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Palaeoecology of the Late Badenian foraminifera and ostracoda from the SW Central Paratethys (Medvednica Mt., Croatia)

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Key words: Benthic foraminifera, Ostracoda, Palaeoecology, Biostratigraphy, Late Badenian, Medvednica Mt., Croatia.

Abstract

The quantitative study of microfossil communities from the Late Badenian marls at the Sveta Barbara locality (eastern Medvednica Mt.) enabled reconstruction of three different palaeoenvironments: middle shelf, outer shelf and upper bathyal. The dominant factors influencing the distribution of biota were the deepening of the depositional basin and fluctuations of the oxygenation rate. The outer shelf biota existed under conditions of decreased oxygen levels in bottom water, compared to communities from the middle shelf and upper bathyal environments.

1. INTRODUCTION

From the Late Egerian (Early Miocene) up to the Middle Sarmatian (Middle Miocene) the sedimentary basin of Northern and Central Croatia belonged to the south-western part of the Central Paratethys sea (PAVELIĆ et al., 1998). Sedimentation in Paratethys is known for its peculiar palaeoenvironmental characteristics, due to temporary connections and disconnections with the Mediterranean (Tethyan) realm (RÖGL, 1998). In the Late Badenian (Fig. 1) the seaway from the Mediterranean to Central Paratethys in Slovenia was closed. However, the Eastern Anatolian seaway had opened again as shown by the presence of Indo–Pacific microfossil assemblages in Central Paratethys (RÖGL, 1999). All over Paratethys a final marine transgression covered all the different facies.

The geological composition of Medvednica Mt., N of Zagreb, together with the surrounding Cenozoic basin sediments, has been subject to numerous geological and palaeontological studies (GORJANOVIĆ-KRAMBERGER, 1908; ŠIKIĆ et al., 1979; AVANIĆ, 1997; KOVAČIĆ, 2004). A detailed description of the Miocene deposits from the southern and south-western slopes of Medvednica Mt., and a detailed list of Late Badenian macrofossils is given by KOCHANSKY-DEVIDÉ (1944, 1957). ŠIKIĆ (1967, 1968) proposed a biostratigraphic zonation of Badenian and Sarmatian deposits on the basis of foraminiferal communities. BAJRAKTAREVIĆ (1984) described the fossil microfauna and nannoflora of the marly Middle Miocene deposits in detail (Badenian and Sarmatian). Badenian ostracods from Medvednica Mt. were determined by HAJEK-TADESSE (2006). More detailed studies of microfossils from north-western Croatia can be found in the unpublished reports of the Croatian Geological Survey.

Up-to-date research of the Late Badenian sediments from the Medvednica Mt. has mostly been restricted to taxonomic determination of fossils and descriptions of lithological types. Palaeoecological studies with detailed statistical analyses are notably absent. Therefore the main scope of this paper is a detailed palaeoecological interpretation of the Late Badenian depositional environments at the Sveta Barbara locality (Fig. 2), based on quantitative data analysis of the foraminifera and ostracods.

The authors hope that their efforts will contribute to the general reconstruction of the Late Badenian sedimentary basins in the wider area of the southern Pannonian Basin System.

2. GEOLOGICAL SETTING

Medvednica is an approximately 40 km long mountain in Northern Croatia, striking from the south-west towards the north-east. Its core is composed of Pre-Cenozoic rocks, surrounded by Neogene (Miocene, Pliocene and Pleistocene) deposits (ŠIKIĆ, 1995). Badenian deposits represent the most prominent part of the Cenozoic complex of Medvednica Mt. They transgressively overlie the lacustrine to marine Lower Miocene deposit cover and the Palaeocene to Pre-Cenozoic basement rocks forming a palaeo-island on the south-western margin of the Pannonian Basin System. These deposits are known for the high diversity of facies and Early, Middle and Late Badenian ages can be clearly

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Fig. 1 Location of Medvednica Mt. in Central Paratethys during the Late Badenian (after RÖGL, 1999 – modified).

distinguished due to the index microfossil distribution. This enables accurate correlation with the Standard Central Paratethys ecostratigraphic benthic foraminiferal zonation (PAPP et al., 1978; BASCH, 1983).

During the Early Badenian planktonic taxa dominated the microfossil communities (ŠIKIĆ, 1995). These Badenian deposits belong to the Lagenidae Zone, divided into 2 subzones on the basis of the uvigerinids. The Middle Badenian can be recognized through the domination of agglutinated foraminifera (‘Sandschaler Zone’), containing the abundant specimens of *Spiroplectinella carinata* D’ORBIGNY. Late Badenian sediments reflect the maximum of the marine transgression and basinal deepening, respectively, onlapping in most cases Pre-Cenozoic basement rocks (LUČIĆ et al., 2001). Their lower part, the Bulimina–Bolivina Zone, contains numerous small benthic foraminiferal taxa, while the uppermost Badenian (‘Barren Zone’, ‘Rotalia Zone’) can be recognized by the impoverishment of the fauna. The genus *Elphidium* dominates, together with the *Ammonia beccarii* (LINNÉ) and the genus *Quinqueloculina*.

The Sveta Barbara section is located west of the Sesvete–Čučerje road, in the Lipa creek trench, near Pukleki village (Fig. 2). The outcrop is approximately 9 m thick (Fig. 3). The lower part of the section is represented by weathered laminated marls, which are light brown in colour (samples S1, S2). In the upper part of that unit, three lens-shaped intercalations of a grey, massive marl (sample S3) can be observed. These lenses are 30–50 cm thick, irregularly embedded within the light brown marl. In the central part of the section, brownish-grey clay-rich marls prevail (samples S4, S5 and S6), while the uppermost part of the section is composed of greyish clay (samples S7 and S8). Samples were taken at intervals of 1 m.

