Acta Geologica Polonica, Vol. 59 (2009), No. 4, pp. 523–544

Palaeoenvironmental reconstruction of the Karpatian–Badenian (Late Burdigalian–Early Langhian) transition in the Central Paratethys. A case study from the Wagna Section (Austria)

SILVIA SPEZZAFERRI [1], STJEPAN ĆORIĆ[2] AND KARL STINGL[3]

[1] *Department of Geosciences, Earth Sciences, Ch. du Musée 6, 1700 Fribourg, Switzerland.*
E-mail: silvia.spezzaferri@unifr.ch
[2] *Geological Survey, Neulinggasse 38, 1030, Vienna, Austria.*
[3] *Department of Geosciences and Geophysics, University of Leoben, 8700, Leoben, Austria.*

ABSTRACT:

Spezzaferri, S., Ćorić, S. and Stingl, K. 2009. Palaeoenvironmental reconstruction of the Karpatian–Badenian (Late Burdigalian–Early Langhian) transition in the Central Paratethys. A case study from the Wagna Section (Austria). *Acta Geologica Polonica*, **59** (4), 523–544. Warszawa.

The Karpatian–Badenian (Burdigalian–Langhian, Early–Middle Miocene) transition is a key interval in the evolution of the Paratethys and the proto-Mediterranean Sea. We present here, based on the Wagna section (Styrian Basin, Central Paratethys), a study of a quantitative analysis of the microfossils (foraminifera and calcareous nannofossils) and a statistical treatment of data to reconstruct the palaeoenvironmental condition during this time.

During the Karpatian, relatively deep water, cool conditions with a relatively high nutrient input prevailed in the Styrian Basin, as suggested by the high abundance of cool-water foraminifera and calcareous nannofossils. The Badenian was generally warmer, with a lower availability of nutrients, and was characterized by carbonate units and patch reefs and associated microfossil assemblages (e.g., *Eponides* spp.). Riverine plumes brought fresh water into the Styrian Basins during the Badenian and induced high productivity and the proliferation of species highly tolerant of low salinity such as *Ammonia tepida*. The passage from calcareous nannofossil Zone NN4 to NN5 is characterized by a reorganization of water masses and the transition from cooler and nutrient-rich to warmer and nutrient-poorer waters. Based on the microfossil abundance trends we interpret the planktonic foraminiferal species *Globigerina tarchanensis* as preferring cooler nutrient-rich waters and *Reticulofenestra minuta* as preferring warmer and nutrient-poor waters.

The application of cluster analysis based on the Bray-Curtis Similarity and non-metric MultiDimensional Scaling (nMDS) adds important information to that obtained only from microfossil abundance curves, enabling identification of cryptic trends and correlation with sequence stratigraphy. This method may even complement biostratigraphic interpretation and support age attribution in the Paratethyan area, where marker species are missing.

Key words: Paratethys; Mediterranean; Miocene; Palaeoenvironment; Foraminifera; Calcareous nannofossils; Statistical treatment.

INTRODUCTION

The Mediterranean Sea and the intracontinental Paratethys were formed as new marine realms during the Late Eocene (e.g., Popov *et al.* 1993; Rögl 1999). From the Oligocene through the Miocene, the Paratethys, an extended marginal sea which developed from Switzerland to Central Asia, underwent complex palaeogeographical changes e.g., opening and closing of marine connections with the Indian Ocean to the east and with the Mediterranean Sea and Atlantic Ocean to the west, especially in the Miocene (Rögl 1999, 2001).

The Styrian Basin belonged to the Central Paratethys bioprovince as part of the intra-Carpathian Pannonian Basin system (e.g., Rögl *et al.* 2002). It was separated by the South Burgenland Swell from the Pannonian Basin and was subdivided into different sub-basins by ridges and faults. These basins were formed during an Early Miocene synrift phase, probably beginning in the Ottnangian, corresponding to the Middle Burdigalian (Ebner and Sachsenhofer 1995; Sachsenhofer 1996; Tari 1996). The synrift phase was characterized by fault tectonics and rapid subsidence, forming relatively deep basins into which the Mediterranean waters ingressed (Kollmann 1965). The sedimentary expression of these events is the deposition of calcareous mudstones and siltstones: the Karpatian "Steirischer Schlier" (Kollmann 1965; Auer 1996; Rögl *et al.* 2002).

