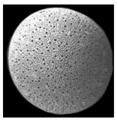
Foraminifera as environmental proxies of the Middle Miocene (Early Badenian) sediments of the Central Depression (Central Paratethys, Moravian part of the Carpathian Foredeep)

JITKA KOPECKÁ



Middle Miocene sediments of the Central Depression have been studied based on foraminifera with a view to characterize palaeoenvironmental conditions. Rock material from HV-5 Rybníček core were used. Foraminiferal evidence indicates biostratigraphic range of the lower part of the Upper Lagenid Zone (Early Badenian–Langhian, Middle Miocene). The sediments originate from a deeper marine basin at the level of outer shelf with potential extension deeper into the bathyal realm. Bottom waters were well-oxygenated with a redox boundary a few centimeters from the sea floor which was colonized by sub- and dysoxic foraminifers. Palaeotemperature of marine water corresponds to the Miocene climatic optimum with short-time climatic oscillations of cooler climate. • Key words: Middle Miocene, Early Badenian, Central Paratethys, Carpathian Foredeep, foraminifera, palaeoecology, Czech Republic.

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The Carpathian Foredeep was a large intracontinental sea consisting of a chain of basins extending through the Alpine-Carpathian region and exhibits striking lateral changes in basin width, depth, stratigraphy and sedimentary infill, along with variations in pre-Neogene basement composition and tectonic subsidence (*e.g.* Kováč 2000). The basins were frequently connected with the Mediterranean, the Indo-Pacific and the Atlantic, but periodically also isolated (Rögl & Steininger 1983, Rögl 1998, Popov *et al*. 2004).

The Badenian Carpathian Foredeep was a peripheral foreland basin in the northwest Central Paratethys developed at the European plate margin due to Carpathian accretionary wedge overthrusting and deep subsurface loading (*e.g.* Kováč *et al.* 2007, Nehyba & Šikula 2007). The Early Badenian transgression occurred in the Central Paratethys in two phases (Hohenegger *et al*. 2009). The first phase is documented by planktonic foraminiferal assemblages with *Praeorbulina sicana* and *P. glomerosa* within the NN4 calcareous nannoplankton Zone around 16.3–16.2 Ma (Rögl *et al*. 2002). The sea flooding crossed the Dinarides via Slovenia and northern Croatia (Transtethyan Trench Corridor) reaching the Pannonian Basin system (Popov *et al*. 2004). The second Early Badenian transgression was characterized by dominant planktonic assemblages with *P. glomerosa circularis* and *Orbulina suturalis* within the calcareous nannoplankton NN5 Zone around 14.7 Ma (Rögl *et al*. 2002). This transgressive event widened the North West Croatian Basin, Vienna Basin, Danube Basin, East Slovak Basin and Transylvanian Basin and reached also the Carpathian Foredeep (Kováč *et al.* 2007).

The Early Badenian sedimentation in the Carpathian Foredeep began with deposition of conglomerates containing reworked Early Miocene mollusks, which pass upward into a series of claystones and sandstones (Papp *et al.* 1978). The basal levels are overlain by pelitic sediments (grey-green calcareous clays, so called "tegels") with sandstone intercalations and biohermal bodies (Cicha & Čtyroká 1995, Cicha 2001). The morphology of the basin changed to a grabenlike structure with the deepest part above 400 m in the center of basin (Brzobohatý 1997, Nehyba *et al*. 2000). The third-order depositional sequence was recognized for the Early Badenian deposits, which was dominated by both eustacy and tectonics (Nehyba & Šikula 2007).

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Figure 1. Position of the HV-5 Rybníček core in the Moravian part of the Carpathian Foredeep.

The Central Depression is an axial part of the Carpathian Foredeep (Czech Republic) and the analyzed area is situated in its middle part (Fig. 1). In previous studies of the locality, Molčíková (1963), Burghard & Molčíková (1964), and Kopecká (2009) have presented the foraminiferal fauna and the age of deposits was interpreted as Early Badenian (Kopecká 2009).

This paper focuses on the foraminifera-rich Badenian deposits in the Moravian part of the Carpathian Foredeep. Its aim is to interpret palaeoenvironmental conditions during the Early Badenian based on detailed sampling of the deposits and quantitative processing of the foraminifers.

Material and methods

The rock material from the HV-5 Rybníček core was studied. Because the rock material has degraded over time (the core was drilled in 1962), the lithological characteristics are presented based on the data from the e-Earth application (the core database, Czech Geological Survey, available at: https://www.geofond.cz/mapsphere/EEARTH/default.aspx?lang=cs). Individual strata of the core had a massive character without clear separating of overlying and underlying strata. There were recognized lithofacies of light grey-green calcareous clays and calcareous clays with sandy or gravel intraclasts. Some parts of the core contained shell fragments and volcanic glass (Fig. 2).

The core material was sampled at approximately 1 meter intervals. Foraminifers in all the samples were picked from 63 μm–2 mm fractions after washing disintegrated rock samples in water. For palaeoecological analyses, seventy samples were processed and from each sample 200–300 specimens of foraminifera were identified to species level.

Foraminiferal fauna were classified to the benthic and planktonic foraminiferal clusters using Ward's method and Euclidean distance.

Palaeoecological analysis was based on following data:

(1) Palaeodepth, which was estimated in terms of the relationship between bathymetry and relative abundance of planktonic foraminifera as determined by Van der Zwaan *et al.* (1990):

$$D\ (m) = e^{3.58718 + (0.03534 \times Pc)},$$

where D is estimated depth in meters, e is Euler's number and Pc is corrected ratio of planktonic/benthic foraminifera and it is calculated according the formula:

$$Pc = (P \times 100)/[P + (Bt - Bi)],$$

where P is the number of planktonic foraminifera, Bt is total number of benthic foraminifera and Bi is the number of deep infaunal species as stress markers after Van der Zwaan (1990), Van Hinsbergen *et al.* (2005) and Báldi (2006), which are excluded from analysis because they are not directly dependent on the flux of organic matter to the sea floor. The reliability of the calculated palaeodepth can be biased by observation that the plankton/benthos ratio (P/B – ratio) is not only influenced by depth, but also by changes in oxygenation of bottom waters (Sen-Gupta & Machain-Castillo 1993, Jorissen *et al.* 1995). Discrepancy between calculated palaeodepth and sedimentology has been pointed out *e.g.* for the Middle Miocene of the Central Paratethys (Hohenegger 2005). Therefore, estimation of palaeodepth using modified plankton/benthos – ratio was compared with depth ranges of individual benthic taxa (*e.g.* Murray 1991, Rögl & Spezzaferri 2003, Hohenegger 2005, van Hinsbergen *et al.* 2005).

