 3, Fig. 2). This is interpreted as lowering oxygen levels and increasing food resources causing increasing stress observable through the studied section. This trend can be related to the general eutrophication trend throughout the Badenian (Báldi 2006). The paleowater depth proxies document a shallowing trend.

4. The boundaries of the five recognized biofacies units (Fig. 7) based on multivariate techniques correlate to shifts in the stable isotope and susceptibility record (Figs. 8, 9). This suggests, that changes in the physical environmental parameters (oxygen, food, salinity) inducing a turnover of benthic foraminiferal assemblages are controlled by proximity to the land. This idea is in accordance with the general geological setting of the Baden-Sooss borehole located in a rather shallow part of the Paratethys not too far from the land.

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Table 1: Abundance of benthic foraminifera in 100 g sediment of the Baden-Soos core. Part 1 from 4.

Depth in core (m)	*Allomorphina trigonia* (Reuss)*	*Amphycorina badenensis* (d'Orbigny)	*Ammonia beccarii* (Linné)	*Biapertorbis biaperturatus* Pokorny	*Asterigerinata planorbis* (d'Orbigny)	*Astrononion* cf. *italicum* (Cushman & Edwards)	*Bolivina antiqua* (d'Orbigny)*	*Bolivina hebes* (Macfadyen)	*Bolivina plicatella* (Cushman)	*Bolivina scalprata* var. *miocenica* (Macfadyen)	*Bolivina spathulata* (Williamson)*	*Bolivina trajectina* (Marks)	*Bolivina viennensis* (Marks)*	*Bolivina* undetermined (contorted forms)	*Bolivina* spp.	*Bitubulogenerina reticulata* Cushman	*Bulimina aculeata* (d'Orbigny)*	*Bulimina elongata* (d'Orbigny)*	*Bulimina costata* (d'Orbigny)	*Cancris auriculus* (Fichtel & Moll)	*Cassidulina carinata* (Silvestri)	*Cassidulina oblonga* (Reuss)*	*Cassidulina subglobosa* (Brady)*	*Cassidulina laevigata* (d'Orbigny)	*Cassidulina* spp.
8.410						8			7		5		36			1	5	3					10	9	
10.015	2					1			2		5		9				5	9	7				4	4	
11.210		1							3		4		7				3	13	2				10	21	
12.440									3		6		10		1	1	10	6	3				7	10	
13.620	1	1			2	1			6		6		7		1		2	8	2				11	13	
14.810	1			1	3				4				12		1		1	5					4	6	
16.410		1			1				1		1		1				6	27	2				9	13	
17.610					1	1			2				7			1	10	7					15	5	
18.880	1		1		1				1	6			17				8	6	3				22	14	
20.020		1	3		2	2			3		9		6			1	2	11					1	13	
22.410			2		6				4	12					7		6	67					3	14	
23.610					4	1			2	7						1	6	53				9		26	
24.855						1			1		7						6	51						31	
26.410			1		4	2			1		7				2	1	5	68					2	25	
27.615					3						5		1				5	50		1			5	22	
28.855	1	1			14	1			2		17				2	2	26	25	1				10	8	
30.010					17	4					15						17	46					2	5	
31.215			2		3	3			2		6					2	9	20					13	1	