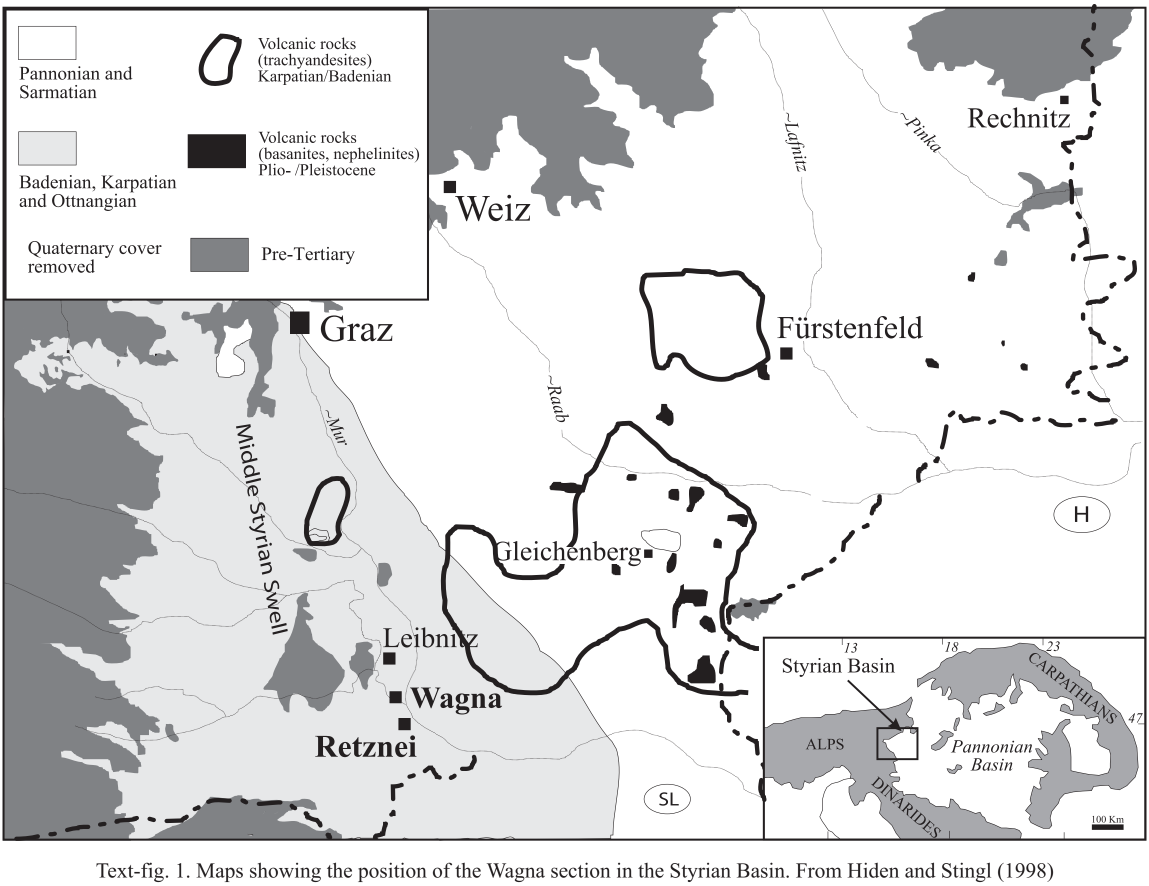
The tectonic activity was also accompanied by extensive volcanism (Sachsenhofer 1996). The transition from the Karpatian to Badenian (Early to Middle Miocene) corresponds to a pulse of tectonic activity recorded in all circum-Mediterranean regions, termed the "Styrian Tectonic Phase" (Stille 1924). Its geological expression is a sedimentary hiatus: the "Styrian Discordance", which is clearly identified throughout the Paratethys (Rögl *et al.* 2002, 2007).

The Karpatian–Badenian (Burdigalian–Langhian, Early–Middle Miocene) transition, is therefore a key interval in the evolution of the Paratethys and the proto-Mediterranean Sea. This study deals with the paleoenvironmental reconstruction of this interval in the Central Paratethys based on planktonic and benthic foraminifera and calcareous nannofossils.

GEOLOGICAL SETTING

The investigated Karpatian–Badenian sedimentary succession in the Styrian basin (Text-fig. 1) is characterized by the calcareous mudstones and siltstones of the "Steirischer Schlier", which are interpreted as deep marine turbidites, based on the sedimentary structures, faunal content and types of bioturbation (Krainer 1988, 1989; Schell 1994).