(2) Benthic Foraminiferal Oxygen Index (BFOI), which was interpreted by Kaiho (1994, 1999) and was used to estimate oxygen content. It was calculated according the equation:

$$BFOI\ (\%) = O/(O+D) \times 100,$$

where O is the number of oxic indicators and D is the number of disoxic indicators. These indicators were classified according to Kaiho (1994, 1999), Den Dulk *et al.* (2000), Spezzaferri *et al.* (2002) and Báldi (2006).

(3) Palaeotemperature changes in the upper layer of the water column, which were estimated based on the ratio among cool- and warm-water species of planktonic foraminifera (Spezzaferri & Ćorić 2001, Spezzaferri *et al.* 2002, Bicchi *et al.* 2003).

Results

Characteristics of the foraminiferal assemblages

One hundred and fifty two benthic and 24 planktonic species were identified. Well-preserved foraminiferal tests

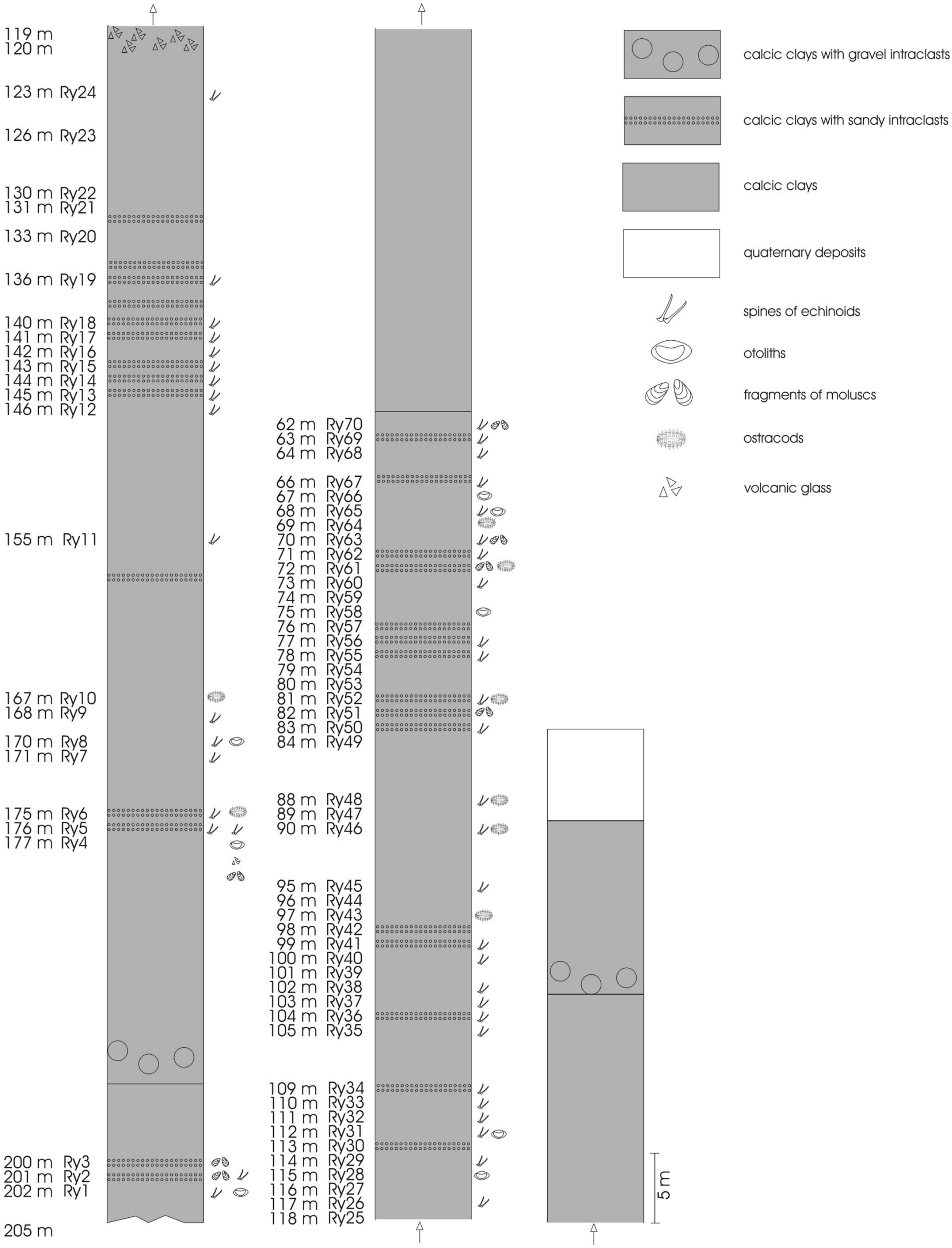


Figure 2. Lithology and location of sampling points for the HV-5 Rybníček core.