3. MATERIALS AND METHODS

Approximately 300 g of the sediment per sample was dried, treated with hydrogen peroxide and washed through 0.5, 0.25, 0.125 and 0.063 mm sieves. Fractions >0.63 mm were chosen for analysis. All standard samples were obtained by the multiple “splitting” of the sample into equal parts, and about 300 specimens of foraminifera were extracted. As ostracods, unlike foraminifera, are scarce in the samples, they were hand picked from 1 g of the dried residue (>0.63 mm).

Statistical analysis

Qualitative and quantitative analysis of the foraminifera and ostracod communities were the next steps in the taphofacies analysis.

(1) The determination of the collected foraminifera genera and species was performed according to PAPP et al. (1978), PAPP & SCHMID (1985), CICHA et al. (1998), and BALDI (1999), while the higher taxonomic categories were taken from LOEBLICH & TAPPAN (1988a, b).

For the analyzed samples the following quantitative data were calculated:

– Planktonic/benthic ratio (P/B) – percentage of the planktonic foraminifera in foraminifera community was calculated on the basis of 300–350 specimens,

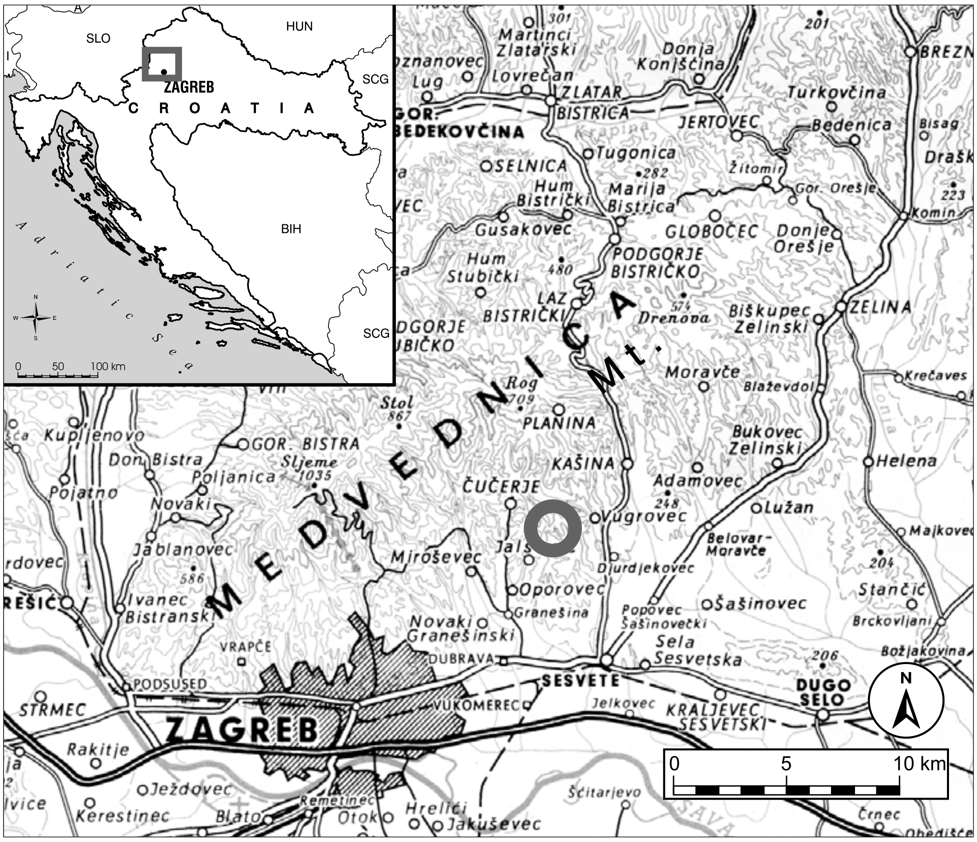

Fig. 2 Detail of the topographic map of Medvednica Mt. and location of the investigated Sveta Barbara profile.

using the formula P/B = P/(P+B) x 100%. Interpretation of the obtained data was done according to MURRAY (1991), with divisions into inner shelf (<20% planktonic tests), middle shelf (20–50%), outer shelf (50–70%) and upper bathyal zones (>70% planktonic tests).

- Number of Benthic Foraminifera (BFN) – number of specimens of benthic foraminifera in 1 g of sediment was calculated.
- Number of species of benthic foraminifera (S).
- Relative abundance of benthic species within the community was estimated according to MURRAY (1991): dominant species (>10%); common species (4–10%); accessory species (1–4%); rare or accidental species (<1%).
- Species diversity of benthic foraminifera was estimated by the Shannon–Wiener index (H), Dominance (D) and Fisher α index (α).
- Benthic foraminifera were classified according to the wall structure: agglutinated, porcellaneous, hyaline.
- In order to determine the quantity of oxygen in the bottom water, the classification proposed by KAIHO (1994) was applied. Oxic indicators (>1.5 ml/l); suboxic indicators (0.3–1.5 ml/l) and disoxic indicators (0.1–0.3 ml/l) can be distinguished. Benthic Foraminiferal Oxygen Index (BFOI) – index for quantity of dissolved oxygen was calculated for benthic foraminifera (KAIHO 1994; 1999), and the infauna/epifauna ratio was estimated.