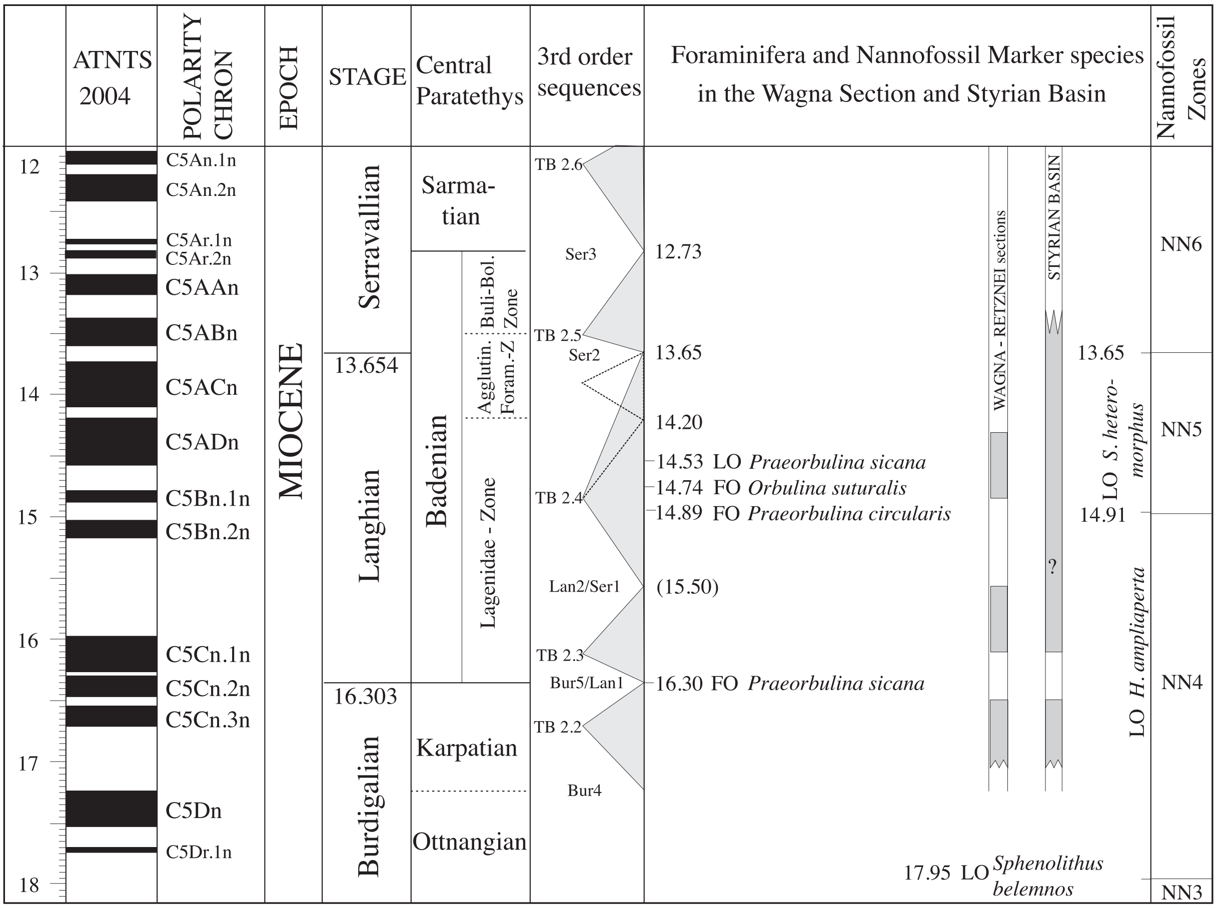
To the west, the "Steirischer Schlier" interfingers



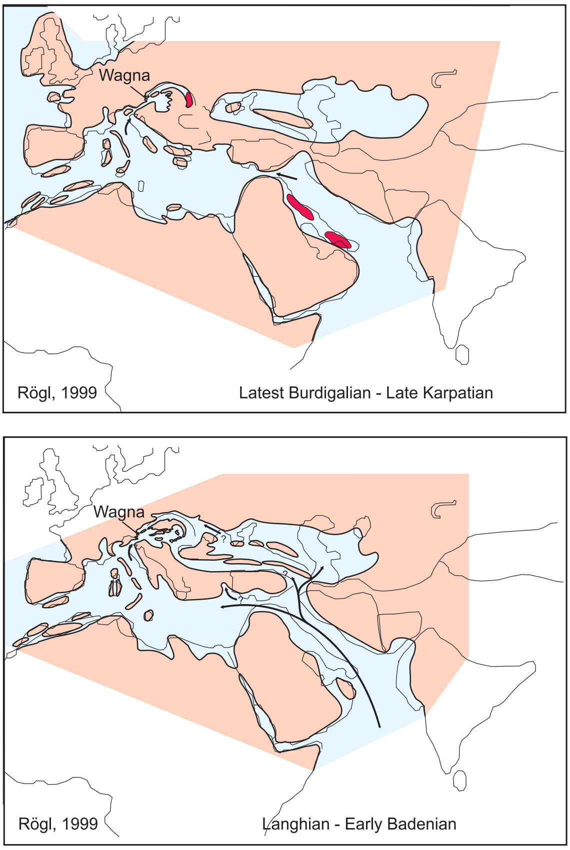
Text-fig. 1. Maps showing the position of the Wagna section in the Styrian Basin. From Hiden and Stingl (1998) with gravel mass-flow deposits (“Arnfelser Konglomerate”), which are interpreted to be the subaquatic parts of a fan delta system (Schell 1994). At the top of the “Steirischer Schlier” is observed a sedimentary deposit commonly described as the “Geröllmergel” (Kollmann 1965). It consists of reworked components of the “Steirischer Schlier” together with crystalline pebbles in a silty to sandy calcareous matrix, possibly deposited in a coastal zone (Kollmann 1965) and characterized by the ichnogenus *Gastrochaenolites* (Friebe 1991; Fenninger and Hubmann 1997).