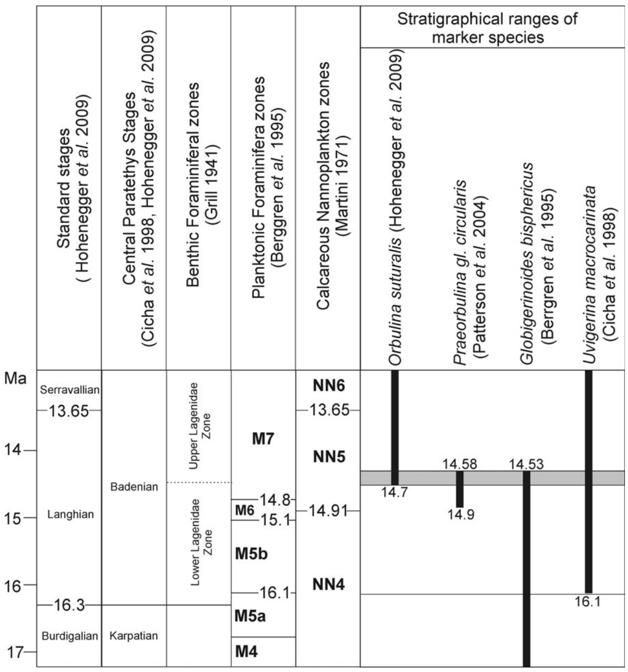


Figure 3. Biostratigraphical correlation and stratigraphical ranges of marker species from the HV-5 Rybníček core.

without evidence of abrasion and corrosion, no size sorting and occurrence of both adults and juvenile individuals indicate that the assemblages are not markedly taphonomically changed.

Assemblages are generally abundant and diverse, plankton/benthos ratios vary from 30 to 90% in the samples. The benthic assemblages are characterized by good mature individuals and dominated by the following genera: *Uvigerina*, *Bulimina*, *Cibicidoides*, *Melonis*, *Neugeborina* and *Stilostomella*. Assemblages of planktonic foraminifers are characterized small tests of individuals and by occurrence of *Globigerinoides trilobus*, *G. bisphericus*, *Globigerina praebulloides*, *G. bulloides*, *Globorotalia bykovae*, *Gl. transsylvanica*, *Paragloborotalia mayeri*, *Praeorbulina glomerosa circularis* and *Orbulina suturalis*.

Biostratigraphy

HV-5 Rybníček sections can be correlated with the planktonic foraminiferal standard global zonation (Berggren *et al*. 1995) as well as Paratethyan zonations (Rögl 1986, Cicha *et al*. 1998, Harzhauser & Piller 2007, Piller *et al*. 2007). Correlation (Fig. 3) was based on the co-occurrence of planktonic foraminiferal species *Orbulina suturalis*, *Praeorbulina glomerosa circularis* and *Globigerinoides bisphericus* and thus this section can be correlated with the lower part of the "upper lagenid zone" (Middle Miocene, Badenian; Grill 1941, Papp & Turnovsky 1953, Hohenegger *et al*. 2009).

Palaeoecological and statistical indices

Benthic foraminifera

Benthic foraminiferal fauna were grouped into seven distinct assemblages using cluster analysis (Fig. 4A). All of the assemblages are characterized by relatively high occurrences of high productivity indicators, mainly sub- and dysoxic species. The *Cibicidoides-Melonis* cluster, represents a group of samples with a marked mixture of oxiphylic (mainly *Cibicidoides*) and sub-/dysoxic (mainly *Melonis*) taxa. The proxies are sumarized in Table 1.

1. The *Uvigerina* cluster groups seven samples with a relative abundance of benthic infauna of 31–53%. The Shannon-Weaver index of diversity within this cluster ranges from 2.8–3.3; the Jaccard index of equitability has values of 0.8–0.9. P/B-ratio varies from 37–56%. The calculated palaeodepth based on the modified P/B-ratio is at the interval of 428 to 617 m (Fig. 5B) and the estimated palaeodepth based on depth ranges of benthic foraminifera is more than 150 m (Fig. 5A). Values of BFOI range from 19–53 (low to high oxic environment) (Fig. 6A).

2. The *Bulimina* cluster groups 15 samples with suboxic and agglutinated foraminifers. The cluster can be divided into a "*Martinottiella-Bulimina*" subcluster with

Table 1. Proxies of benthic foraminifera grouping in the clusters.

Cluster	Number of samples	Plankton/ benthos ratio (%)	Relative abundance of sub-/ disoxic indicators (%)	Relative abundance of shallow water indicators (%)	Shannon-Weaver diversity index (H)	Index of equitability (J)	Estimated palaeodepth (m) after Van der Zwaan (1990)	Estimated palaeodepth after Hohenegger (2006) and Rögl & Spezzaferri (2003)
Uvigerina	7	51–72	31–53	2.8–3.3	0.8–0.9	428–617	>150	19–53
Bulimina	15	61–77	11– 20	2.7–3.5	0.9	467–618	100–150	6–75
Praeglobobulimina	8	73–86	31–38	2.6–3.0	0.9	589–878	>150	41–63
Cibicidoides-Melonis	14	65–87	12–40	2.6–3.4	0.9	496–888	>100	22–75
Neugeborina	8	55–62	38–60	2.3–3.3	0.8–0.9	260– 449	>100	12–61
Neugeborina-Stilostomella	4	55–62	42–59	2.5–3.0	0.9	315–325	>200	44–79
Melonis	14	59–76	25–79	2.6–3.3	0.8–0.9	378–627	>200	30–90