34.010					1	2			4		6		4			1	35	8					2	2	
35.210			3		4	1			10		1		8		1	1	16				5	2	20	1	
36.810		1	3	1	1	2	3		5		4		1		1	2		1				15	9	2	
37.610					4			8	9				2		4		17	3	21		6	3	1	2	
38.810			3		5		5	10	5				3				1	12	25		2		3	11	
40.010			1					20	5		3				3		16	3	17			2	5		
41.210		2	1			1		5	1		1		6		4		1		13		1		3	2	
42.410	1				2	1	7		5				14	1	1		35	3	23	1	2		9	5	
42.610		3			3				1				2				15		43			1	8		
43.810			1		1				1				16			1	10		36			10	7		
45.010			1		2		2		3				1		3	1	13	2			1	10	8	11	
46.410			3												1		4	15				16	4	6	
47.610			2				3								1		9	18				4	1	10	
48.810		1	2		1	1	1		2		3		1				15	14			4	7	3	9	
50.010			1		4		1	1	1						3		29	6			1	8	7	8	7
51.410			2		2		1		1		5				4		31	19				7	2	18	
52.610			3		1				3						1		21	8				10	2	3	
53.810		1	1		5	1	3	4	2		2		9				23	5	27		2	6	5	4	
55.010		1			1	3		2	1				6		1		18	3	19			5	3	5	1
56.410			2		2	3		15	3				7		2		18	3	15		4	5	2	4	
57.610		1	1		3	4	2	22	1		3		2		2		13		19	1		3		9	
58.810			1			1		17	1				3				13	1	22		2	3	5	2	
60.010		1		1	3	1		10	2	1			5		4		11					2	4	9	2
61.410			3	1	3	2		20	4				1		1		8	1	13			1	5	23	
62.610				1	2	5		32	5				1	1			10	1	13	7		2	1	8	
63.815								9	3								12		23			5	2	4	
65.010	1				1			21	2		3			2			21	1	23		1	6	4	4	2
66.415			2		4	2	1		2		2		3				29	3	19		1	6	3	1	
67.61		1			3			9	2		3		1				22		10	1		1	3	1	
68.810				1	3	1		4	3		2		1				18	3	12	1	1	4	3	7	1
70.010				1	8	2			3				1				18	2		1	2	4	13	16	
71.415		1	5		9		1		5		5		3				14	5	1		2	13	3	14	
72.61	1	2	3	1	2			9	3				2		1		20	3				9	4	2	
73.810	1	2		1	4	3		4	2					1			16	1	4		2	3	9	7	
75.010		5	1	2	8	7		7	2				3				7	6	13		3	20		6	
76.410		7	5	1	7	4	5	4	6				2				11	2	26		2	1	9	13	
77.610		4		1	2	3	3	2	8		1						4	12	23	2			9	3	3
78.810		1			1	1		10	1								11	2	18			1	6	1	
80.010		3			2	1		14	8						2		11	3	11		1	3	10	4	
81.410		1		1		7		15	15	2			1	1					6	1		4	7	3	
82.610		3			2	5		7	8				1		7			3	7				6	3	
83.830		1						5	6					1	2			3	7		5		3	6	
85.010	1	1	3		4	2		1	4		2			1			6	5	7		1		11	6	
86.410			2		2			6	1					1					16		5	1	12		
87.610				1	3	2	3	1	5	1			1					1	11	4	2		5	8	
88.810		1	1		1	2			5		1		1				2	1	10	1	1		6		
90.010		1	1	1	5	7	1	5	3					1			4		11		1		9	1	
91.410					6	3	5	5	12				9				4	1					4	4	
92.630				1	4	5	4	3	1				2		1		2		31	1			16		
93.810	1	1	1	2	4			2	8		2		2		1		8	1	14				19	2	1
95.010			1		3	2		1	1				2				5		26	2	1	7	14	1	
96.410	1			1	5			2	2		2						11		6		1	1	10	1	
97.610						3	2		2				3				7	3	12	1	3	5	7	5	1
98.810				1	7	2	6	4	4		1		4				7		10		6	6	10	13	1
100.010		2		1	11	3	4	9					8		2		12	3	1	1	2		4	1	
101.410																	1		10						

Table 1: *Continued.* Part 2 from 4.