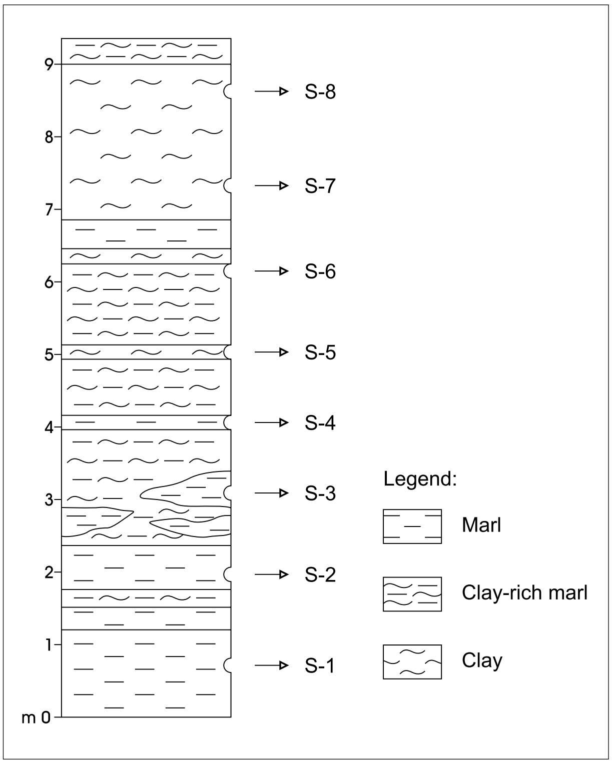

Fig. 3 Simplified lithological column at Sveta Barbara locality.

Palaeoecological interpretations of the studied species were done after MURRAY (1991), JORISSEN et al. (1995), DEN DULK et al. (2000) and DUIJNSTEE et al. (2004).

These results were combined with quantitative and qualitative analysis of the ostracoda communities.

(2) Ostracoda were determined according to HUBER-MAHDI (1984), BRESTENSKA & JIŘÍČEK (1978), YASSINI (1978) and HAJEK-TADESSE (2006), while higher taxonomical categories were taken from VAN MORKHOVEN (1962, 1963).

The following features were taken into consideration:

– Ostracod number (ON) – number of ostracods valves in 1 g of dry sediment. Whole carpaces were calculated as two valves (DANIELOPOL et al., 2002).
– Number of species and their relative abundance within the community. The same classification was applied as that used for the foraminifera.
– Carpace/valve ratio was calculated.

4. RESULTS

The microfossil community at the Sveta Barbara locality is, in general, well preserved, diverse in species and extremely rich in the number of foraminiferal specimens in most samples. Numerous ostracod specimens were observed in samples S7 and S8. Sample S3 did not contain ostracoda and planktonic foraminifera, and benthic foraminifera are scarce and poorly preserved; therefore this sample was not included in the statistical analysis. All together, 36 genera with 49 species of benthic foraminifera were determined: 4 species from the suborder Textulariina, 1 species from suborder Miliolina, 12 species from the suborder Lageniina and 32 species from the suborder Rotaliina (Table 1). Planktonic foraminifera are represented by 4 genera and 9 species (*Globigerina regularis* D'ORBIGNY, *G. bulloides* D'ORBIGNY, *G. obesa* (BOLLI), *Globigerinoides trilobus* REUSS, *Orbulina universa* D'ORBIGNY, *O. suturalis* BRÖNNIMAN, *Globorotalia* cf. *mayeri* CUSHMAN & ELLISOR, *Globigerina* sp., *Globigerinoides* sp.). Furthermore, 18 genera with 21 species of ostracoda from the suborder Podocopina were recognized (Table 2).

Figure 4 shows the graphic trends of the planktonic/benthic ratio and the Benthic Foraminiferal Oxygen Index. Mean values of these indices, including species diversity (Fisher α index, Shannon–Wiener index and Dominance), Benthic Foraminifera Number, number of species of benthic foraminifera and ostracods, Ostracod Number, dissolved oxygen indicators, infauna/epifauna ratio and wall composition from the resulting different Badenian environments are shown in Table 3.

Along the profile, the percentage of planktonic foraminifera increases, thus indicating the deepening of the depositional basin. Values of the planktonic/benthic ratio (Fig. 4, Table 3), indicate that the microfossil communities from samples S1 and S2 (average 44.81% planktonic tests), probably lived on the middle shelf, at depths of 100–150 m. Communities from samples S4, S5 and S6 (average 61.59% plankton) lived slightly deeper, probably at the outer shelf, between 150–200 m. The plankton content in samples S7 and S8 (average 83.31%) is typical for the upper bathyal zone (200–600 m).

High oxic conditions (BFOI=50–100) are typical for middle shelf environments, while moderate oxic conditions (BFOI=15–50) prevail in the upper bathyal environment, and low oxic conditions (BFOI 0–15) are recorded in the outer shelf environment (Fig. 4). The highest value of the Fisher α index (α=16.210) and the greatest number of species of benthic foraminifera (S=49) is recorded in the middle shelf environment, while a less diverse assemblage is observed in the outer shelf environment (α=3.624; S=16). The Shannon–Wiener index ranges between 1.902–3.147, with the highest values in the middle shelf environment. Dominance ranges between 0.06161–0.28860, with the highest values in the outer shelf environment. The greatest number of benthic foraminifera in 1 g of the sediment is recorded in the outer shelf environment (BFN=7452/g), while ostracods are the most abundant in the upper bathyal environment (ON=490/g).

Most of the determined benthic foraminifera are typical for shelf and upper bathyal environments. It is interesting that in the outer shelf and upper bathyal environments shallow-water taxa (*Elphidium*, *Asterigerinata*, *Neoconorbina*, *Cibicides*) only occur in the finest fraction. They are poorly preserved, with abraded tests. It is most likely that they were post-mortally transported to deeper environments, and therefore were not statistically analyzed.