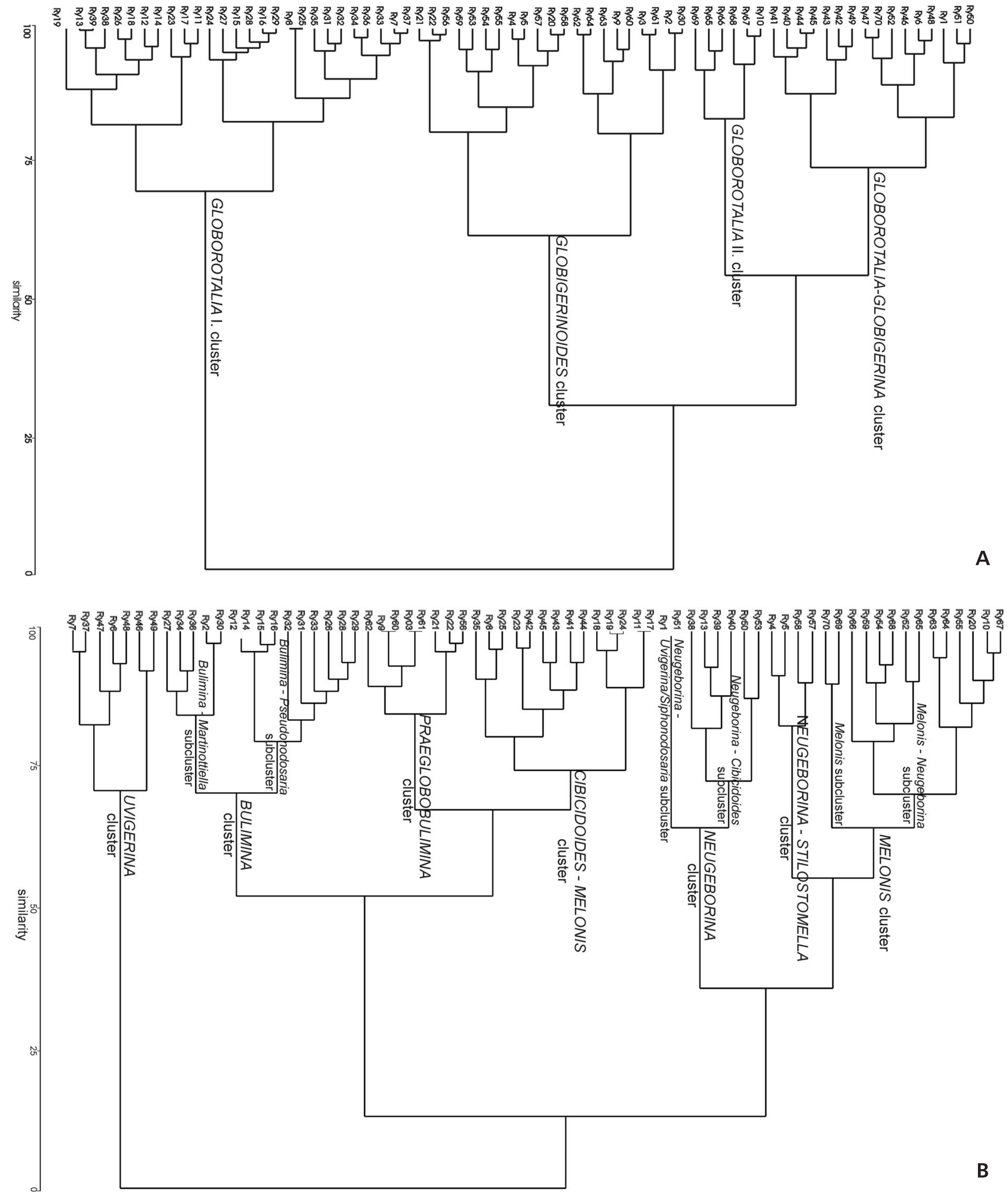


Figure 4. Hierarchical tree obtained by cluster analysis using Ward's method and Euclidean distance for: A – benthic foraminifera, B – planktonic foraminifera.

13–20% of sub-/dysoxic species and 5–9% of agglutinated species and a "*Pseudonodosaria-Bulimina*" subcluster with 11–19% of sub-/dysoxic species and 1–6% of agglutinated species.

In the cluster, the Shannon-Weaver index of diversity values range from 2.7 to 3.5; the Jaccard index of equitability has values of 0.9 in all the samples. P/B-ratios vary from 44 to 62%; BFOI values vary widely from 6 to 75 (low to high oxic environment) (Fig. 6A). The calculated palaeodepth varies from 467 to 618 m (Fig. 5A) and the estimated palaeodepth is between 100–150 m (Fig. 5B).

3. The *Praeglobobulimina* cluster groups eight samples including three samples (Ry9, Ry21 and Ry60) with relatively high relative abundance of benthic infauna (31–38%). The Shannon-Weaver index of diversity values range from 2.6–3.0; the Jaccard index of equitability is 0.9 for all the samples; P/B-ratios vary from 57 to 74%. BFOI values of 41–63 (medium to high oxic conditions) are seen in this cluster (Fig. 6A). Calculated palaeodepths vary from 589–878 m and the estimated palaeodepth is more than 150 m (Fig. 5A, B).

4. The *Cibicidoides-Melonis* cluster groups fourteen samples with sub-/disoxic (12–40%) foraminifers and agglutinated (2–16%) foraminifers mixed with a high occurence of oxiphylic foraminifers (7–34%). The Shannon-Weaver index of diversity values range from 2.6–3.4; Jaccard index of equitability is 0.9 and the P/B-ratio varies from 48 to 72%. BFOI is at the interval of 22–75 (low to high oxic conditions) (Fig. 6A). Calculated palaeodepth for these samples varies from 496–888 m and the estimated palaeodepth is more than 100 m (Fig. 5A, B).

5. The *Neugeborina* cluster groups eight samples with dominant species *Neugeborina longiscata* (d'Orbigny) and abundant sub-/dysoxic and agglutinated foraminifers. Shannon-Weaver index of diversity values are at the interval of 2.3–3.3 and the Jaccard index of equitability is 0.8–0.9; P/B-ratio varies from 30 to 49%. The cluster can be divided to two subclusters: a *Uvigerina/Siphonodosaria* subcluster and a *Cibicidoides* subcluster. The *Uvigerina/Siphonodosaria* subcluster is characterized by 60% sub-/dysoxic species (with high abundances of *Uvigerina* and *Siphonodosaria*) and 11% of agglutinated species (with high abundances of *Martinottiella*). The *Cibicidoides* subcluster is characterized by a mixture of sub-/dysoxic species (38–60%) with dominant *Uvigerina* and *Bulimina*, oxiphylic species (3–17%) with dominant *Cibicidoides* and agglutinated species (1–10%) with dominant *Martinottiella*.

In the cluster, BFOI reached values from 12 to 61 (low to high oxic environment) (Fig. 6A). The calculated palaeodepth varies from 260 to 449 m and the estimated palaeodepth is more than 100 m (Fig. 5A, B).

6. The *Neugeborina/Stilostomella* cluster groups four samples and is characterized by the presence of suboxic species (42–59%) and agglutinated forminifers, mainly *Martinottiella karreri* (5–9%) with a co-occurence of *Heterolepa dutemplei* (2–15%). Values for the Shannon-weaver index of diversity varies from 2.5 to 3.0; the Jaccard index of equitability has value of 0.9; P/B-ratio is 38–39% and BFOI values in the range of 44–79 (medium to high oxic). The calculated palaeodepth varies from 315–325 m and the estimated palaeodepth is more than 200 m.