Depth in core (m)	*Ceratocancris hauerina* (d'Orbigny)	*Cibicides lobatulus* (Walker & Jacob)**	*Cibicides kullenbergi* (Parker)**	*Cibicides ungerianus* (d'Orbigny)**	*Cibicides* spp.	*Cornuspira plicata* (Czjzek)	*Dentalina communis* (d'Orbigny)	*Dentalina brevis* (d'Orbigny)	*Dentalina elegans* (d'Orbigny)	*Ehrenbergia serrata* Reuss	*Elphidium* spp.	*Alabamina* sp.	*Fissurina* spp.	*Fursenkoina acuta* (d'Orbigny)*	*Gavelinopsis praegeri* (Heron-Allen & Earland)	*Glandulina* sp.	*Globobulimina pyrula* (d'Orbigny)*	*Globulina* sp.	*Guttulina* sp. (d'Orbigny)	*Gyroidina parva* (Cushman & Renz)	*Gyroidina soldanii* (d'Orbigny)	*Gyroidina umbonata* (Silvestri)	*Hansawaia boueana* (d'Orbigny)**	*Heterolepa dutemplei* (d'Orbigny)**	*Hoeglundina elegans* (d'Orbigny)
8.410		30							1		1			3	11		1						2	22	
10.015		10		3			4		33		1	1		2	6								1	15	
11.210		9		5					6					1	14		1					2	1	4	
12.440		36		3					15					2	14							1		9	
13.620		22		5							3				18		2					2	2	4	1
14.810		26		11											5		2							16	
16.410	1	9		2							1				8		4							23	
17.610	2	42									2			3	21									24	
18.880	4	12		9								5		1	13		9			1		3	6	14	
20.020	2	33							4		1			2	9							1	6	18	
22.410		5									8			5			1						2	20	
23.610		7									7		2	7	1							1		4	
24.855		7							2		3			3	10								2	4	
26.410		8									3			5	3								3	5	
27.615		14		1							4		2	6	5						1		1	11	
28.855	2	25									5			17	4		1					1	1	32	
30.010	1	22									6	3	1	10	5		2					5	2	10	
31.215		13									2			7	5						1	1	1	25	
34.010		2									1			7	1								1	2	
35.210		55		11					3.5	11	4			2	3						5	16	5	4	1
36.810	2	22	7	4					12	4	6			2			4				3	4	3	6	2
37.610		10	5	2			2		2		1	1	2		13		5				2	1	3		3
38.810	3	14		5					5	1	3	5	1		14		1				2	5	6	1	
40.010	1	6		3					3		1	1			4		51					3	4	8	
41.210	8	12	3	5					5		1	4			14		5		1		1	1	2	7	5
42.410	2	13		4							1	1		1	14				1	1			4	1	1
42.610	4	9		3				1		1	2		2		14		8					1		5	
43.810	3	16	3	2							2	2	1		9		1				2	2	1	4	3
45.010	2	12		5	1						3		3		10		1					1	2		
46.410	2	6					5						2		8		3					1	1	3	1
47.610	2	4		1							3			1	7		2			3			1	1	2
48.810	2	8					1						2		6					1			4	3	3
50.010	2	5									4		1		6							2	1	1	
51.410		3		1							4	1	2		12								1	1	1
52.610		2					1				1	1		11	4		3			1			4		
53.810	6	11							1		2	8	2	2	7		1					2	1	2	1
55.010	6	9			2						1	3	2	3	8	1	2			1		3	3	3	8
56.410	13	13		1							2				11		1				5	3	2	1	1
57.610	5	17									3		2	3	9		5		1			5	5	4	3
58.810	1	13			1				1.5			1	1		7	1	3				2	6	1	1	5
60.010		17									1		1	1	15		1			6	2	9	1	4	4
61.410	6	17		4							1	14	1		6						5	5	9	3	5
62.610	8	18					2				3	1	2	3	17						3	8	6	3	1
63.815	16	3	1	4					2			1	1	2	5							3	1	12	6
65.010	17	10		3	2		1				4	4		3	12		1					5	2	4	7
66.415	4	7	1	3						2	3	6	2		5		1					7		2	4
67.61	10	8		3	1	1		1			2	9	3		7		3				1	4	1	4	7
68.810	4	11	2	1							3	2	3	3	8		1					5	4	9	3
70.010		15	2								3	7		1	10							5	6	2	2
71.415		13	1	6							6	6		5	13							15		5	1
72.61	2	10		4			2				3	4	2		3	1				1	2	6	1	6	2
73.810		8					1				4		1	3	5	1	2					9	3	2	3
75.010	4	36					3				5	10	1	2	9		1				4	8	7	5	1
76.410	4	21	1	6			1		1	1	13	4	2	1	14		3		1		6	16	13	13	7
77.610	6	15		3					1	1	5			1	4		3			2	2	7	4	9	4
78.810	3	11	2	9					2		1	3			3		8				5		6	22	6
80.010	6	31		4	4	1	1		16		2		1	3	6		9			1	2	3	10	9	6
81.410	5	17	2	4		2	1				7	1	1	1	8		10		1				6	2	3
82.610	2	16		3	1		1		6		2	4	1	2	1		6			2		4	12	2	7
83.830	1	24	1	4								2			3		3		1		4	9	1	5	8
85.010	4	14		5	2	3					2		2	2	4		2		1			2	5	4	8
86.410	1	16	4	8			1		1		2		1		3		7				4	4	5	5	10
87.610	4	20	2	1	2	2					3		1	1	5		1					2	12	2	1
88.810	1	21		7	1	1			3		1	2	1	1	2		3			2	6	3	2	6	6
90.010		15	4	4						3		2	2	1	8		7		2	2	1	5	9	4	18
91.410	1	10		3						2	2	4	1	1	7		10				1	3	8	3	14
92.630	8	27							2		5	1	1		6		3					11	2	10	3
93.810	7	25		10							3		2	1	5		3					17	6		1
95.010	15	20		10							2			2	9		9					4	13	3	2
96.410	15	19	2	2							11	2	3	3	3		5					7	2	8	7
97.610	13	27	2	9							2		3		8		8		1		4	3	12	1	1
98.810	11	14	1	2							11	4	2	3			4				1	5	6	6	
100.010	12	13		10		3			3						3		2			8		4	6	4	4
101.410	4	6	3	11				2		4						2	4				5			6	7

Table 1: *Continued.* Part 3 from 4.

