Geologia Croatica	63/3	259–269	3 Figs.	2 Tabs.		Zagreb 2010

Evidence for Badenian local sea level changes in the proximal area of the North Croatian Basin

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doi: 104154/gc.2010.21

Geologia Croatica

ABSTRACT

Quantitative analysis of palynomorphs, foraminifera and ostracods enabled the recognition of biotic events and the reconstruction of environmental change in the Badenian sediments from the Vrhovčak section of Mt. Samoborsko gorje (NW Croatia). During the Middle Miocene the investigated area of Mt. Samoborska gora was located at the south-western margin of the North Croatian Basin, which represents the south-western edge of the Pannonian Basin System and the Central Paratethys Basin. This marginal position within the basin controlled the specific evolution of the depositional area during the Badenian. The occurrence of coal bearing horizons and freshwater flora and fauna in the middle part of the Vrhovčak section provide new data for the reconstruction of Badenian palaeoenvironments. A fall in sea level and the probable isolation of this area in the Badenian seems to be responsible for the appearance of a new fauna and flora.

The marine sediments from the base of the Vrhovčak section may be correlated to cycle TB 2.4 of the main Badenian transgression, which affected the entire Central Paratethys area. This was followed by a regression and lowstand (Ser2), which, correlated to the middle part of the section, with freshwater sediments and coal bearing horizons. The upper part of the Vrhovčak section with marine sediments represents the Late Badenian cycle TB 2.5.

Keywords: Miocene, Badenian, North Croatia Basin, Coal bearing horizons, palaeoecology, biostratigraphy

1. INTRODUCTION

New results obtained during investigation of the Vrhovčak section, located about 2 km west of the town of Samobor, at the eastern end of Mt. Samoborsko gorje are presented. During the Middle Miocene, the investigated area of Mt. Samoborsko gorje was located at the south-western margin of the North Croatian Basin, which represents the south western edge of the Pannonian Basin system and Central Paratethys See (Fig. 1). Formation of the North Croatian Basin was connected with passive continental rifting. A syn-rift phase began during the Ottnangian and lasted until the Middle Badenian. The post-rift phase lasted from the Middle Badenian to the Pliocene (PAVELIĆ, 2001). This positioning within the basin controlled the specific evolution of the studied depositional area during the Miocene.

Miocene sediments are most commonly in tectonic contact with Mesozoic carbonates, and less often with Paleogene rocks which constitute a major part of the core of Mt. Samoborsko gorje (ŠIKIĆ et al., 1979; VRSALJKO et al., 2005). The overlying strata consist of Neogene deposits that belong to the Ottnangian?, Late Badenian, Sarmatian and Early and Late Pannonian. Following the Badenian transgression, Mt.

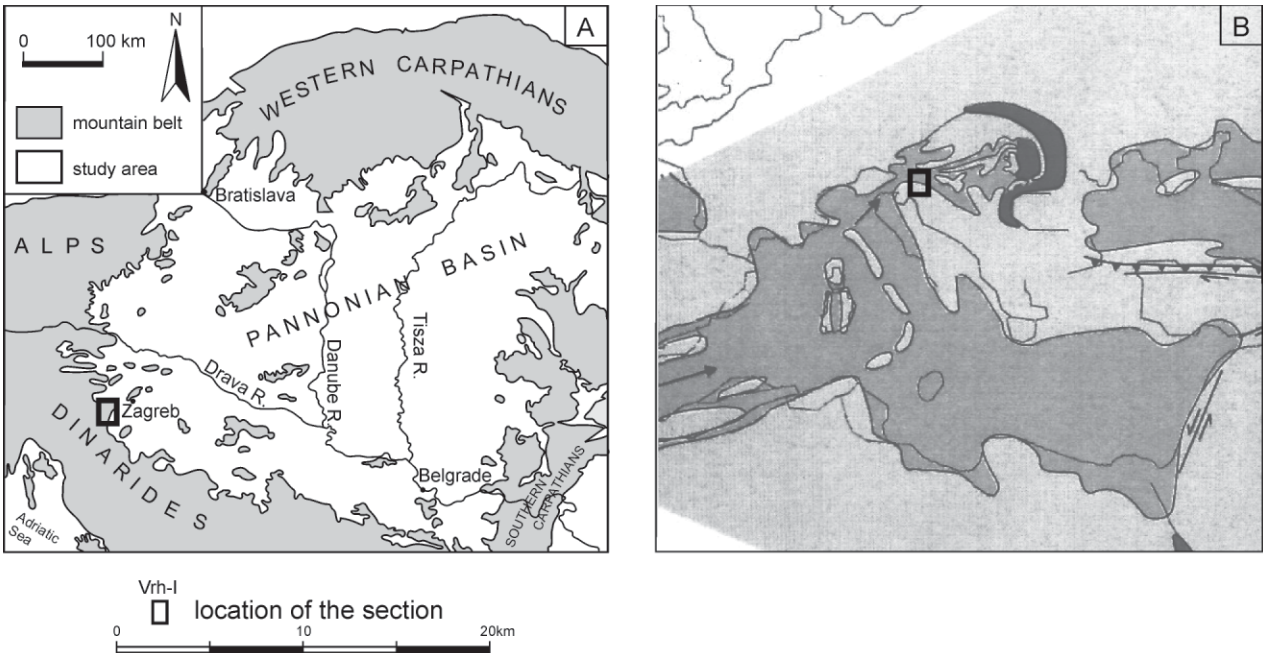

Figure 1: Location map of investigated section Vrhovčak. A) Geographic location, B) Paleoeographic situation in Middle Badenian, RÖGL (1998).