This facies corresponds to the “Styrian Discordance”, which represents the Karpatian–Badenian transition and is presently correlated with the Burdigalian/Langhian sequence boundary Bur5/Lan1 of Hardenbol *et al.* (1998), which is clearly identified in all Paratethyan areas (Rögl *et al.* 2002, 2007) (Text-fig. 2).

The “Geröllmergel” is topped by the marine shallow-water sandy deposits or the extended carbonate units of the Weissenegg Formation. This formation includes both carbonate units aligned as patch reefs along the Middle Styrian Swell (Friebe 1990, 1993) as well as the associated siliciclastic basin facies (Friebe 1991). These sediments are composed of corallinacean-rich limestones with intercalation of coral-rich horizons. Most of the coral colonies occur in-situ, whereas some are reworked in debris. The development of these carbonate bodies is not contemporaneous throughout the Styrian Basin, as patch reefs of different Badenian ages can be observed. Their age and development depends on their position with respect to the relief generated by the “Styrian Tectonic Phase” (Friebe 1993). These carbonate bodies represent the westernmost occurrence of coral limestones in the Central Paratethys and their growth and development were influenced by various local and regional factors. In particular, these factors include siliciclastic input from the fan deltas from the Middle Styrian Swell, braided rivers from the eastern and northern basin margins (Friebe 1993) as well as broader palaeogeogeographical changes, possibly related to the opening of marine connections between the Paratethys and the adjacent seas and oceans (Rögl 1999, 2001) (Text-fig. 3).



Text-fig. 2. Regional zonation in use for the Paratethys compared with the standard zonations of foraminifera and calcareous nannofossil (modified after Rögl *et al.* 2007)



Text-fig. 3. Palaeogeographic maps showing the position of the Wagna section in the Styrian Basin during A) the Early–Middle Karpatian (Burdigalian) and B) the Early Badenian (Langhian). From Rögl (1999, 2001)

The continuous succession of the described facies and tectonic signatures from the "Steirischer Schlier" (hereafter termed "basin facies"), to the "Styrian Discordance", the "Geröllmergel" topped by the Badenian Weissenegg Formation, is clearly visible in only three sections in the Styrian Basin: Retznei, Wagna and Spielfeld-Katzengraben (Text-fig. 1). Of these sections, the Wagna section is the best exposed.

THE WAGNA SECTION

The Wagna section is located approximately 20 km south of Graz close to the town of Leibnitz near the Middle Styrian Swell basement high (Text-fig. 1). The profiles studied are here named A and C. The lithology and a detailed description of the sediments from Profile C are shown in Text-fig. 4. The lithology of Profile A, reported in Spezzaferri *et al.* (2004) is also included to better clarify and represent the geological setting and the variations of the foraminiferal assemblages.

A wide terrace separates the two profiles (Text-fig. 4), and sometimes single beds are slightly displaced (5–10 cm) by small faults. This setting makes bed-by-bed correlation difficult and, in some cases, impossible, with the exception of the angular unconformity between samples Wag-25 and -26 in profile A and samples Wag-7 and 8 in profile C. The two profiles are therefore treated separately.