Depth in core (m)	*Lagena* spp.	*Lenticulina calcar* (Linné)**	*Lenticulina arcuata* (d'Orbigny)**	*Lenticulina* sp.**	*Melonis pompilioides* (Fichtel & Moll)*	*Adelosina* spp.**	*Pyrgo* spp**	*Triloculina* spp.**	*Quinqeloculina* spp.**	*Rosalina*	*Spiroloculina excavata* (d'Orbigny)**	*Sigmoilinita tenuis* (Czjzek)**	*Miliolid* spp.**	*Marginulina hirsuta* (d'Orbigny)	*Nodosaria* sp. 1	*Nodosaria* sp. 2	*Nodosaria raphanistrum* (Linné)	*Nonion commune* (d'Orbigny)	*Nonionella turgida* (Williamson)	*Oolina* spp.	*Oridorsalis umbonatus* (Reuss)	*Planulina* sp.	*Pullenia bulloides* (d'Orbigny)*	*Pullenia quinqueloba* (Reuss)*	*Reusella spinulosa* (Reuss)
8.410				2	26				4			1			2	1		1					3		
10.015	1		2	2	18		1						1		3			9		1	1		1		
11.210				2	8	3						2						22					1		
12.440			1		23							2						7					5	1	
13.620	1			1	17							2					1	4					3		
14.810			2		13							3			4			19					2		
16.410			2		8		1										2	47					3		
17.610			1		15	1	1					3					1	13					1		
18.880			2		6				4			1						1					3		
20.020			1	1	20	3	1	2				1	2		1					1			3		
22.410				2	3				1									50					2		
23.610					4		1					1	1					41							
24.855	1			1	3							3						49					3		
26.410					3										2			37							
27.615					4								1		1			38					2		
28.855				1	10					1		1	1		2		1	35		1	1		5		
30.010					4													36		3					
31.215				2	4							1						11					4	1	
34.010	1				2	1	1		4			4					5	103		2			1		1
35.210				5	21				5			1	1	1				3			5		1		
36.810			3	4	8	4			7	3		2	4	1	1	2		1							1
37.610		2	3	5	5		1		1	3			5		2	2					2		2		
38.810		6		5	4		4		1			1	3	2	1			4		1	1		1		1
40.010				1	9		1		1	1		2	1		1						3		4		
41.210				3	10	1			1	3		1	7								2		3		
42.410				3	3	1			2			4	2	2	2						4		1	1	
42.610		2		3	10					1	1	1	2	3						1	2		2		1
43.810	1	1			6				2	4		2	3	2	1			1	1					2	1
45.010	4	4		1	7	2	3	1	3			2	3	3				11					4		
46.410		2		2	4	1	2		11			1	5				1	41							1
47.610	1	2		6	10	6	3		5		1	3	6		1	1		39					2	1	1
48.810		1		2	7	3			3		2		2		1			19	1					1	
50.010		4		2	14				5		5	8	4		2			63						2	
51.410	2			2	10							1	4					34							
52.610	6	1		5	16				1		1	3	1					36			1		2	4	
53.810	1			6	6							4		1			1	9			3		2		
55.010	3			4	10				1	1		3						11					1		
56.410				1	7						1	7	1					9	1				1		
57.610	3			2	7				3		1	4						10			1		1	1	
58.810				4	8						2			1				14					7		
60.010	2			8	14				2		2	1	2		1	1		15	2		1		4	2	
61.410				1	14			1	1			2	1		1	2		33	1		1		1		
62.610	2	2		7	13				4		4		1		1			9	1	1					
63.815				19	18	2			4			2	3		1	1	1	12					1		
65.010	5			1	13				4		5	2	1		2			19	1		2		2	2	
66.415				8	6					1		1	1		1			8			2		6		
67.61	7			13	11						2	4			1			5					7	2	