Samoborsko gorje was submerged, which resulted in a very variable palaeo-relief. This contributed to the contemporaneous deposition of an assortment of different sedimentary facies. Apart from breccia and conglomerate deposits, biogenic limestone developed at reefs and the edges of reefs (ŠIKIĆ et al., 1979). Marls were deposited in the shelf environment, while silty marls with coal intercalations represent estuarine deposits. According to the geological map (ŠIKIĆ et al., 1979) Late Badenian sediments occur along the northern and southern sides of Samobor. On the northern side, which includes the studied Vrhovčak section, Badenian sediments appear as erosional remains. However, on the southern side these sediments extend as strip zones up to 4 km in length. Biogenic limestones and marls constitute the main parts of these deposits which are rich in macro and micro fossils. In this strip zone, Sarmatian and Pannonian sediments continuously overlie Late Badenian sediments. These younger sediments are absent on the northern side of Samobor.

The investigated locality has previously been known as Zaprešić-brijeg in publications, and had been described as a rich community of mollusc fauna. The Vrhovčak outcrop represents a geological section with clearly visible, horizontally bedded, sandy limestones, clastic silty marls with coal intercalations in the middle part, and bioclastic limestones in the upper part of the profile.

The first paper dealing with the deposits of Zaprešić-brijeg was published by GORJANOVIĆ- KRAMBERGER (1894, 1896). Based on faunal remains, he compared them with the deposits of "Grund" layers in the Vienna Basin, which were older and assumed to belong to the "Helvetian". The "Grund fauna", originally defined in Austria, was developed during the early Middle Miocene and was widespread within the entire Central Paratethys (HARZHAUSER et al., 2003). Later, ŠUKLJE (1929) undertook a detailed investigation of the fauna from this location and compared it to the Helvetian fauna from Switzerland and the Vienna Basin, which confirmed the results of Gorjanović- Kramberger. PAVLOVSKI (1957, 1960) revised and determined the rich community of molluscs from Zaprešić-brijeg, which is archived in the Samobor museum. She concluded that the fauna from the Zaprešić-brijeg matched the "Grund" fauna, however the age of the fauna is not "Helvetian", but rather belongs to the Early "Tortonian" sensu KOCHANSKY (1944), (Early Badenian). BAJRAKTAREVIĆ (1978) studied the microfossils of Mt. Samoborsko gorje, and documented the existence of Badenian sediments at many localities. In the Basic Geological map ŠIKIĆ et al., (1979) assigned these deposits as did GORJANOVIĆ-KRAMBERGER (1894, 1896), to the "Helvetian" (Ottnangian). VRSALJKO (2003) on the basis of a rich molluscan community from Žumberak Mt. and the Samoborsko Gorje Mts., suggested the zonal distribution of Miocene sediments. In the Grdanjci unit, gravels, silts, and coal intercalations probably represent the products of terrestrial deposition immediately before the Late Badenian transgression, but deposits weren't biostratigraphically investigated in detail. These are special features of this unit as such sediments are not present in other units of Žumberak Mt. and the Samoborsko Gorje Mts. (VRSALJKO et al., 2005).

This paper deals with integrated micropalaeontological and petrographic analyses of the Vrhovčak section, and provides new results regarding the biostratigraphy and palaeoecology of the investigated sediments. Three microfossil groups are present in the sediments in varying abundance: foraminifera, ostracods and palynomorphs (organic walled dinoflagellate cysts or dinocysts, prasinophytes, chlorophycean algae, spores and pollen).

2. STUDY SITE AND METHODS

2.1. Study site

The Vrhovčak section is located on the eastern slopes of Mt. Samoborsko gorje (GPS N45°48’33”, E15°41’22”), in the vicinity of an access road to local vineyards. The total thickness of the Vrhovčak section is around 7.8 m (Fig. 2).

The lowermost part of the section, where the first sample was taken, has a thickness of 0.45 m and consists of clayey-sandy silt, rich in fossil shell fragments and plant remains. The second layer is 1.90 m thick and is composed of biocalcilutites and calcarenites. Samples 2–5 inclusive, were collected from this second layer. Rich microfossil assemblages have been discovered and determined in most of these samples. In the middle part of the section, within a total thickness of 1.20 m, silty marls rich in floral and faunal remains are intercalated with coal layers. Samples 6–9 were collected from these coal-marl layers. Clayey limestones with fossil shell fragments occur in the next 0.40 m (sample 10), after which a 1.50 m thick portion of the section is unexposed. The last investigated sample 11 was taken from the uppermost part of the Vrhovčak section which consists of a clayey limestone 1.80 m thick.

2.2. Methods

For the micropalaeontological investigation the collected samples were disaggregated by soaking in a hydrogen peroxide solution for 24 hours, then washed through sieves (0.5; 0.25; 0.125; 0.063 mm) and dried. Some of the samples needed extra cleaning and were soaked again in hydrogen peroxide and treated ultrasonically for approximately 20 seconds. 100 g of each dried residue was observed under a stereomicroscope. Foraminifera, ostracods and other remains (gastropods, shells, otoliths) were hand-picked, counted and determined. Ostracods were picked qualitatively but not selectively, in order to preserve the relative composition of the thanatocenosis.

Standard palynological processing techniques (FAEGRI & IVERSEN, 1989; MOORE et al., 1991) were used to extract the organic matter. The samples were treated with sodium pyrophosphate ($Na_4P_2O_7$), HCl (15%), and HF (40%), removing clay minerals, carbonates and silica, followed by separation of the organic residue by means of $ZnCl_2$ (density>2.0). The residue was sieved at 10 µm using a nylon mesh, mixed with glycerin, and mounted on microscope slides. Slides were counted using an Olympus BH-2 transmitted light microscope at ×400, ×600 and ×1000 (oil immersion), magnifications combined with the interference contrast. A fluorescence technique was used in order to distinguish reworked palynomorphs. Whole slides were counted for palynomorphs. A minimum of 300 palynomorphs (*Pinus* and indeterminable Pinaceae excluded) was counted in each sample, if possible. The residues were stored and mounted in silicone oil. Photos were taken using a Moticam 2300. Botanical identification of the pollen grains was carried out and a pollen diagram (Fig. 3) plotted using the software C2 Version 1.5 (JUGGINS, 2007).