Unlike foraminifera, ostracods from the middle and upper shelf samples are well preserved, but extremely scarce. Therefore statistical analysis of abundance could not be performed. In the upper bathyal environment, a significant increase in the number of ostracod valves was observed (more than 32x), and 16 new species appear (Tables 2, 3).

A list of species of benthic foraminifera and ostracods with a relative abundance greater than 5% in at least one sample are shown in Table 4.

Biostratigraphic position

The biostratigraphy of the studied section is based on the standard Zonations for Paratethys (PAPP et al., 1978; PAPP & SCHMID, 1985; CICHA et al., 1998).

Within the benthic foraminiferal community, dominant taxa are *Bulimina*, *Bolivina* and small globigerinids, thus indicating the Bulimina–Bolivina Zone of the Late Badenian. Further evidence of this correlation is the presence of important species, e.g. *P. neudorfensis* TOULA and *U. bellicostata* LUCZKOWSKA, which are indicative of the Late Badenian of Central Paratethys (PAPP et al., 1978).

SPECIES / SAMPLES	Oxic preference	Mode of life	S1	S2	S3*	S4	S5	S6	S7	S8
Suborder: Textulariina DELAGE & HEROUARD										
Martinottiella communis (D´ORBIGNY)	O	E	2	3	0	0	0	0	1	1
Textularia gramen D´ORBIGNY	O	E	1	1	0	1	1	1	3	5
Textularia laevigata D´ORBIGNY	O	E	1	2	0	0	0	0	2	0
Textularia mariae D´ORBIGNY	O	E	3	5	0	0	0	0	0	0
Suborder: Milioliina DELAGE &HEROUARD										
Sigmoilinita tenuis (CZJZEK)	O	E	7	9	0	2	2	0	5	5
Suborder: Lageniina DELAGE &HEROUARD										
Laevidentalina elegans D´ORBIGNY	S	I	1	0	0	0	0	0	2	4
Nodosaria guttifera (D´ORBIGNY)	S	I	1	0	0	0	0	0	1	0
Nodosaria sp.	S	I	1	0	0	0	0	0	0	0
Pseudonodosaria brevis D´ORBIGNY	S	I	1	0	0	0	0	0	1	0
Lenticulina gibba (D´ORBIGNY)	S	E	3	0	0	0	0	0	0	0
Lenticulina inornata (D´ORBIGNY)	S	E	2	2	2	1	0	0	3	3
Lagena striata (D´ORBIGNY)	S	I	1	0	0	0	0	0	0	0
Lagena sp.	S	I	2	0	0	0	0	0	0	0
Guttulina communis D´ORBIGNY	S	I	4	0	0	0	0	0	1	3
Glandulina ovula D´ORBIGNY	S	I	2	0	1	0	0	0	0	0
Fissurina sp.	S	I	1	0	0	0	0	0	2	2
Hoeglundina elegans (D´ORBIGNY)	S	E	1	0	0	0	0	0	1	1
Suborder: Rotaliina DELAGE &HEROUARD										
Bolivina antiqua D´ORBIGNY	D	I	1	0	0	4	0	0	5	3
Bolivina dilatata REUSS	D	I	25	19	1	54	86	153	37	47
Bolivina pseudoplicata HERON-ALLEN & EARLAN	D	I	2	3	0	1	0	0	10	6
Cassidulina laevigata D´ORBIGNY	S	I	37	47	0	26	17	21	2	2
Globocassidulina oblonga (REUSS)	O	I	31	33	0	9	4	17	13	23
Bulimina elongata D´ORBIGNY	S	I	23	30	6	33	12	10	3	16
Bulimina insignis LUCZKOWSKA	S	I	1	1	0	12	11	5	0	0
Globobulimina pyrula (D´ORBIGNY)	D	I	7	4	0	23	14	8	7	4
Pappina neudorfensis TOULA	S	I	3	1	0	4	5	0	1	0
Uvigerina brunnensis KARRER	S	I	2	1	0	3	0	0	2	0
Uvigerina bellicostata LUCZKOWSKA	S	I	6	7	0	3	5	3	12	1
Uvigerina semiornata D´ORBIGNY	S	I	19	14	0	52	57	13	40	56
Uvigerina venusta FRANZENAU	S	I	21	6	0	27	8	15	42	24
Fursenkoina acuta (D´ORBIGNY)	S	I	15	12	0	2	4	3	1	2
Eponides repandus (FICHTELL & MOLL)	O	E	1	8	0	0	0	0	3	2
Sphaeroidina bulloides D´ORBIGNY	S	I	3	1	0	0	0	0	3	1
Neoconorbina sp.	O	E	1	1	0	0	0	0	1	0
Cibicidoides pseudoungerianus (D´ORBIGNY)	O	E	30	41	0	3	8	17	20	29
Cibicidoides sp.	O	E	1	6	0	1	0	0	6	4
Planulina austriaca (D´ORBIGNY)	O	E	4	3	0	0	0	0	11	6
Cibicides boueanus D´ORBIGNY	O	E	1	2	0	4	0	0	2	0
Cibicides lobatulus (WALKER & JACOB)	O	E	1	0	0	3	1	3	1	2
Asterigerinata planorbis (D´ORBIGNY)	O	E	2	5	0	0	0	0	1	1
Nonion commune (D´ORBIGNY)	S	I	13	14	2	6	14	11	6	4
Melonis pompilioides (FICHTELL & MOLL)	S	I	17	9	0	21	6	9	19	23
Pullenia bulloides (D´ORBIGNY)	S	I	1	1	0	1	5	2	3	3
Allomorphina trigona REUSS	S	I	2	1	0	1	0	0	1	0
Chilostomella ovoidea REUSS	D	I	8	3	2	31	44	6	6	4
Oridorsalis umbonatus (REUSS)	S	E	1	0	0	0	0	0	4	3
Heterolepa dutemplei D´ORBIGNY	S	E	1	3	0	2	0	0	5	2
Hansenisca soldanii D´ORBIGNY	S	E	2	10	0	2	3	0	6	6
Elphidium sp.	O	E	1	2	0	1	4	4	2	2
			317	**310**	**14**	**333**	**311**	**303**	**297**	**300**

Table 1 List of identified benthic foraminifera species with their oxic preferences, modes of life and absolute abundance for each standardized sample (O – oxic, S – suboxic, D – disoxic, I – infauna, E – epifauna).