68.810				3	12		1		1			2		2	1			6			2			5	
70.010	2	1		3	21							4			1			3		1	3		2		2
71.415				3	17							5						17					12	1	
72.61	4			4	17	2			2	1		2					1	13	1	2	1		10		
73.810	3			1	10		2		5	1	1	7			1			15			2		6		
75.010	11			5	25				3	1	2	3	2					2	2				6	1	1
76.410				3	20		1		11		2	4						3					8	4	
77.610	5			2	9		1		6	1		3								1			7	2	
78.810	2	2		7	16		2	4	2		1		5		1						1		1		
80.010	2			12	11	2				2		3	4			1	1	1							1
81.410	2			3	13		1	1	3		1	5	3			1							1		2
82.610	4			5	6				1	1	2	8	3			2					1		1		
83.830				4	21		1	2		1		3	3			1				1			2		
85.010	2	1		7	10				1	1		1		2	1			13		1			2		
86.410				2	3			2	2	2		6	3	2	1	1					1			1	
87.610	1			1	9	14	2	1	6		2	2		1				3							4
88.810	2			8	6		3	5	1	1	2	1	1	3		1									
90.010					8				1	2	3	2	3		1			2	1				2		
91.410				5	14	2			2	1			4					1			1		2		
92.630				5	2					1	1	1	2	1		1	2						3		
93.810				2	1				2			3	1	1		1		3			1		1		
95.010				2	3				6		3	2	3	1	1		2	6	1		4		2		
96.410				7	5			2	1			1						6	1				1		
97.610	3			3	4				1				6					4	1		4		5		
98.810					2	1			2	5	1	4	3					8			2		4		
100.010	5			3	5				3	1		4	1			1		16			1		2		1
101.410		3		8	6				2		1		3					1					2	1	

Table 1: *Continued.* Part 4 from 4.

Depth in core (m)	*Siphonina reticulata* (Czjzek)**	*Sphaeroidina bulloides* (d'Orbigny)*	*Stilostomella adolphina* (d'Orbigny)	*Trifarina angulosa* (Williamson)	*Trifarina bradyi* (Cushman)	*Pappina parkeri* (Karrer)*	*Uvigerina semiornata* (d'Orbigny)*	*Uvigerina pygmea* (d'Orbigny)*	*Uvigerina venusta* (Franzenau)*	*Uvigerina aculeata* (d'Orbigny)*	*Uvigerina acuminata* (Hosius)*	*Uvigerina acuminata* f. *macrocarinata**	*Uvigerina* spp.*	*Vaginulopsis pedum* (d'Orbigny)	*Valvulineria complanata* (d'Orbigny)*	Undetermined calcareous specimens	*Haplophragmoides* sp.	*Martinotiella communis* (d'Orbigny)	*Spiroplectammina* spp.	*Spiroplectammina carinata* (d'Orbigny)	*Textularia* sp.	*Textularia* spp.	*Textularia* cf. *mexicana*	*Sigmoilopsis* sp.	*Vulvulina* spp.	Undetermined agglutinated specimens
8.410		4					4								8	1				6	2		1		2	3
10.015		2	5	3			6			1					9	3				3	1	1			4	2
11.210					1		14								25		1	1		18		3		2		1
12.440			2				14								9	2		1	15			6	5			3
13.620		5		3			8								27	3		2		8		4		1		1
14.810		3		2	1		23								18	3			2	5		2		2		
16.410			1				12								8	2			7			1		2		
17.610				3	1		19								5	4				22		2	2			1
18.880				4	1		9				2				7					3		9		1		1
20.020				2			22								17	2				7	2	2				
22.410						1									19	2				3						1
23.610						1	1								20	3		1		5		2		2		
24.855															9	1				3				5		
26.410															9	3				5				1		
27.615	1						7								5	3				19				1		