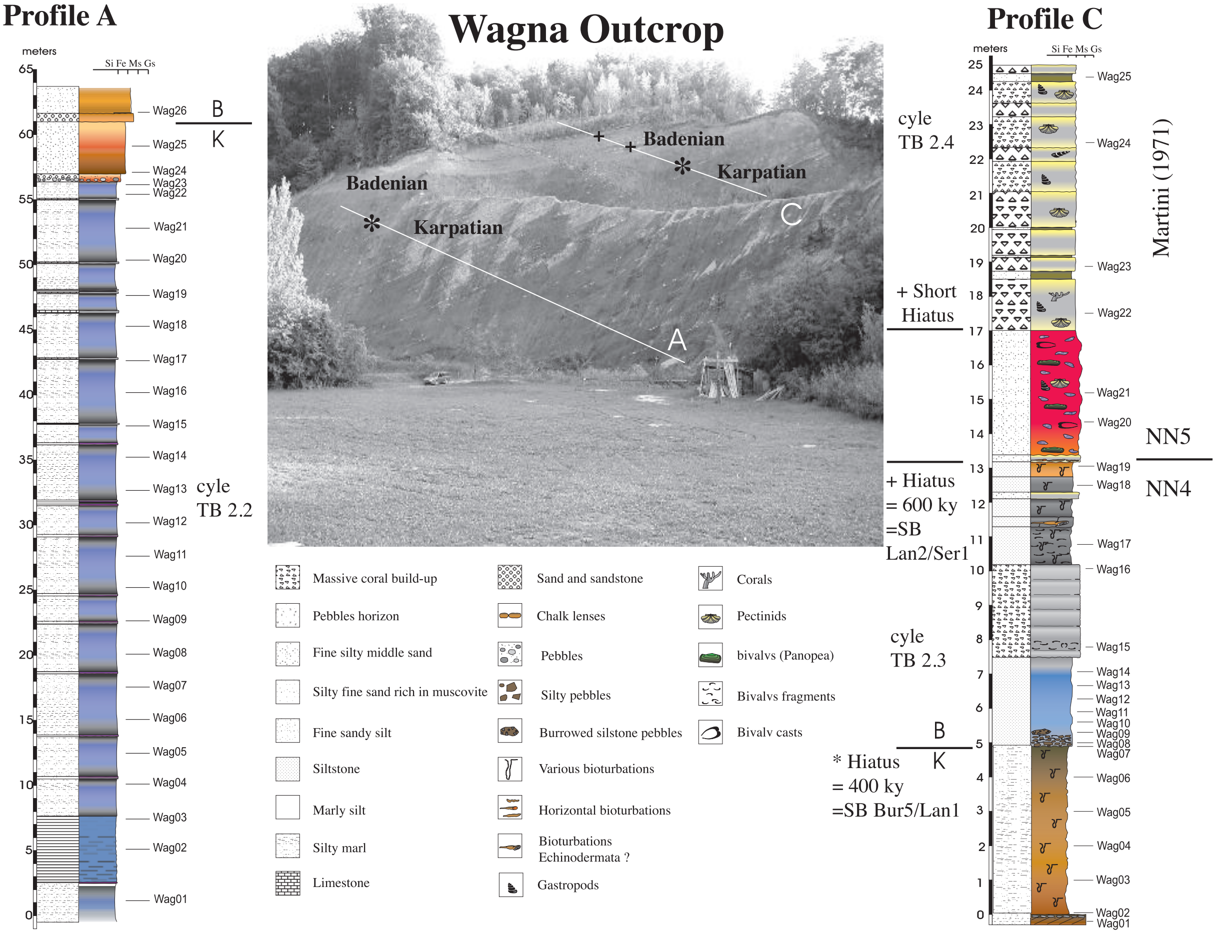
Profile A

Profile A records the middle to upper part of the "Steirischer Schlier" (Middle Karpatian). The sediments consist of 2 to 5 metres-thick levels of dark-grey calcareous shales with cm-thick intercalations of siltstones ("Schlier"). Crystalline pebbles in sample Wag-23 (Profile A) represent a channel deposit.

This part of Profile A may correlate with cycle TB 2.2 of Hardenbol *et al.* (1998) as described in Rögl *et al.* (2007). A distinct angular unconformity (Text-fig. 4) separates the middle Karpatian shales from the lower Badenian sandy sediments (sample Wag-26 – Badenian). This unconformity, the duration of which has been estimated to span about 400 ky (Rögl *et al.* 2005, 2006), is related to the "Styrian Discordance" and corresponds to the sequence boundary Bur5/Lan1 of Hardenbol *et al.* (1998), as described in Rögl *et al.* (2007).

Spezzaferri *et al.* (2002) studied the Karpatian sediments of this profile. They compared the palaeobiogeography of foraminifera and calcareous nannofossils in the Molasse and Styrian Basins. Spezzaferri *et al.* (2004) studied the distribution and significance of agglutinated foraminifera in the Styrian Basin and their relationship to water depth. These studies revealed drastic changes in foraminiferal assemblages, palaeoenvironmental and hydrographic conditions in the Styrian Basin, which were related to the "Styrian Tectonic Phase". They also suggested that cool palaeoeclimate, high surface water fertility, suboxic condition at the sea floor, high accumulation of organic matter and relative $CaCO_3$ undersaturation of the sea water occurred during the Middle Karpatian in the relatively deeper parts of the Styrian Basin.