SPECIES / SAMPLES	S1		S2		S4		S5		S6		S7		S8	
	c	v	c	v	c	v	c	v	c	v	c	v	c	v
Suborder: Podocopina SARS														
Bairdoppilata sp.	0	0	0	0	0	0	0	0	0	0	0	3	0	0
Argilloecia cf. *acuminata* MÜLLER	0	0	0	0	1	0	0	2	0	0	62	14	48	32
Paracypris sp.	0	0	0	0	0	0	0	1	0	0	0	43	2	19
Callistocythere canaliculata (REUSS)	0	0	0	0	0	0	1	7	0	0	0	3	0	2
Cnestocythere lamellicosta TRIEBEL	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Aurila haueri (REUSS)	0	4	0	2	1	0	0	1	0	0	0	19	0	5
Urocythereis sp.	0	0	0	0	0	0	0	0	0	0	0	2	0	1
Henryhowella asperrima (REUSS)	0	0	0	1	0	0	0	0	0	0	1	17	1	34
Olimfalunia sp.	0	1	0	0	0	0	0	0	0	0	0	2	0	0
Krithe papillosa (BOSQUET)	0	0	0	0	0	0	0	0	0	0	8	19	10	8
Parakrithe dactylomorpha RUGGIERI	0	0	0	0	1	3	0	1	0	0	25	34	18	21
Semicytherura cf. *alifera* (RUGGIERI)	0	0	0	0	0	0	0	0	0	0	1	13	1	4
Cytheropteron cf. *alatum* SARS	0	0	0	0	0	0	2	5	2	0	2	9	3	12
Eucytherura sp.	0	0	0	0	0	0	0	2	0	0	0	23	1	20
Semicytherura sp.	0	0	0	0	0	0	0	0	0	0	0	3	0	1
Loxocorniculum hastatum (REUSS)	0	0	0	0	0	0	0	0	0	0	0	14	0	0
Loxoconcha punctatella (REUSS)	0	0	0	4	0	0	0	0	0	0	0	11	1	2
Loxoconcha cf. *parallela* MÜLLER	0	0	0	0	0	0	0	0	0	0	0	13	0	0
Paracytherois sp.	0	0	0	0	2	0	0	3	0	0	11	3	6	1
Xestoleberis margaritea (BRADY)	0	3	1	5	0	1	0	0	0	0	1	11	1	6
Xestoleberis cf. *glabrescens* (BRADY)	0	0	0	1	1	0	4	2	0	0	0	8	0	1
	0	**8**	**1**	**13**	**6**	**4**	**7**	**24**	**2**	**0**	**113**	**264**	**92**	**169**

Table 2 Lis

Samples from the Sveta Barbara locality contain vast quantities of planktonic foraminifera, but the important index species, particularly of the genus *Globorotalia* are missing. Other species of the genera *Orbulina* and *Globigerina*, which have wider stratigraphic ranges are more abundant.

Among the ostracods, the Badenian species *Cnestocythere lamellicostata* TRIEBEL and *Aurila haueri* (REUSS) are the most important (BRESTENSKA & JIŘÍČEK, 1978; RIHA, 1989; JIŘÍČEK & RIHA, 1991).

5. DISCUSSION

Recent research has shown that foraminifera and ostracods provide an excellent source of palaeoecological/ecological data (MURRAY, 1991; MAZZINI et al., 1999; ELEWA, 2004). This is partly due to their abundance, wide geographic distribution and the variety of environments where they can be found.

It is a known fact that their distribution depends on the interaction of a large number of abiotic and biotic ecological factors. Therefore, through detailed analyses

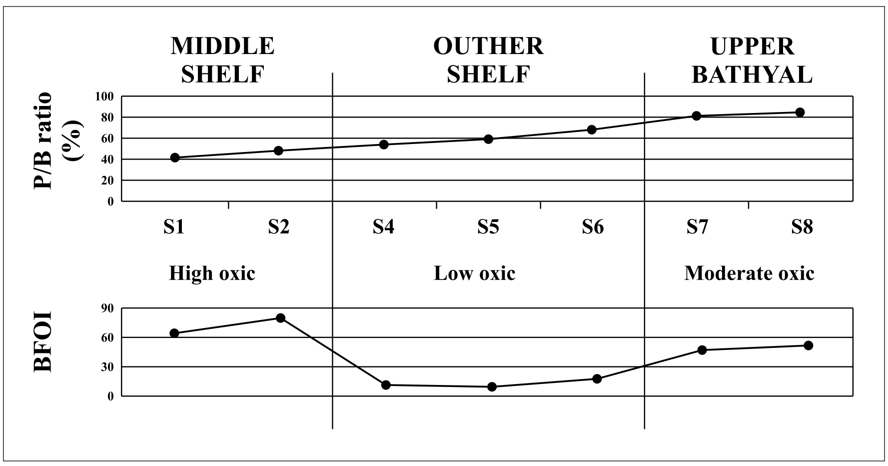

Fig. 4 Graphical trends of the planktonic/benthic ratio and Benthic Foraminiferal Oxygen Index.