7. The *Melonis* cluster groups fourteen samples with a high occurrence of sub-/dysoxic species (25–79%, with the following dominant genera: *Melonis*, *Stilostomella and Bulimina*) and agglutinated species (6–17%, with dominant *Martinottiella*) and can be characterized by Shannon-Weaver index of diversity values of 2.6 to 3.3, Jaccard index of equitability with values of 0.8 to 0.9 and P/B-ratio with values of 44 to 61%. BFOI values are in the range of 30 to 90% (medium to high oxic conditions) (Fig. 6A). Calculated palaeodepth varies from 378 to 627 m and the estimated palaeodepth is more than 200 m (Fig 5A, B).

Planktonic foraminifera

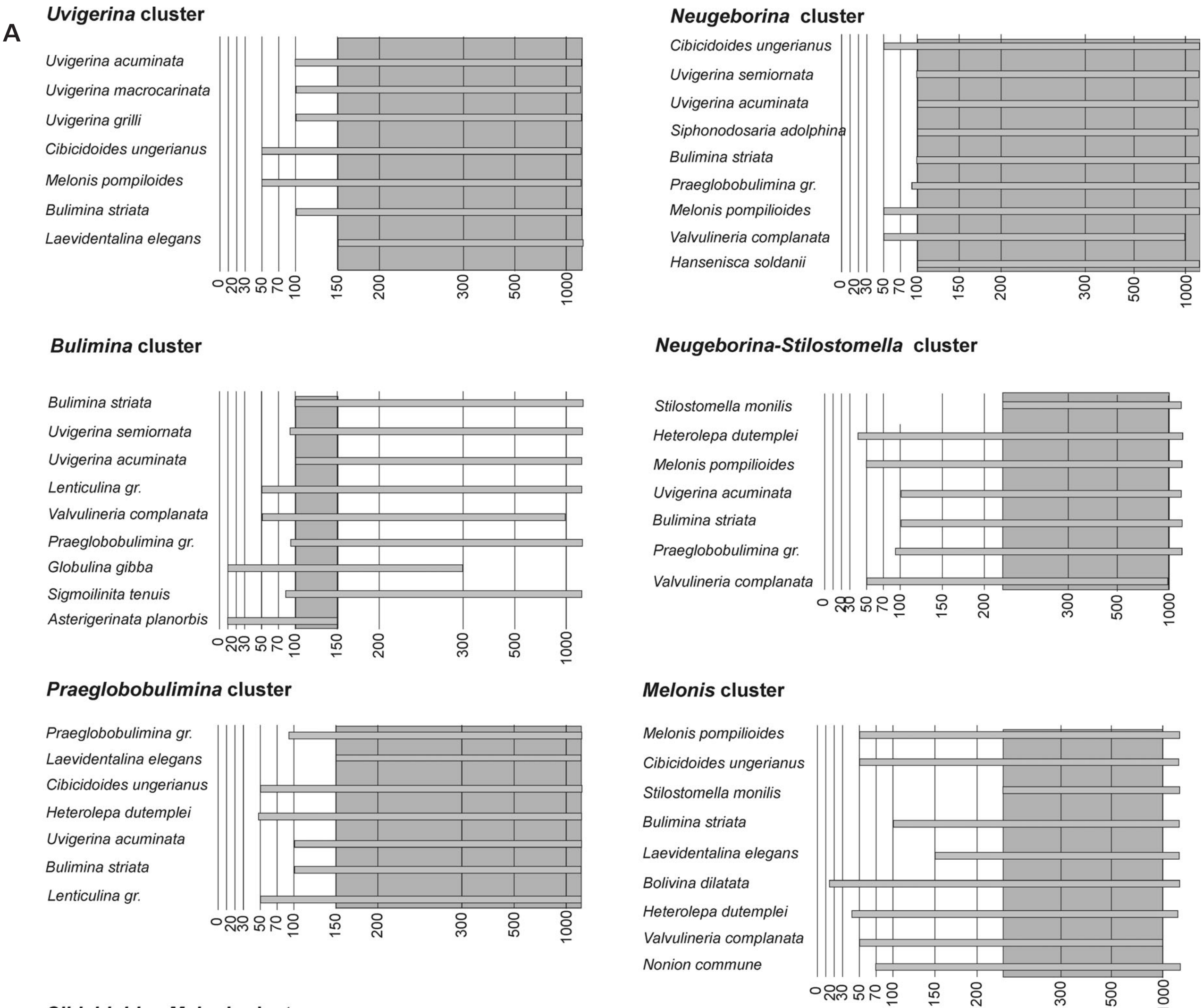
The ecological preferences of planktonic foraminifera are herein retained following Spezzaferri *et al.* (2002) and Bicchi *et al*. (2003). The present *Globigerina* (except *G. diplostoma*) and *Turborotalia* are considered cool-waters indicators; *Globorotalia* and *Globoturborotalia* are considered cool-temperate waters indicators. *Praeorbulina-Orbulina*, *Globigerinoides*, *Paragloborotalia, Globoquadrina altispira* and *Globigerina diplostoma* are considered warm-water indicators and *Paragloborotalia mayeri* considered warm-temperate water indicators.

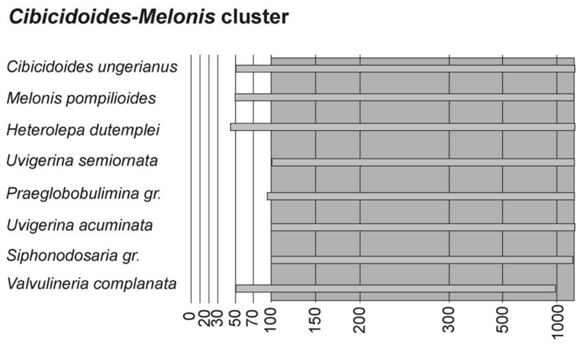
Planktonic foraminiferal fauna were grouped, using Ward's method of cluster analysis, into four assemblages (A–D) (Fig. 4B). The proxies are summarized in Table 2.