Thin sections of collected rock samples were prepared and their composition was determined using a polarization microscope.

The 0.09–0.045 mm mineral fraction was separated from the sandy and silty sediments and used for modal analysis after carbonate removal with 4 % cold hydrochloric acid.

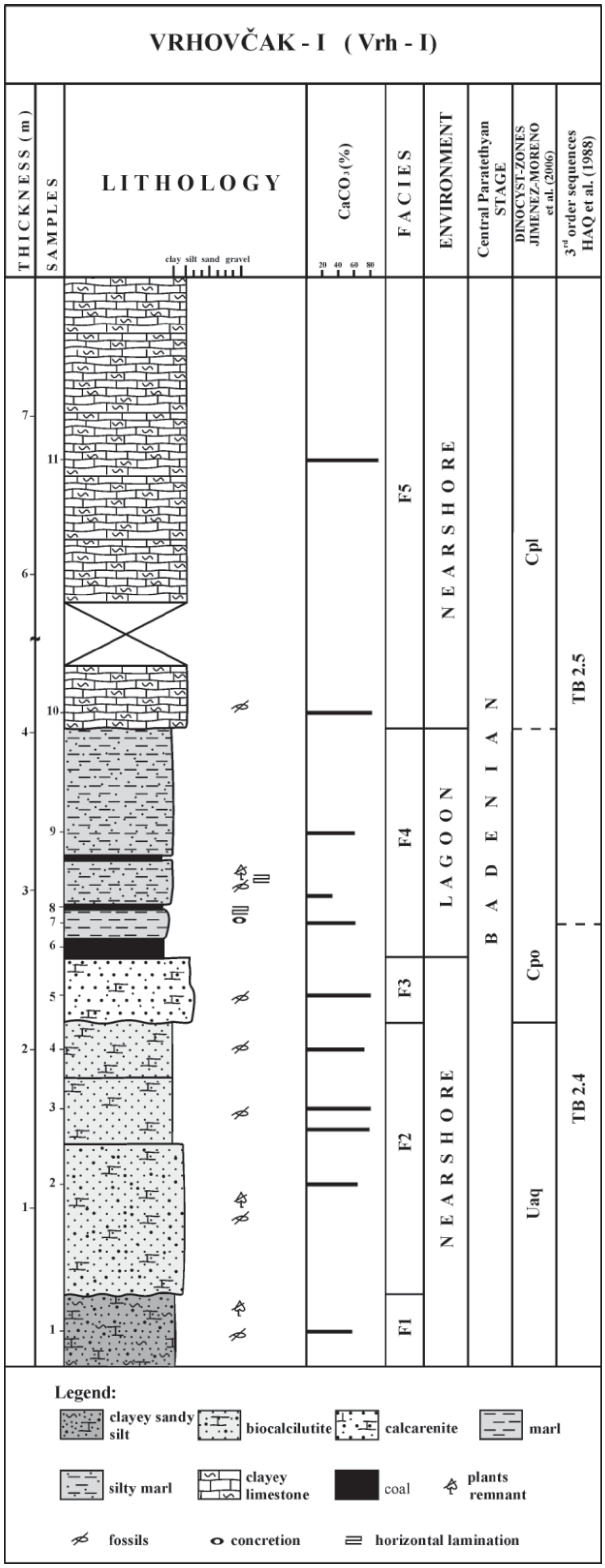

Figure 2: Stratigraphical log of the Vrhovčak section.

Qualitative and quantitative analyses were performed by determination of 300–400 grains per sample using the ribbon counting method according to MANGE & MAURER (1992).

The $CaCO_3$ content was determined using a Collinson calcimeter (HEAD, 1992).

X-ray powder diffraction (XRPD) patterns were recorded using a Philips vertical X-ray goniometer (type X`Pert) equipped with Cu tube, with the following experimental conditions: 45 kV, 40 mA, PW 3018/00 PIXcel detector, primary beam divergence 1/4°, continuous scan (step 0.002 °2θ/s).

The sediment samples, palynological residue and slides are stored in the collection of the Croatian Geological Survey, Department of Geology, Zagreb, Croatia, under the collection number Vrh-2009.

3. RESULTS AND DISCUSSION

3.1. Sediment description

Based on macroscopic observations, thin section, modal and granulometric analyses and carbonate content, five lithofacies were distinguished in the investigated Vrhovčak section: clayey-sandy silt facies, biocalcilutite facies, calcarenite facies, silty marl facies with intercalated coal remains and clayey limestone facies.

Clayey-sandy silt facies (F1) (sample 1) is 0.45 m thick and is located at the base of the investigated section. It consists of poorly sorted silt with 20% clay and 20% sand content. Calcite (60%) dominates the mineral composition. Quartz is the second most abundant mineral, followed by lithic fragments and feldspar. Among the heavy minerals, the most abundant is dolomite, followed by opaque minerals (pyrite). Translucent heavy minerals are sparse, only a few grains of tourmaline, rutile and epidote were determined.

Biocalcilutite facies (F2) (samples 2−4) is 1.50 m thick and overlies F1. The calcilutite is weakly lithified and in its lowermost part is enriched with sand. The carbonate content ranges from 65% – 80%. Besides calcite, the most dominant minerals are dolomite and quartz. Potassium feldspars and lithic fragments are represented in smaller amounts. The biocalcilutite is composed of recrystallized microsparite with benthic foraminifera, shell fragments and annelids.