	MIDDLE SHELF (S1–2)		OUTER SHELF (S4–6)		UPPER BATHYAL (S7–8)	
	range	average	range	average	range	average
FORAMINIFERA						
P/B ratio (%)	41.47–48.15	44.81	55.08–68.09	61.59	81.40–85.21	83.31
Number of species	35–49	42	16–26	21	31–37	34
*BFN	3124–3751	3438	5002–7452	6227	1586–2004	1795
Fisher α index	10.140–16.210	13.175	3.624–6.651	5.138	8.735–11.260	9.998
Shannon-Wiener index	2.936–3.147	3.042	1.902–2.586	2.244	2.743–2.982	2.863
Dominance	0.06161–0.07657	0.06909	0.09834–0.28860	0.19347	0.07603–0.09633	0.08618
BFOI	65.04–78.68	71.86	8.86–16.92	12.89	47.15–51.88	49.52
Oxic indicators (%)	25.24–34.52	29.87	4.58–11.49	8.04	20.00–23.39	21.69
Suboxic indicators (%)	56.13–61.20	58.67	32.09–60.61	46.36	54.92–57.59	56.26
Dysoxic indicators (%)	9.35–13.56	11.46	34.77–56.42	45.60	21.69–22.41	22.05
Infauna (%)	66.77–79.18	72.98	93.92–96.31	95.12	75.86–77.29	76.58
Epifauna (%)	20.82–33.23	27.02	3.69–6.08	4.88	22.71–24.14	23.42
Aglutinated (%)	2.22–3.54	2.88	0.30–0.33	0.32	2.00–2.02	2.01
Porcellanous (%)	2.20–2.91	2.56	0–0.64	0.32	1.67–1.68	1.68
Calcareouos (%)	93.55–95.58	94.56	99.05–99.67	99.36	96.30–96.33	96.31
OSTRACODA						
Number of species	3–5	4	1–9	5	16–21	19
*Ostracod Number	8–15	12	4–38	21	353–490	422

*specimens p.g.

Table 3 Mean values of planktonic/benthic ratio and different palaeoecological indicators of benthic foraminifera and ostracoda from various Late Badenian environments.

of foraminiferal and ostracod palaeocommunities, we can obtain data on the depth, temperature, salinity, amount of oxygen and quality of substrate in their palaeoenvironments (BONADUCE et al., 1975; VAN HARTEN, 1986; MURRAY, 2001; DE DECKKER, 2002; SMITH & HORNE, 2002).

5.1. Benthic foraminifera

In the analyzed samples, deep-water taxa of benthic foraminifera are present, but significant differences can be observed in the number of species and the variation in dominant and common species. Current research has shown that these differences in most cases reflect the changes in palaeobathymetry, or ecological stress, which is usually linked to shifts in the palaeoproductivity of ancient oceans and seas – changes in nutrient supply and quantity of oxygen in the bottom water (DEN DULK et al., 2000). JORISSEN et al. (1995) emphasize the important role that oxygen in pore water within the sediment has on the distribution of foraminifera in shelf and continental slope environments. It can be expected that the quality of the available diet (composition of nutrients) will change with decreased oxygen in the bottom water, which can be fatal for foraminifera with specialized feeding habits. In contrast, species tolerant of the lack of oxygen (opportunistic taxa), could benefit from the food supply, and become more abundant (VAN DER ZWAAN et al., 1999; MURRAY, 2001).

5.1.1. Middle shelf environment

Middle shelf environment is characterized by the maximum number of species, and significant numbers of specimens of benthic foraminifera in 1 g of sediment (Table 3). Values of Shannon–Wiener index and Fisher α index indicate a normal marine environment with high species diversity, while a rather low value of Dominance indicates the poorly expressed domination. Dominant species are *Cassidulina laevigata*, *Cibicidoides pseudoungerianus* and *Globocassidulina oblonga. C. laevigata* is typical for the inner–middle shelf environments (LOUBERE, 1996; MENDES et al., 2004). Researching the distribution and microniches of benthic foraminifera on the Southern Adriatic shelf DE STIGTER et al. (1998), noticed that *C. laevigata* abruptly decreases in number with increasing depth and decreasing food supply. The species *C. pseudoungerianus* and *G. oblonga* do not tolerate environmental stress, particularly reduced oxygen levels in bottom water (JORISSEN, 1999).

This community is characterized by the significant number of oxic indicators, such as *G. oblonga* and *C. pseudoungerianus* and suboxic indicators: *C. laevigata*, *Bulimina elongata*, *Fursenkoina acuta*, *Uvigerina semiornata*, *Nonion commune*, *Uvigerina venusta* and *Melonis pompilioides*. Disoxic indicators are less abundant (most common is *Bolivina dilatata*).

The high percentage of oxic indicators and epifaunal taxa within the community, as well as the high value of