A. The *Globorotalia* I. cluster groups 27 samples and is characterized by the dominant *Globorotalia* group (39–79%) in association with the *Globigerina* group (3–23%), the *Globigerinodes* group (3–36%) and the *Paragloborotalia* group (5–11%). The ratio between cool- and warm-water indicators varies from 43 to 88% (Fig. 7A). Shannon-Weaver index of diversity values vary from 1.4 to 2.3 and the Jaccard index of equitability has values of 0.6–0.9.

B. The *Globigerinoides* cluster groups 19 samples and is characterized by dominant *Globigerinoides* group (5–53%) with *Globorotalia* group (12–40%), *Globigerina* group (5–22%) and *Praeorbulina/Orbulina* group (2–49%). The ratio between cool- and warm-water indicators varies from 18 to 57% (Fig. 7A). Shannon-Weaver index of diversity values vary from 1.3 to 2.3 and Jaccard index of equitability has values of 0.6–0.9.

C. The *Globorotalia* II. cluster is small and groups only six samples. Predominant *Globorotalia* group (51–73%)





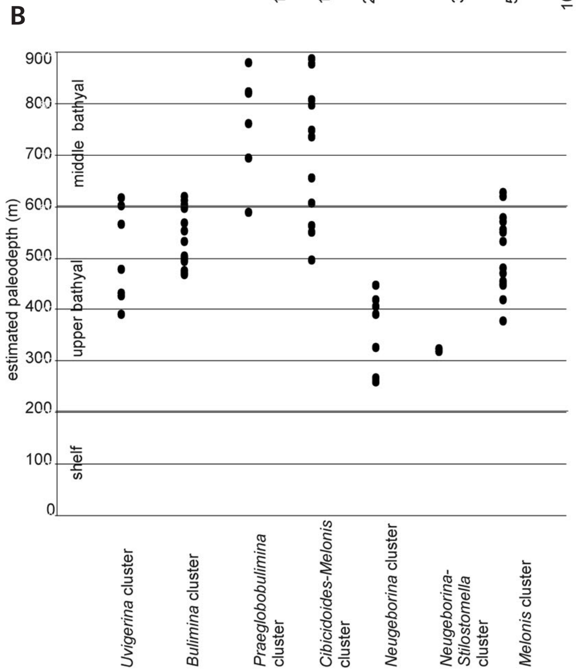
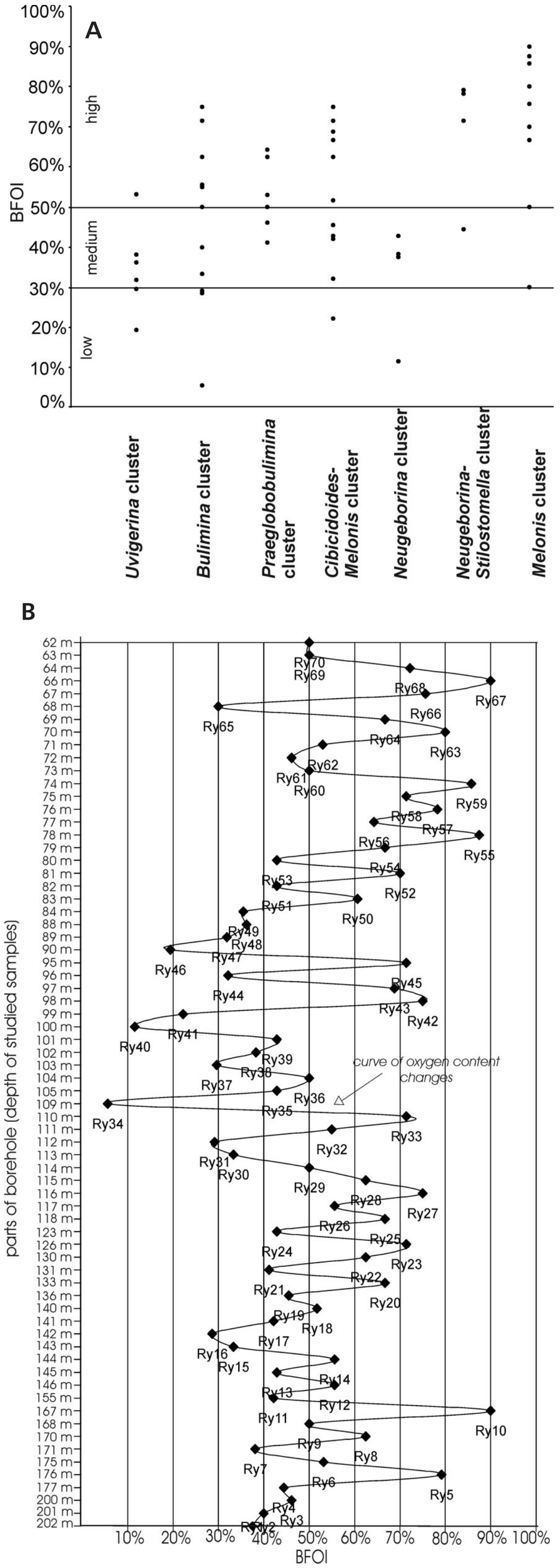


Figure 5. Palaeodepth estimation for benthic foraminiferal clusters. • A – estimated palaeodepth based on depth ranges of benthic foraminifera. • B – estimated palaeodepth based on modified P/B-ratio.



and high values of the ratio between cool- and warm-water indicators (68–84%) characterize this cluster (Fig. 7A). Shannon-Weaver index of diversity values vary from 1.3 to 2.3 and Jaccard index of equitability has values of 0.6–0.9.

D. The *Globorotalia-Globigerina* cluster groups 18 samples with *Globorotalia* group (15–52%) and *Globigerina* group (3–43%), *Paragloborotalia* group (2–38%) and *Globigerinoides* group (4–35%). The ratio between cool- and warm-water indicators varies from 32 to 75% (Fig. 7A); the Shannon-Weaver index of diversity reaches values of 1.7–2.3 and the Jaccard index of equitability reaches values of 0.7–0.9.