Calcarenite facies (F3) (sample 5) is 0.40 m thick and can be observed in the middle part of the section. It is weakly lithified and poorly sorted. Calcite (around 80%) predominates.

Marl facies with intercalated coal remains (F4) (samples 7 and 9) is represented in the middle part of the section. It is 120 cm thick. In its lower part the marl has a carbonate content of around 60%, while in the middle and upper part it is enriched in silt, with 30% – 60% carbonate, predominately aragonite, while calcite can be found in smaller amounts. In the lower part of this facies, a few cm thick coal layers are visible.

Clayey limestones facies (F5) (samples 10, 11) represents the uppermost 3.70 m of the section. Microscopically, the sediment can be described as a weakly lithified clayey

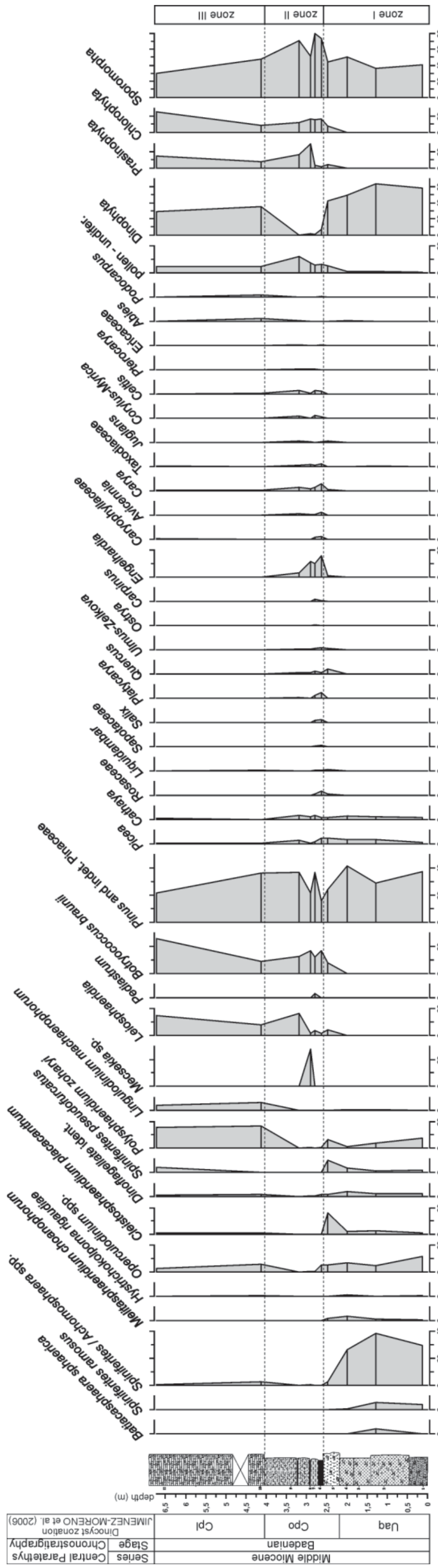

Figure 3: Palynomorphs distribution in the Vrhovčak section.

microsparite. Recrystallized foraminifera and shell fragments, as well as carbonate grains, were recognized inside the recrystallized microsparitic matrix. The origin of the carbonate grains cannot be determined. Siliciclastic detrital grains (quartz, quartzite and feldspars) are less abundant and of silt size dimensions.

3.2. Palynomorphs

Palynomorphs were recorded in all the studied samples, but their preservation varies from poor to good. Changes in palynomorph assemblages through the studied section (Fig. 3) allow the definition of three local zones. Generally, the dinocyst assemblages dominate in the lower part (samples 1–5) and in the upper part (samples 10–11). The middle part (samples 6–8) is dominated by sporomorphs and chlorophycean freshwater algae (*Botryococcus* and *Pediastrum*), and sample 9 by prasinophycean algae indicating environmentally unfavourable conditions for most dinoflagellates.

Lower part of Zone I (facies F1-F2; samples 1–4) is marked, beside *Spiniferites/Achomosphaera* spp., by *Batiacasphaera sphaerica* STOVER and *Spiniferites ramosus* (EHRENBERG) MANTELL, indicating a deeper marine environment. This part of the section could be correlated with the Uaq zone – *Unipontidinium aquaeductum* (JIMENEZ-MORENO et al., 2006). It should be noted that assignment to this zone is considered most likely, although such index fossils as *Unipontidinium aquaeductum* and *Labyrinthodinium truncatum* are absent.

The species diversity of the dinoflagellate cysts decreased substantially, indicating a regression (local sea level was lowered), which resulted in unfavourable conditions for the dinoflagellate community. The Upper part of Zone I (facies F3; sample 5) is marked by *Cleistosphaeridium placacanthum* (DEFLANDRE & COOKSON) EATON et al., *Spiniferites pseudofurcatus* (KLUMPP) SARJEANT and *Polysphaeridium zoharyi* (ROSSIGNOL) BUJAK et al., reflecting a neritic environment.