28.855						3	6								15	1				23		2		2	4	
30.010						2	6								12	5				13		3				4
31.215							20								14	3				33		2	4	1		
34.010				1		1	5					4			16	2		2.5		21		9		2		4
35.210				1	1						5	3			18	5				4	1	8	4	2		4
36.810		13		11	2					2					5	3		1		5		7		1		4
37.610		4	2	2											14	9		0.3		3	4	3				
38.810	2	1	2	6											19	6				2		3			2	1
40.010			2	10											20	6				3		2	5			1
41.210	1	1	3	7											25	3	1	1		10		2	2	1	2	
42.410		1	2	20			1						2		5	3		2		4			1	1	4	1
42.610			2	27											10	1		1		1			2		4	
43.810			2	32									1		21			1		5		1	1		4	
45.010		1		26			1				1		1		18	9	1	2		5		3	3	1	1	4
46.410				16						2					9	6				8		2	4		1	
47.610			2	8		2									12	4				5		4	3	3		4
48.810			1	16			3								13	4		1	9	5	3	2		8	1	4
50.010			4	27			1				2				7	3				6			1			3
51.410				20		1	1								11	6				2					2	
52.610				7											28	2		1		13		1		3	2	2
53.810				4		1					1				10	6		1		13		1			1	
55.010		1		3			2				7	1			23	5		3		21	4		2	3	2	3
56.410		3		2											15	4		1		3	2			4	2	3
57.610							1								9		1	2		5		2		2	1	3
58.810		1	3	2							2				12	6				10	11	3	3		1	
60.010		1	5	7							3				4	4				10	9	1	3	1	2	4
61.410		2									5				14					3	2	6	1		2	4
62.610			3	10							1				18	4		1		8	6	1		1	1	
63.815				1		1					1				12	5		5		21	10	5	11	4		
65.010				4									2		17			4	2	5		4	5	2		4
66.415				1											19	7				5	1		1	2	5	
67.61			1	1	1						5				5	2				6	1	1	1		1	1
68.810			1	2											7	7		1		14		4	2	1	4	1
70.010			1	3						1					9	3				14		3	1		1	2
71.415				5											14	2		3		15		2	4	6	2	
72.61			7		1								1		5	5				10		2	2	1	3	
73.810				2		2									1	6				25	1		12	5	2	
75.010		4		4		3				1					3	1				7		6				
76.410			1	5						1			4		11	13		2		11	3	4	3	4	8	3
77.610		1		8						5	2		3		9	4			6	2		2	1	2		4
78.810		5	2	6		2				7					5	7		2		2		2	1	1	3	1
80.010	1		2	11	3					2					12	9		3		2		2		2	1	2
81.410	1	2	2	1			2								6	12		1		3		3		6	1	
82.610	2		6	10	3		15								2	9										7
83.830		2	4	7		1	27								12	5		1		3				2	1	4
85.010		2	3	4	4	1	13								12	6				3		1	1	2		2
86.410	3	6	5	4	2		26								7	2				2		2		1	1	2
87.610	1	3	9	2	4		12									11		1	1	1		4			1	
88.810	1		10	1	1		23								9	7				6		2	2		1	1
90.010		1		6			13			2					1	6		1		4		5	2	1		2
91.410		1	1	4			9								13	6		2		6		3	3	1	2	2
92.630		6	5	3	2		1			6			4		1	6		1				1	2		7	
93.810		2	4.5	8		2				10			2		1	9				1		1	1		1	
95.010		2	0.5	4						23						6				1	4	3	3	5	2	4
96.410		1	1		1					12			4		6	2						3	6	1	3	6
97.610		1	2	3						36					4	4		2		2			10	1	2	2
98.810		4		5						15					3	9						1	5	2	5	2
100.010		6		3						30					4	5		1	1	2		2		3		
101.410		7								79					1	2				5	1	3	4	7	2	3