Discussion

Benthic foraminiferal assemblages and their proxies

Benthic foraminiferal fauna have relatively low values of diversity (Shannon-Weaver index in range of 2.3–3.5), high values of equitability (Jaccard index in range of 0.8–0.9) and high occurrence of high productivity markers (infauna) in assemblages.

Oxygen content

A common feature of all assemblages is a relatively high occurence (12–79%) of high primary productivity markers (infaunal taxa) (Den Dulk *et al*. 2000), which are dysoxic and suboxic indicators (Kaiho 1999) – mainly *Bulimina striata, B. schischinskayae, Melonis pompilioides, Praeglobobulimina pyrula, P. pupoides, Fursenkoina acuta, Uvigerina macrocarinata*, *U. grilli*, *U. uniseriata*.

The sub- and dysoxic foraminifers are mixed with oxiphylic epifaunal species (mainly cibicidoids). This mixture of sub-/dysoxic and oxiphylic species is typical of dead foraminiferal assemblages from muddy environments. The palaeoenvironment was characterized by well-aerated bottom water with a redox boundary a few centimeters from the see floor which was colonized by sub- and disoxic foraminifers (Murray 2001). Number of dead foraminiferal assemblages and their decomposition had an effect on the oxygen content at the sea floor.

Changes in oxygen content are evident from the values of BFOI (Fig. 6A). Low to medium oxygen content is characterized by the *Uvigerina* cluster and *Neugeborina* cluster, low to high oxygen content) by the *Bulimina* cluster and the *Cibicidoides-Melonis* cluster and medium to high

Figure 6. Benthic Foraminiferal Oxygen Index (BFOI). • A – BFOI-marker of oxygen content in the assemblages of the benthic clusters. • B – changes of the oxygen content along the core.

oxygen content for the *Praeglobobulimina* cluster, the *Neugeborina-Stilostomella* cluster and the *Melonis* cluster. In the core, values of BFOI reflect periodic changes in oxygen content, mainly from medium to high. In the middle part of the profile (depth of 109–99 m), there is significant decrease in BFOI values (changes between low and medium oxygen content; Fig. 6B).

Relatively high occurence of benthic infauna and common occurence of oxyphylic species in the samples point to decrease of oxygen levels caused by decomposition using up oxygen at the sea floor, not to total sub- or disoxic environment. It supports also by occurrence of good mature benthic foraminifera as on of indicators of good oxygen conditions and by small individuals of planktonic foraminifera as one of indicators of eutrophization.

Estimated palaeodepth

Palaeowater depth estimates 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 modified P/B-ratio, while the proxy of Hohenegger (2005) is based on depth ranges of recent benthic foraminifera.

Both proxies showed palaeodepth conditions at the level of outer shelf to bathyal. Estimated palaeodepth based on modified P/B-ratio showed a deep-water condition with an estimated palaeodepth in the range of 260–888 m which probably reflects limited validity of the equation generated by Van der Zwaan *et al*. (1990) in the suboxic conditions (Jorissen *et al*. 1995). Palaeodepth estimated from the bathymetric ranges showed palaeodepth conditions of outer shelf zone (*Bulimina* cluster, 100–150 m), outer shelf to bathyal zone (*Uvigerina* cluster, *Cibicidoides-Melonis* cluster, *Neugeborina* cluster) with estimated palaeodepth in the range of 100 m and deeper, and the bathyal zone (*Praeglobobulimina* cluster, *Neugeborina-Stilostomella* cluster and *Melonis* cluster) with estimated palaeodepths of 230 m and deeper (Fig. 5A).

Because the applied P/B ratio method is sensitive to eutrophy causing high productivity surface water and oxygen deficiency at the bottom culling benthic life (Van der Zwann *et al.* 1990), the calculated palaeodepth can be overestimated. It is evident from the *Bulimina* cluster with the occurrence of shallow water marker *Asterigerinata planorbis* where the calculated palaeodepth based on P/B-ratio is in the range of 467–618 m but the palaeodepth based on depth ranges varies from 100–150 m. On the other

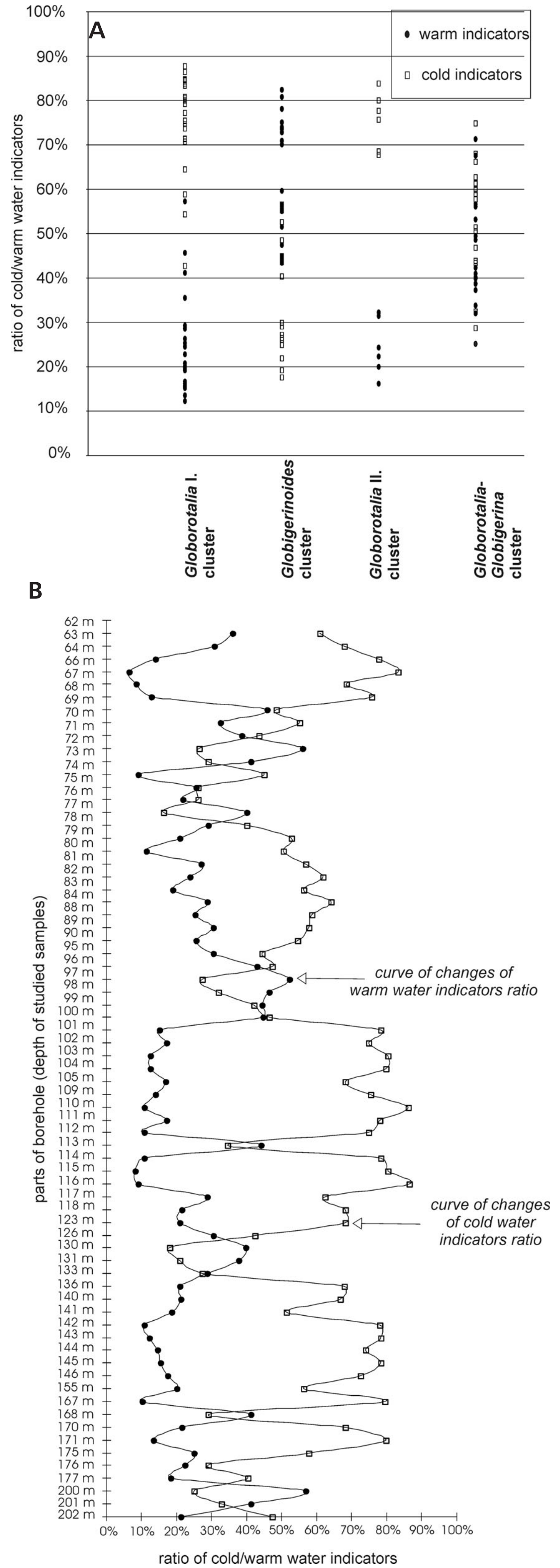


Figure 7. Palaeotemperature indices in the upper layer of the water column. • A – ratio of cool-water and warm-water indicators in the assemblages of the planktonic clusters. • B – changes of the ratio of cool-water and warm-water indicators along the core.