Dominant species in Zone II are *Pinus*, chlorophycean algae *(Botryococcus, Pediastrum*) and palynomorphs of unknown origin - similar to Type 303 (VAN GEEL et al., 1981) or *Mecsekia* sp. (but without spines). Coal sediments (lower part of facies F4), from which samples 6 and 8 were taken, are of a sapropel type. Organic matter is dominated by amorphous liptinite and algae, while spores and phytoclasts generally aren't represented, which excludes a terrestrial swamp origin for the coal. Sample 6 are dominated by *Botryococcus*, but *Engelhardia* pollen is also numerous, indicating evergreen forest in the vicinity. A few marine dinocysts (*Operculodinium* spp.) suggest some marine influence. Therefore, it can be concluded that the deposits which belong to samples 6 and 8 were deposited in a quiet closed lagoon under the influence of marine and fresh water, but without the influence of tides and underwater currents. Sea level then dropped further. Chlorophycean freshwater algae *Pediastrum* (abundant in sample 7), indicate that between the coals, deposition occurred within a freshwater lake, possibly more than 7m deep, with higher pH, and nutrient loading (TYSON, 1995). The following plant ecosystems can be distinguished in the pollen data (based on JIMÉNEZ-MORENO, 2006): a coastal marine environment (characterized by the presence of an impoverished mangrove composed of *Avicennia*, mainly accompanied by halophytes - such as Chenopodiaceae); broad-leaved evergreen forest (*Engelhardia,* Taxodiaceae and Sapotaceae); evergreen and deciduous mixed forest (*Quercus, Engelhardia, Platycarya, Carya, Pterocarya, Liquidambar, Carpinus, Celtis* and *Acer*); riparian vegetation (*Salix, Alnus, Carya, Carpinus, Zelkova, Ulmus* and *Liquidambar*); a shrub layer (Ericaceae); mid-altitude deciduous and coniferous mixed forest (*Cathaya* and *Cedrus*) and coniferous forest (*Abies* and *Picea*). Evergreen trees such as *Engelhardia*, typical of present day rain and evergreen forest at low altitudes, indicates a subtropical climate - Miocene climatic optimum (JIMÉNEZ-MORENO, 2006). Local influences cannot be ruled out, but it seems possible that lowstand Ser2 of HARDENBOL et al., (1998) between global cycles TB 2.4 and TB 2.5 (sensu HAQ et al., 1988) can be seen in this part of the investigated section. KOVÁČ et al. (2007) very roughly correlate the Early (and "Middle") Badenian with the global sea-level changes of the TB 2.3 and TB 2.4 cycles. The TB 2.5 cycle can be regarded as Late Badenian in age. PAVELIĆ (2005) also correlate the Lower Badenian NCBC 3 cycle with TB 2.3 and TB 2.4 cycles, and the Late Badenian NCBC 4 cycle with the TB 2.5 cycle. A regional unconformity between syn-rift and post-rift deposits could be a consequence of closure of the seaway to Mediterranean in the middle Badenian, and can be correlated with sea-level fall at the end of the TB 2.4 cycle (PAVELIĆ, 2005).

Sample 9 (from the upper part of facies F4) is barren of dinocysts, while prasinophycean algae (especially *Leiosphaeridia*) are abundant. Prasinophytes are most abundant in the absence of other plankton (TAPPAN, 1980), and are commonly reported to be associated with distinctive water-column features. These usually include low temperature, enhanced productivity and a stratified water column, exhibiting brackish or low-salinity surface waters, overlying low oxygen to anoxic bottom waters (TYSON, 1987). The dominance of prasinophyte algae has also been recorded from some restricted lagoon and shallow water carbonate facies (TYSON, 1995). The late Badenian is characterized by stratification of the water column as indicated by the deposition of dysoxic pelites in basinal settings over the entire Central Paratethyan area (HUDÁČKOVÁ et al., 2000). Even the platforms became affected by repeated hypoxic events as documented by SCHMID et al., (2001). HARZHAUSER & PILLER (2007) correlate this event with global cycle TB 2.5 (sensu HAQ et al., 1988). Probably, such conditions affected the investigated area, because foraminifera are already present, whereas conditions were unfavourable for dinocysts. Dinocysts occur in samples 10 and 11, but only a few euryhaline species that are tolerant of lower salinity and water column stratification. Prasinophycean algae (especially *Leiosphaeridia*) are still present. The dominant dinocyst species in Zone III (facies F5; samples 10–11) is *Polysphaeridium zoharyi* (ROSSIGNOL) BUJAK et al., indicating a warm tropical/subtropi-

Table 1: Distribution of the foraminiferal species within the samples of the Vrhovčak section.

Species / Samples	1	2	4	5	6	7	8	9	10	11
Ammonia cf. *tepida* (Cushman)				x			x			
Ammonia pseudobeccarii (Putrja)	cf		cf	x		x		x		x
Ammonia viennensis (d'Orbigny)	x	x	x	x		x	x	x	x	x
Angulogerina angulosa (Williamson)	x	x	x							x
Asterigerinata planorbis (d'Orbigny)	x	x	x	x						x
Aubignyna sp.				x					x	
Biapertorbis biaperturatus Pokorny	x	x	x	x						x
Bitubulogenerina reticulata Cushman	x	x	x							x
Bolivina cf. *sagitulla* Didkovskiy	x	x	x	x					x	x
Bolivina dilatata Reuss	x	x	x							x
Bolivina fastigia droogeri Cicha & Zapletalova	x	x	x							x
Bolivina matejkai Cicha & Zapletalova	x	x	x							
Bolivina papulata Cushman	x	x	x	x						x
Bolivina plicatella Cushman	x	x	x						x	x
Bolivina pokornyi Cicha & Zapletalova	x	x	x	x						x
Bolivina pseudoplicata Heron-Allen & Earland	x	x	x	x			x	x		x
Buccella granulata (Di Napoli)	x	x	x							
Bulimina aculeata d'Orbigny	x	x	x							x
Bulimina elongata d'Orbigny	x	x	x	x						
Cancris auriculus (Fichtel & Moll)	x		x							x
Cassidulina laevigata d'Orbigny	x	x	x							x
Coryphostoma digitalis (d'Orbigny)	x	x	x							
Cycloforina badenensis (d'Orbigny)			x	x		x			x	x
Cycloforina contorta (d'Orbigny)			x	x		x			x	x
Elphidium cf. *reussi* Marks				x			x	x		x
Elphidium macellum (Fictell & Moll)	x	x	x	x				x		x
Elphidium rugosum (d'Orbigny)	x	x	x							x
Globulina gibba d'Orbigny		x	x			x				x
Globulina spinosa d'Orbigny	x	x	x	x						
Hanzwaia boueana (d'Orbigny)	x	x	x	x				x		x
Heterolepa dutemplei (d'Orbigny)	x	x	x	x				x	x	x
Islandiella punctata (Reuss)	x	x	x							x
Lenticulina inornata (d'Orbigny)	x	x	x							
Lobatula lobatula (Walker & Jacob)	x	x	x							x
Nonion commune (d'Orbigny)	x	x	x	x			x	x	x	x
Nonion tumidulus Pishvanova				x			x	x		
Nonionides sp.				x						x
Porosononion granosum (d'Orbigny)	x	x	x							x
Quinqueloculina akneriana d'Orbigny				x		x			x	x
Reussella spinulosa (Reuss)	x	x	x	x					x	x
Rosalina spp.	x	x	x							
Sinoloculina consobrina (d'Orbigny)	x	x	x	x					x	
Texstularia gramen d'Orbigny		x	x							
Trifarina bradyi Cushman	x	x	x	x						
Virgulopsis tuberculatus (Egger)	x	x	x	x						