SPECIES / SAMPLES	S1	S2	S4	S5	S6	S7	S8
FORAMINIFERA							
Bolivina dilatata	7.87	6.13	16.22	27.65	50.49	12.46	15.67
Chilostomella ovoidea	2.52	0.97	9.31	14.15	1.98	2.02	1.33
Globobulimina pyrula	2.20	1.29	6.91	4.50	2.64	2.36	1.33
Uvigerina venusta	4.73	1.94	8.11	2.57	4.95	14.14	8.00
Uvigerina semiornata	5.98	4.51	15.62	18.33	4.29	13.46	18.67
Uvigerina costatoides	1.89	2.26	0.90	1.61	1.65	4.04	5.33
Bulimina elongata	7.24	9.68	1.80	3.86	3.30	1.01	0.33
Fursenkoina acuta	6.62	3.87	0.60	1.29	0.99	0.34	0.67
Melonis pompilioides	4.10	2.91	6.31	1.93	2.97	6.40	7.67
Nonion commune	5.36	4.51	9.91	4.50	3.63	2.02	1.33
Cassidulina laevigata	11.66	15.17	7.81	5.47	6.94	0.67	0.67
Globocassidulina oblonga	9.78	10.66	2.70	1.29	5.61	4.38	7.67
Cibicidoides pseudoungerianus	9.46	13.23	0.90	2.57	5.61	6.73	9.66
OSTRACODA							
Argilloecia cf. *acuminata*						28.16	36.26
Parakrithe dactylomorpha						17.14	16.15
Henryhowella asperrima						3.88	10.20
Paracypris sp.						8.78	6.52
Krithe papillosa						7.14	7.93
Eucytherura sp.						4.69	6.23

Table 4 List of benthic foraminifera and ostracod species with a relative abundance greater than 5% in at least one sample.

BFOI (high oxic environment) indicate that the microfossil community of the middle shelf lived in a normally oxygenated environment, with plenty of food.

5.1.2. Outer shelf environment

Compared to the previous community, number of specimens in the samples from the outer shelf increases by almost 100%, while the number of species decreases (Table 3). Additionally, lower values of the diversity indicators, such as Shannon–Wiener index and Fisher α index, as well as the increase of domination indicate environmental changes and more stressful conditions. Typical species of middle shelf benthic foraminifera decrease in number, and the fauna is dominated by the species *B. dilatata*, *U. semiornata*, *Nonion commune* and *Chilostomella ovoidea*, which represent more than 54% of the entire benthic community.

This community consists of semi-equal numbers of suboxic indicators (*U. semiornata*, *N. commune*, *U. venusta*, *C. laevigata*) and disoxic indicators (*B. dilatata*, *C. ovoidea* and *Globobulimina pyrula*). Oxic indicators are present in minor quantities.

The predominance of suboxic and disoxic indicators indicate lower values of the oxygen content, compared to the middle shelf community. The presence of *B. dilatata* is significant as it is generally connected with poorly oxygenated environments (BERNHARD, 1986; SEN GUPTA & MACHAIN-CASTILLO, 1993). Some genera, including *Globobulimina* and *Chilostomella* are typical for low oxygen environments. They are common in the surface sediments of recent poorly oxygenated basins (SEN GUPTA & MACHAIN-CASTILLO, 1993), but they can also live several centimeters deep in oxygen poor subsurface sediments in open ocean environments (DE STIGTER et al., 1998; JORISSEN, 1999).

Oxygen depletion can be confirmed through a low value of BFOI (low oxic environment) and a decrease in the number of epifaunal biota within the benthic foraminiferal community, as well as lower species diversity, higher domination, and a reduced number of taxa. Furthermore, in this sample, the percentage of porcellaneous foraminifera is lower, and it is generally known that miliolids are sensitive oxygen indicators, being scarce, or completely absent in poorly oxygenated deep-water environments (DUIJNSTEE et al., 2004).

It is evident that in the open shelf Badenian environment at the Sveta Barbara locality, the amount of oxygen in the bottom water was decreased. The large number of specimens in the sediment can be explained by fast reproduction, due to the high amount of nutrients. It is generally known that the biomass, as well as the abundance of foraminifera, depends on the food supply. At the same time, the benthic biota must adapt to disoxic conditions, which are often a consequence of a large quantity of organic matter. Oxygen content in pore waters becomes the limiting ecological factor in such environments, and foraminiferal communities are mostly composed of taxa tolerant to disoxic conditions (DEN DULK et al., 2000).

5.1.3. Upper bathyal environment

In the upper bathyal environment, the number of specimens evidently decreases, but, at the same time, the number of species increases (Table 3). Dominant species are *U. venusta*, *U. semiornata* and *B. dilatata.*

Suboxic indicators are the dominant species in this community (*U. venusta*, *U. semiornata*, *Melonis pompilioides*). Oxic indicators (*C. psudoungerianus* and *G. oblonga*) and disoxic indicators (*B. dilatata*) are present in similar quantities.

A decrease in the typical disoxic indicators, followed by an increase in the oxic indicators, compared to the outer shelf community, indicates the increase of the oxygen content in this environment. This can be confirmed through the value of BFOI (moderate oxic environment), and the increase in the number of epifaunal biota within the community. Diversity is increased, domination is low, and there is a rise in the number of porcellaneous foraminifera within the community. Therefore, the upper bathyal community lived in a deeper, but better oxygenated environment, than the community from the outer shelf.

During the palaeoecological reconstruction of the Sveta Barbara profile, sample S3 should also be taken into consideration. This sample was taken from the lense of grey massive marl in the central part of the profile. In this sample only 14 specimens of poorly preserved and probably transported benthic foraminifera were found in 1 g of sediment. Considering the lithological data, these lenses could be blocks of older sediment transported from the palaeoshore or a submarine slide.

5.2. Planktonic foraminifera

The planktonic foraminiferal community is marked by a large number of specimens, but rather small number of taxa. The dominant species are *Globigerina bulloides* D'ORBIGNY, *Globigerina obesa* (BOLLI) and *Orbulina universa* D'ORBIGNY. *Globigerina regularis* D'ORBIGNY, *Globigerinoides trilobus* REUSS, O*rbulina suturalis* BRÖNNIMAN, *Globigerina* sp. and *Globigerinoides* sp. are also present. In samples from the upper shelf tests are smaller, but completely developed, thus indicating the more stressed ecological conditions in this environment.