Table 2. Proxies of planktonic foraminifera grouping in the clusters.

Cluster	Number of samples	Shannon-Weaver diversity index (H)	Index of equitability (J)	Cold/warm indicators ratio
Globorotalia I.	27	1.4–2.3	0.6–0.9	43–88
Globigerinoides	19	1.3–2.3	0.6–0.9	18–57
Globorotalia II.	6	1.3–2.3	0.6–0.9	68–84
Globorotalia-Globigerina	18	1.7–2.3	0.7–0.9	32–75

hand, the *Neugeborina-Stilostomella* cluster and the *Melonis* cluster with the occurrence of *Stilostomella monilis*, which prefers a depth range of more than 200 m (Rögl & Spezzaferri 2003), and the co-occurrence of planktonic deep water element *Globorotalia bykovae* (Hilbrecht *in* Rupp & Hohenegger 2008, Itou *et al. in* Rupp & Hohenegger 2008) suggest, that palaeowater depth could extend from the level of shelf to bathyal. Bathyal deep water conditions in the HV-5 Rybníček core and at the other localities in the Moravian part of the Carpathian Foredeep (Hrušovany nad Jevišovkou, Brno-Královo Pole, Myslejovice, Drahanovice) have been described also by Brzobohatý (1981, 1997) based on an occurrence of a great number of mictophid otoliths indicating depths below 400 m (Brzobohatý 1997).

Planktonic foraminifera and palaeotemperature water indices

Planktonic foraminiferal assemblages are characterized by very low values and fluctuations of diversity (Shannon-Weaver index in range of 1.3–2.3) and high values of equitability (Jaccard index in range of 0.6–0.9) throughout the core. Low diversity planktonic foraminiferal assemblages can be an index of palaeotemperature conditions because in modern oceans, the diversity of planktonic foraminifera is lower in cool than in warm waters (Boltovskoy & Wright 1976).

In the HV-5 Rybníček core, low values of diversity are positively correlated with high relative abundance of cool water indicators (mainly *Globorotalia* and *Globigerina*) in the *Globorotalia* II. cluster (68–85% of cool water indicators) and partly in the *Globorotalia* I. (42–88%) and the *Globorotalia-Globigerina* cluster (the highest values do not exceed 75%). High values are thought to be an expression of cool water conditions. Fluctuation of the relative abundance of cool water indicators along the core show an extreme increase in cool water indicators (relative abundance more than 70%) between 167–141 m, 116–101 m and 66–69 m of the core depth.

Decrease in relative abundance of cool water foraminifera in assemblages of the *Globigerinoides* cluster, where values of the relative abundance of cool water indicators do not exceed 55% (and in most of the samples do not exceed 30%) and values of relative diversity of warm water indicators (mainly *Globigerinoides*) are in range of 44–83%, signaling an increase in surface water temperatures. Along the core, increasing of warm water indicators (relative abundance more than 30%) are obvious between 201–200 m, 133–126 m, 101–84 m and 74–70 m and at 113 m and 78 m of core depth.

Described changes in the relative abundance of cool and warm water indicators in the assemblages may indicate short-time climatic oscillations of cooler climate during the Miocene climatic optimum, which can be characterized as fairly uniform for the Badenian climate of the Central Paratethys realm (Böhme 2003, Doláková & Slamková 2003).

These oscillations are also described in the Middle Miocene of the Central Paratethys by Bicchi *et al*. (2003), Holcová & Zágoršek (2008) and Rupp & Hohenegger (2008).

Conclusions

Foraminifera from seventy samples from the HV-5 Rybníček core were studied. The foraminiferal fauna were grouped into the seven clusters of benthic and four clusters of planktonic foraminifers with the goal of determining the palaeoenvironmental conditions of the Moravian middle part of the Carpathian Foredeep based on faunal parameters and palaeoecological indices.

The HV-5 Rybníček core can be well correlated with the Early Badenian time interval, characterized by the co-occurrence of the planktonic foraminiferal species *Orbulina suturalis*, *Praeorbulina glomerosa circularis* and *Globigerinoides bisphericus* with the lower part of the Upper Lagenid Zone.

In the clusters of benthic foraminifera, high occurrence of stress markers with the co-occurrence of oxiphylic species is common feature in all of the assemblages. The palaeoenvironment, where mixed sub-/dysoxic and oxiphylic species, was characterized by well-aerated bottom water with a redox boundary a few centimeters from the seafloor which was colonized by sub- and dysoxic foraminifers. Fluctuations between high oxic and suboxic oxygen content at the sea bottom is evident along the core and is depend on the nutrient content in photic zone. Eutrophization as a factor of fluctuations between high oxic and suboxic oxygen content at the sea floor is also documented by occurrence of small tests of planktonic foraminifera.

Palaeodepth conditions were estimated ranging from outer shelf to bathyal. But interpretation of the palaeodepth is complicated due to the high occurrence of high productivity indicators hence the estimated palaeodepth based on P/B-ratio, compared with depth ranges of benthic foraminifera, may be overestimated.

In clusters of planktonic foraminifera, cool/cool-temperate and warm/warm-temperate water indicators indicate temperature fluctuations along the HV-5 Rybníček core. Increasing cool/cool-temperate water indicators may indicate short-time climatic oscillations of cooler climate during the Miocene Climatic Optimum.

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