cal setting with sub-normal salinity. *P. zoharyi* has been recorded from subtropical and tropical regions, generally in coastal sites near upwelling cells and river mouths. The highest relative abundances have been found in tropical low-salinity areas, where this species can dominate the associations (MARRET & ZONNEVELD, 2003). *Lingulodinium machaerophorum* (DEFLANDRE & COOKSON) WALL is considered to be a temperate to tropical, coastal species distributed within a very broad salinity range (from brackish to fully marine environments). Blooms of *L. polyedrum* can be related to high nutrient input and warm, stratified surface water conditions (MARRET & ZONNEVELD, 2003). Because of the only ecological character of this assemblage, this zone couldn't be correlated with any palynostratigraphic zones. Decreasing salinity and water depth caused loss of diversity.

Thermophilic dinoflagellate species such as *L. machaerophorum, P. zoharyi*, and *M. choanophorum*, indicate subtropical conditions for the lower and upper part of the section (MARRET & ZONNEVELD, 2003). Also, pollen of thermophilous evergreen trees such as *Engelhardia* suggest a subtropical climate. Fluvial systems occurred along the coastline, transporting both terrestrial pollen grains and freshwater algae out to the marine depositional area.

Based on palynomorphs, the Vrhovčak section could be correlated with the Hidas-53 core in Hungary. The middle part of the Hidas-53 borehole (Hidas Lignite Formation) is considered as Middle Badenian in age. The lower part of the succession (limestone) contains mostly marine plankton with less sporomorphs. Further upwards there are lignite beds with freshwater algae. Pollen of subtropical swamp forest dominates the sample above the lignite. Microforaminifera reappear at the top, indicating a transgression. The maximum temperature was 20°C, minimum 13.6°C, mean 17.2°C (NAGY, 2005). Similar results are presented in JIMÉNEZ-MORENO (2006) where vegetation from the Hidas-53 core is compared with present day floras of SE China. He also explained that the reduction in thermophilous plants and increase of mesothermic–deciduous and altitude trees as represented in the pollen spectra, could be caused by northward drifting of the Euroasiatic plate, and the modification of the ocean heat transport from an antiestuarine situation to estuarine conditions in Paratethys.

Formation of the lagoon or bay is also documented in the SW part of Medvednica Mt. as a consequence of the proximity of the Dinarides (representing land), while an open marine environment existed in the NE, closer to the central part of Central Paratethys (AVANIĆ et al., 2003; VRSALJKO et al., 2006; ĆORIĆ et al., 2009).

3.3. Foraminifera

The lower part of the Vrhovčak section (samples 1, 2 and 4) contains Badenian benthic foraminiferal assemblages in which the prevailing species are *Ammonia viennensis* and *Nonion commune* (Tab.1). In sample 4, the common species are *Heterolepa dutemplei*, *Hanzawaia horčici* and the agglutinated species *Textularia gramen*.

Other species are represented by only a few individuals. In sample 5, the diversity of benthic foraminifera decreases in relation to the first three samples, but new species appear such as *Ammonia pseudobeccarii*, *A.* cf. *tepida, Nonionides* sp.*, Nonion tumidulus* and *Aubignyna* sp. (sensu RUPP, 1986). Poorer foraminiferal assemblages were discovered in samples 7-9. Sample 10 features an increasing number of species and individuals (especially *A. viennensis* and *N. commune*). However, in sample 11, assemblages with higher diversity and quantities of benthic foraminifera occur (especially *A. viennensis* and *Cancris auriculus*). In samples 1, 2, 4 and 11 only a few individual planktonic foraminifera were observed including: *Globigerinoides trilobus* (REUSS), *Globoquadrina* cf. *altispira* (CUSHMAN & JARVIS), *Globigerinella* cf. *obesa* (BOLLI), *Globorotalia bykovae* (AISENSTAT), *Tenuitellinata* sp. and *Orbulina suturalis* BRONNIMAN. The foraminiferal assemblages in samples 1, 2, 4 and 11 are characterized by *Ammonia viennensis, Nonion commune*, *Heterolepa dutemplei, Lobatula lobatula, Porosononion granosum*, *Elphidium*-group and miliolid species. According to RÖGL & SPEZZAFERRI (2003) and SPEZZAFERRI (2004), this assemblage is characteristic of shallow water environments. In addition, the *Ammonia* group and the species *Nonion commune* are resistant to reduced salinity according to RUPP (1986) and WENGER (1987). Samples 1, 2, 4, 10 and 11 display rich assemblages. We can conclude that the sediments of Vrhovčak were deposited in a shallow water environment; eventually the species of *Ammonia* and *Nonion* group had been transported from the shallow part to the inner part of the shelf with tiny benthic foraminifera (Table 1). Reduced foraminiferal assemblages in samples 7–10 consist of *Ammonia, Nonion, Aubignyna* and miliolids which indicate a reduction in salinity (RÖGL, 1998). Freshwater ostracods have also been detected in these samples.