5.3. Ostracoda

At the Sveta Barbara locality, a typical deep-water ostracod community was collected. In deep-water environments the dominant genera have thin, porous valves, with smooth surfaces. Hinges are in most cases weak, seldom with teeth, and these ostracods have no eyes (PEYPOUQUET, 1983; DALL'ANTONIA et al., 2003). Different species of the genera *Krithe*, *Parakrithe*, *Argilloecia* and *Paracypris* are very common, and several taxa with more ornamented valves are also present, belonging to genera such as *Eucytherura* and *Henryhowella*.

In the middle shelf samples several specimens of *Aurila haueri*, *Xestoleberis margaritea* and *Olimfalunia* sp., and in the outer shelf, a few specimens of *Paracytherois* sp., *Parakrithe dactylomorpha*, *Argilloecia* cf. *acuminata*, *Xestoleberis* cf. *glabrescens* and *Aurila haueri* occur.

The dominant species in the upper bathyal environment (Table 4) are *Argilloecia* cf. *acuminata*, *Parakrithe dactylomorpha* and *Henryhowella asperrima*. Common species include *Paracypris* sp., *Krithe papillosa*, *Paracytherois* sp. and *Eucytherura* sp. The genera *Argilloecia*, *Krithe*, *Parakrithe*, *Paracypris* and *Paracytherois* are typical representatives of deep-water ostracoda faunas, in most cases appearing below 100 m depth, while the genus *Eucytherura* usually lives below 50 m, but has been also found at depths over 1000 m (SZCECHURA, 1994). *Argilloecia acuminata* has a maximum abundance below 170 m in the Adriatic Sea (BONADUCE et al., 1975; CIAMPO, 2003).

Although the recognition of transported valves is not easy, allochtonous specimens, originating from shallow water environments, can be clearly separated from the autochthonous ostracod community. Bottom streams can be an important mode of transportation. Post-mortal transport of benthic biota is well known. Autochthonous and allochthonous ostracod communities in general can be distinguished by population structure (VAN HARTEN, 1986). The autochthonous community contains adult specimens and numerous larval stages. Larval stages, without adult valves, indicate transport, while the lack of larval stages in the community does not necessarily mean that the valves were transported, but can be a consequence of selective fossilization (POKORNY, 1984). In the samples from the upper bathyal environment, the allochtonous ostracod community is represented by about 20% of the total specimens. It is mostly composed of larval stages and scarce adult specimens of shallow-marine genera *Aurila*, *Semicytherura*, *Loxoconcha*, *Xestoleberis*, *Callistocythere*, *Urocythereis* and *Olimfalunia*, with broken and/or abraded valves. Generally, such mixed ostracod communities are typical for steep continental margins (ELEWA, 2004).

In contrast, the deep-water community contains adult specimens and larvae with well preserved complete carpaces (ca. 30%), thus indicating rather slow sedimentation. The complete/separated valve ratio is a very useful indicator of sedimentation rate (WHATLEY, 1983). Laboratory experiments have shown that only a few hours after death, ostracod valves are separated, due to intensive bacterial activity (POKORNY, 1984). In basins with rapid deposition, most of the complete carpaces sink deep enough into the sediment, so after decomposition of the muscles and ligaments carpaces remain complete.

6. CONCLUSION

At the Sveta Barbara locality Miocene deposits contain a rich microfossil community in which foraminifera are the most abundant fossils with 36 benthic genera (49 species), and 4 planktonic genera (9 species). Ostracods are represented by 18 genera (21 species).

The studied sediments can be attributed to the Bulimina–Bolivina Zone of the Late Badenian (Middle Miocene), due to the presence of some index fossils including *P. neudorfensis* and *U. bellicostata*, as well as the Badenian ostracod taxa *Cnestocythere lamellicostata* and *Aurila haueri*.

Variations in foraminiferal and ostracod communities can be traced along the studied section, as well as significant changes in the number of specimens and taxa. Three different environments can be distinguished: middle shelf, upper shelf and upper bathyal. Along with the typical deep-water species, specimens of benthic taxa transported from the shallow-water environment can be clearly observed in the outer shelf and upper bathyal environments.

High species diversity, average domination and significant abundance of oxic indicators and epifaunal taxa indicate the well oxygenated and nutrient rich middle shelf palaeoenvironment. Dominant species are: *Cassidulina laevigata*, *Cibicidoides pseudoungerianus* and *Globocassidulina oblonga*.

The microfossil community of the outer shelf lived in a less oxygenated environment than the community from the middle shelf. This can be concluded from the following features: higher abundance of suboxic/disoxic indicators, particularly the species *Bolivina dilatata*, *Chilostomella ovoidea* and *Globobulimina pyrula*, higher presence of infaunal taxa, significantly smaller number of species, but larger number of specimens of benthic foraminifera, lower species diversity and more prominent domination as well as the smaller percentage of porcellaneous foraminifera. A large number of specimens indicates the optimal environmental conditions for taxa tolerant to the low-oxygen content in the bottom water.

Upper bathyal communities are characterized by an increase in diversity, and a decrease in the number of disoxic indicators, which shows that they lived in a deeper, but better aerated benthic environment than the open shelf community. Dominant taxa are *Uvigerina venusta*, *Uvigerina semiornata* and *Bolivina dilatata*.

Ostracod specimens are scarce and relatively poorly preserved in the middle and outer shelf, while the upper bathyal ostracod community is very rich, with well-expressed dominance of species *Argilloecia* cf. *acuminata* and *Parakrithe dactylomorpha*.

Our study has shown that the increase in depth of the depositional basin, and oscillations of oxygen content in bottom water, were the dominant factors influencing the composition and abundance of microfossil communities in this area.

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