In Profile A, the passage to Badenian sediments is represented by sample Wag-26 only, just above the hiatus separating Karpatian and Badenian sediments. Thus not enough information was available to reconstruct the palaeoenvironmental conditions immediately after the "Styrian Tectonic Phase". The study of Profile C, which records this interval (sample Wag-7 upward) was undertaken to clarify this issue.



Text-fig. 4. Photograph of the Wagna section (by P. Pervesler) and lithologic log of Profiles A and C. White lines mark the sampled profiles. * marks the hiatus across the Karpatian–Badenian transition and + marks the hiatus spanning the transition to the carbonate build-up. Modified after Spezzaferri *et al.* (2004). The only level that can be clearly correlated in the two profiles is the unconformity marking the Karpatian–Badenian transition

Profile C

In total 25 samples were collected from Profile C (Text-fig. 4). Silty sediments occur from the Karpatian–Badenian transition (sample Wag-7) to the distinct level with dominant *Porites* (corals) from samples Wag-15 to Wag-16 (Text-fig. 4). The sand content increases from sample Wag-17 to Wag-21. Rögl *et al.* (2007) attributed the interval from Wag-8 to Wag-19 to cycle TB 2.3 of Hardenbol *et al.* (1998). Carbonate platform sediments with intercalations of marly layers overlie the sandy interval (samples Wag-22 up to Wag-25). This carbonate body has a wide extent in the Styrian Basin and crops out continuously in the Lafarge quarry at Retznei where Friebe (1990) identified hermatypic corals such as *Porites, Montastrea* and *Tarbellastrea.* However, the carbonate bodies are not continuously present in the Styrian Basin, but in many cases consist only of small patch reefs (e.g., the Retznei and Wagna patch reefs). Rögl *et al.* (2007) attributed the interval from Wag-20 to Wag-25 to cycle TB 2.4 of Hardenbol *et al.* (1998).

An hiatus spans the interval from Wag-19 and Wag-20 (Text-fig. 4). Rögl *et al.* (2005, 2006, 2007) and Hohenegger *at al.* (2009) have related this hiatus to the Lan2/Ser1 sequence boundary of Hardenbol *et al.* (1998) and have estimated its duration at about 600 ky. An additional hiatus of unknown duration is probably present between the sandy sediments and the carbonate unit.

MATERIALS AND METHODS

The samples for foraminiferal investigations were prepared using the standard technique described in Spezzaferri and Ćorić (2001). Approximately 600 to 1000 specimens per sample were counted. Specimens of benthic and planktonic foraminifera were then identified with a binocular microscope and counted.

Smear slides for calcareous nannofossil analyses were prepared following the standard preparation technique of Perch-Nielsen (1985) and studied by light microscope at 1000-x magnification. Approximately 350 specimens for each sample were counted. Raw microfossil data were then transformed into percentages of the total microfossil abundance and percent abundance curves were plotted. Species with phylogenetic affinities and similar environmental significance were also grouped to better interpret the distribution patterns. Criteria for grouping Paratethyan foraminifera follow Spezzaferri and Ćorić (2001) and Spezzaferri (2004).

Univariate and multivariate statistics were applied to quantitative data using the Software PRIMER 5 (Plymouth Marine Laboratory). Application of this method to planktonic and benthic foraminifera is extensively discussed in Basso and Spezzaferri (2000) and Spezzaferri and Ćorić (2001). Data were double-squared root transformed (no standardization, no further species reduction) in order to highlight the contribution of the less abundant species and simplify the interpretation of the data structure (Field *et al.* 1982). Data were used for hierarchical agglomerative clustering based on the Bray-Curtis Similarity (Clifford and Stephenson 1975). Samples were ordered by non-metric MultiDimensional Scaling (nMDS) on the basis of the same similarity matrix (Kruskal 1977). The nMDS is an iterative procedure to represent the "distance" of samples from a multidimensional space on the basis of rank dissimilarities. Clusters identified both in the dendrograms and nMDS plots, at the same similarity level, were further investigated through the Similarity and Dissimilarity Term Analyses, to highlight the contribution of each species to the total average similarity and dissimilarity within each group and between different groups.

RESULTS

Biostratigraphy and micropalaeontology

Text-fig. 2 shows the correlation of Paratethyan regional stages in the interval from the Ottnangian (Burdigalian) to the Sarmatian (Serravallian) with the chrono- and sequence stratigraphy and planktonic foraminiferal bioevents. Abundance curves of selected microfossil species and groups from Profile A are shown in Text-figs 5a–c. Abundance curves of microfossil species and groups from Profile C are shown in Text-figs 6a–c. Quantitative raw data are in Appendix I to III.