The assemblages of benthic foraminifera in the samples from the Vrhovčak section belong to the Badenian. Considering that planktonic specimens are rare and foraminifera such as *Uvigerina* and lagenids, that characterize deeper environments and are zone markers of the Badenian layers in the Paratethys (GRILL, 1941; PAPP & TURNOVSKY, 1953; PAPP et al., 1978) have not been found, it is difficult to determine the chronostratigraphy of the studied section in more detail. Although the presence of *Orbulina suturalis* BRONNIMAN in sample 1, confirmed that the investigated deposits are younger than 14.74 Ma (based on RÖGL et al, 2008) or even 14.56 Ma (based on HOHENEGGER et al, 2009).

3.4. Ostracods

Ostracods were studied in ten samples from the Vrhovčak section. Altogether, 29 species belonging to 22 genera were identified. One genus and five species remain in open nomenclature. The complete fauna is listed in Table 2.

The maximum numbers of species (14) was discovered in sample 4. Sample 7 also had a relatively high number of species (10). In samples 1, 5, 10 and 11, the number of species varies between 5 and 9. Two samples, (2 and 9) each

Table 2: Distribution of the ostracod species within the samples of the Vrhovčak section. Only adult valves for each species in the samples were counted: ○ 1-5, ⊙ 5–10, ◉ 10–20, ● 20–50.

Ostracod species / Samples	1	2	4	5	6	7	8	9	10	11
Aurila angulata (Reuss)	⊙		⊙		no ostracods					○
Aurila cicatricosa (Reuss)			○							
Aurila cf. *galeata* (Reuss)			⊙							
Aurila haueri (Reuss)	○		⊙			○				
Aurila punctata (Münster)			⊙						○	
Aurila sp.										○
Carinocythereis carinata (Roemer)			○	⊙		○			⊙	
Cnestocythere lamellicosta Triebel			○							
Costa edwardsi (Roemer)									◉	
Cytherella compressa (Münster)										○
Cytheridea acuminata Bosquet		●	●	●			○	○	●	◉
Nonurocythereis seminulum Seguenza						○				
Hermanites haidingeri (Reuss)			○							
Loxocorniculum hastaum (Reuss)									○	
Loxoconcha sp.	○									
Olimfalunia plicatula (Reuss)	●	◉	◉	●					●	
Olimfalunia spinulosa (Reuss)	●			●				○	◉	
Parakrithe sp.			○							
Phlyctenophora affinis (Schneider)		○	◉							
Phlyctenophora farkasi (Z alanyi)			⊙			○				○
Pokornyella deformis (Reuss)			○							
Pontocythere curvata (Bosquet)				◉						
Semicytherura cf. acuticostata (Schneider)	○								○	
Urocythereis kostlenis (Reuss)						○				
Xestoleberis sp.									○	
Vestalenula cylindrica (Strauss)						●				
Cypridoidea gen.et sp. indet.						⊙		⊙		
Paralimnocythere rostrata (Straub)						○				
Eucypris sp.						○				

contain 3 species. Sample 8 only has 1 species. In sample 6, ostracods were not recorded.

The selected taxa were divided into two palaeoecological groups. The main ostracod group consists of a typical marine ostracod fauna, and has been identified at the base (samples 1, 2, 4, 5) and at the upper part of the section (samples 9, 10, 11). In most of the samples, the marine faunal assemblage is dominated by three species: *Cytheridea acuminata*, *Olimfalunia plicatula* and *Olimfalunia spinulosa*. Several other species, which also occur in marine sediments, are most abundant and prominent but in different samples: *Phlyctenophora affinis, Phlyctenophora farkasi, Aurila angulata, A. haueri, A. punctata, A.* cf. *galeata* for sample 4; *Pontocythere curvata* and *Carinocythereis carinata* for sample 5*; Costa edwardsi* for sample 10 and *Aurila* sp. for sample 11. Seven species occur in different samples with a single valve: *Nonurocythereis seminulum, Hermanites haidingeri, Loxocorniculum hastaum, Loxoconcha* sp., *Parakrithe* sp., *Urocythereis kostlenis* and *Xestoleberis* sp.

A second ostracod group, occurring only in samples 7 and 9, is represented by freshwater species mixed with respective marine ostracod fauna. The dominance of freshwater ostracod species in the second group indicates a general change in the environment.

The dominant species *Vestalenula cylindrica* in the second group appears exclusively in sample 7 (more than 40 valves). Together with one single remnant of *Paralimnocythere rostrata*, *Eucypris* sp. and parts of valves that belong to *Cypridoidea* gen. et sp. indet. it represents the freshwater ostracod fauna in sample 7. *Cypridoidea* gen. et sp. indet. has also been found in sample 9. The accompanying species to the freshwater ostracod fauna are very small numbers of marine ostracods such as *Aurila haueri, Carinocythereis carinata, Cytheridea acuminata, Nonurocythereis seminulum,* *Olimfalunia spinulosa, Phlyctenophora farkasi* and *Urocythereis kostelensis.*

It is possible to assume that sample 8 with only one registered single valve of *Cytheridea acuminata* and sample 6, barren of ostracods, belong to the second group of samples and represent a phase of environmental changes, in which living conditions were not favourable for ostracods. Freshwater ostracods are always accompanied by freshwater microgastropods.

The ostracod study did not provide detailed biostratigraphical indications, since most of the determined ostracods are wide-ranging taxa. In the North Croatian Basin these species are recorded from Badenian sediments and older stratigraphic horizons. The presence of *Olimfalunia spinulosa* would assign the deposits of Vrhovčak to the Ostracod Biozone NO-8 (Middle Badenian) after JIŘIČEK (1983).

In addition, the presence of *Carinocythereis carinata* and *Phlyctenophora farkasi* zonal markers for Ostracod Biozone NO-10 (the uppermost Badenian) starting from sample 4 allow dating of this level as Upper Badenian (JIŘIČEK, 1983; JIRIČEK & RIHA, 1990). The ostracod zonations should be treated with caution, because some new results in ostracod research have extended the stratigraphic distribution of several species (ZORN, 2003).

Palaeoecological data obtained from ostracod analysis are much more interesting. Most of the genera recorded from the Vrhovčak section are globally widespread, but their presence has ecological implications. Generally, the marine ostracod fauna reflects a shallow water environment. Among genera and species which are more characteristic of deeper infraneritic to bathyal environments only *Parakirthe* sp. was found in sample 4.

Ostracod genera *Cytheridea, Aurila, Callistocythere, Loxoconcha* and *Xestoleberis* are characteristic for upper infralittoral and epineritic facies.

In the middle part of the section, well preserved and numerous freshwater ostracod species with few marine ostracods have been recorded. This indicates that freshwater ostracod fauna are autochthonous and the marine single specimens must have been transported into freshwater sediments. The population structure indicates low water energy and low sedimentation rates in the environment (WHATLEY, 1983).

The preservation of the marine ostracods in the lower part of the section (samples 1, 2, 4 and 5) is very good and for several species larval stages are also documented. From this point of view the fauna seems to be largely autochthonous. From sample 9 to the upper parts of the section, the increasing number of carapaces of marine ostracods in relation to valves, indicates changes in the energy of the environment and sedimentation rates.

4. CONCLUSION

Biostratigraphical, palaeoecological and micropalaeontological investigations of foraminifera, ostracods and palynomorphs have been carried out in the Badenian Vrhovčak section. The diversity in facies and faunistic composition of the investigated sediments allows recognition of biotic events and the reconstruction of environmental change during the Badenian.

The sediments from the investigated section are a result of deposition of suspended clayey-micrite material and redeposited carbonate fossil fragments in a shallow marine environment, with a weak input of terrigenous material. The coal remains indicate occasional sea level regressions and freshwater influence.

Marine sediments of Badenian age at the base and upper parts of the section have been documented with phytoplankton (organic walled dinoflagellate cysts and prasinophyte algae), benthic foraminifera and ostracods.

Palynomorphs in the lower part of the investigated deposits indicate a deeper marine environment. Species diversity of dinoflagellate cysts decreased substantially in the lower part, indicating a regression (local sea level was lowered) and neritic environment. Generally the foraminiferal and ostracod fauna from the marine sediments of the section (the lower and upper parts) reflected a shallow water environment. Few planktonic foraminifera and the deeper ostracod species *Parakrithe* sp. indicate the existence of occasional communication with the open sea and penetration of deep water fauna.

In the middle part of the Vrhovčak section, layers of coal and freshwater sediments appear. In the freshwater sediments (total thickness 0.2 m) the foraminiferal assemblage is less diverse, freshwater ostracods, mixed with a few marine ostracods and freshwater microgastropods.

The coal sediments are of the sapropel type, and were deposited in a quiet closed lagoon under the influence of marine and fresh water, but without the influence of tides and underwater currents. Between the coal horizons, deposition occurred in a freshwater lake, possibly with depths greater than 7m, higher pH, and nutrient loading. The upper part of the section starts with the dominance of prasinophyte algae reflecting restricted lagoon and shallow water carbonate facies, enhanced productivity and a stratified water column (exhibiting brackish or low-salinity surface waters overlying low oxygen to anoxic bottom waters). Later in the section, dinocysts are represented along with prasinophycean algae, but only a few euryhaline species that are tolerant to decreasing salinity and water column stratification.

The climate was believed to be subtropical during deposition of the section material based on palynological evidence. Thermophilic dinoflagellate species indicate subtropical conditions for the lower and upper part of the section, while pollen of thermophilous evergreen trees suggest a subtropical climate for the middle part. Fluvial systems occurred along the coastline, transporting both terrestrial pollen grains and freshwater algae out to the marine depositional area.

The sediments from the base of section (samples 1–5) could be correlated to cycle TB 2.4 of the main Badenian transgression that affected the entire Central Paratethys. It is followed by a regression, and lowstand Ser2 of HARDENBOL et al. (1998), presumed for the middle part of the section (samples 6–8). Finally, sediments from the upper part of section (samples 9–11) belong to the Late Badenian cycle TB 2.5 (sensu HAQ et al., 1988).

ACKNOWLEDGMENT

The authors wish to thank colleagues Mato BRKIĆ, Davor VRSALJKO and Radovan AVANIĆ who participated in the field investigation. The present investigation is part of the basic research that was supported by the Croatian Geological Survey, Department of Geology, and Ministry of Science, Education and Sports Project no. 181-1811096-1093: „Basic Geological Map of the Republic of Croatia 1:50.000". For improvement of the English text we warmly thank Borna LUŽAR-OBERITER. We are grateful to Mathias HARZHAUSER for useful suggestions on the earlier version of the paper, and to Stjepan ĆORIĆ and Gonzalo JIMÉNEZ-MORENO for their valuable and helpful reviews.

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Manuscript received March 05, 2010
Revised manuscript accepted June 25, 2010
Available online November 11, 2010