Profile A

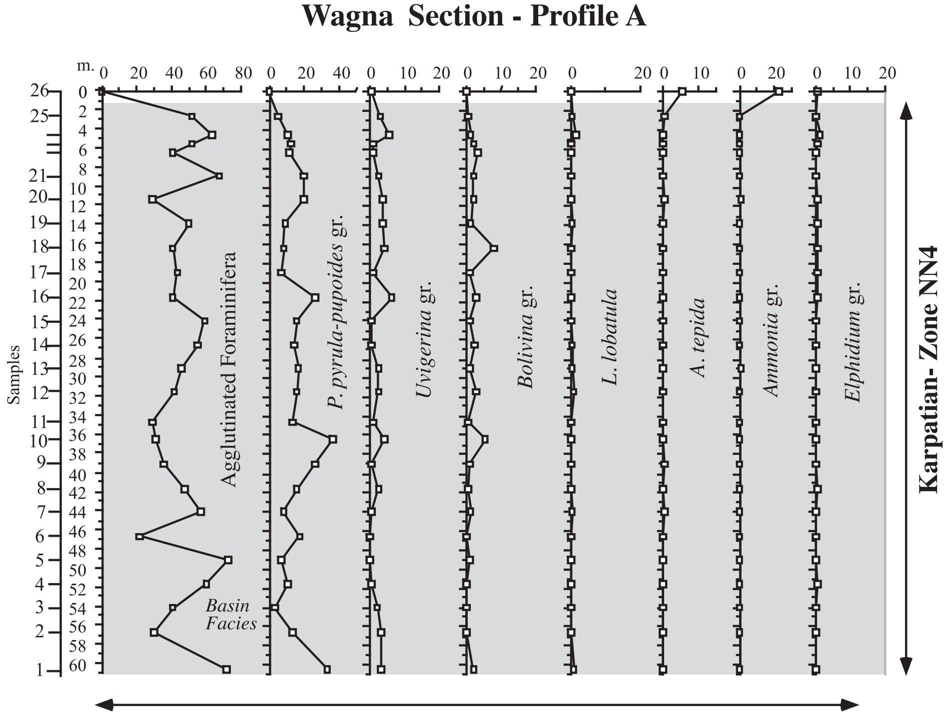
Preliminary description of microfossil assemblages from Profile A (Karpatian) was reported by Spezzaferri *et al.* (2002, 2004) and therefore only information relevant to this study and/or not previously published is given here. Foraminiferal assemblages in Profile A are moderately to well preserved and consist predominantly of agglutinated benthic taxa. The planktonic fauna is rare and dominated by *Globigerina ottnangiensis.* The sediments are attributed to the Middle Karpatian based on the presence of *Uvigerina graciliformis, Pappina primiformis* and a typical small-sized planktonic foraminiferal assemblage in the absence of younger species such as *Globigerinoides bisphericus.* The absence of this marker species suggests that Upper Karpatian sediments are probably missing at Wagna. Sample Wag-26 contains abundant *Ammonia* spp. It is located above the Early Badenian transgression horizon. Although it does not contain any marker species, it is attributed to the Early Badenian because it is placed above the unconformity related to the "Styrian Tectonic Phase" that occurs in the Lowermost Badenian (e.g., Rögl *et al.* 2002, 2007) (Text-fig. 5a–b).

Calcareous nannofossil assemblages from Profile A indicate Zone NN4 of Martini (1971) throughout the section, based on the presence of *Sphenolithus heteromorphus* and rare *Helicosphaera ampliaperta.* Sample Wag-26 from the sandy layer at the top of the section contains more common *H. ampliaperta* than the grey marly sediments below. *Coccolithus pelagicus* predominates throughout the section, whereas *H. ampliaperta* never exceeds 5% (Text-fig. 5c).

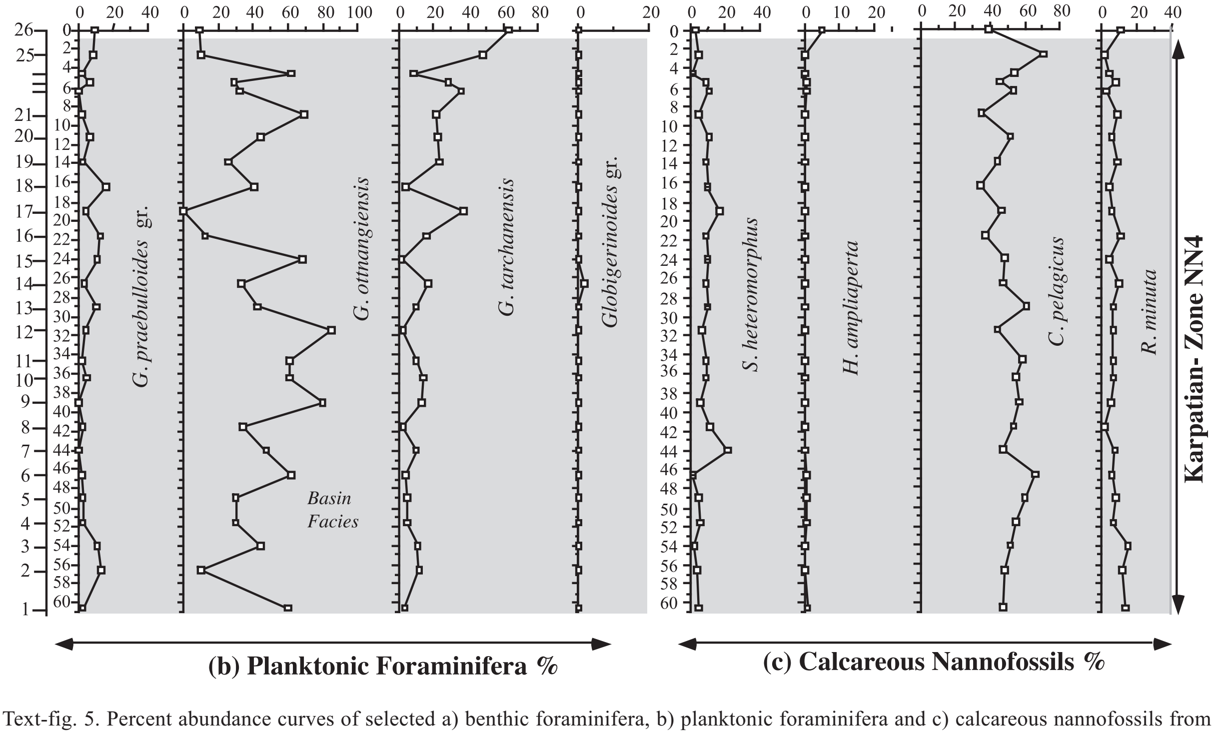
Profile C

Samples Wag-1 to Wag-7 of Profile C record benthic assemblages similar to those described for Profile A. Samples Wag-8 to Wag-14 and Wag-17 to Wag-18 contain shallow water assemblages dominated by *Ammonia* spp. Samples Wag-15 and Wag-16 contain dominant fragments of *Porites*, abundant large eponinids and *Lobatula* spp. Amphisteginids, *Elphidium* spp. and the *Lobatula* group characterize the carbonate unit at the top of the section (Text-fig. 6a, Appendix I). *Praeorbulina sicana,* which marks the Karpatian–Badenian boundary, first appears in sample Wag-9 (Text-fig. 6b and Appendix II). *Praeorbulina circularis* occurs in sample Wag-22. Badenian sediments are also identified from sample Wag-15 based on the presence of large eponinids, which are typical of warm-water carbonate platform sediments from this time interval in the Paratethys (Rögl, personal communication).

Nannofossil assemblages from Wagna Profile C are also very rich and well preserved (Text-fig. 6c; Appendix III). The NN4/NN5 zonal boundary is tentatively placed between samples Wag-19 and Wag-20 based on the presence of *Sphenolithus heteromorphus* and the last occurrence of *Helicosphaera*



(a) Benthic Foraminifera %



(b) Planktonic Foraminifera %

(c) Calcareous Nannofossils %

Text-fig. 5. Percent abundance curves of selected a) benthic foraminifera, b) planktonic foraminifera and c) calcareous nannofossils from Profile A *ampliaperta* in sample Wag-19. *Helicosphaera waltrans* is present in sample Wag-21 and indicates Zone NN5 of Martini (1971). *H. waltrans* was reported from Zone NN5 in the Roggendorf borehole (Ćorić and Rögl 2004), the Mühlbach section (Ćorić 2002), and the Grund section (Ćorić and Švábenická 2004) in the Austrian Molasse Basin. Švábenická and Cyroká (1999) and Švábenická (1993, 2000, 2002) reported this species in sediments from the same interval from the Carpathian Foredeep in the Moravian area, Czech Republic and Lower Austria. In the Slovak part of the Vienna Basin *H. waltrans* was also described in this interval by Andreyeva-Grigorovich *at al.* (2001). Recently Abdul Aziz *et al.* (2008) dated the First Common Occurrence (FCO) of this taxon at 15.476 Ma and its Last Common Occurrence (LCO) at 14.357 Ma. Therefore, *H. waltrans* is a good marker for the lower part of Zone NN5 within the Lower Badenian. A noteworthy feature is the decrease in abundance of *Coccolithus pelagicus* and the corresponding increase in abundance of *Reticulofenestra minuta* at the NN4/NN5 zonal boundary (Text-fig. 6c).

Quantitative analyses and statistical treatment of data

The quantitative analyses of planktonic and benthic foraminifera and calcareous nannofossils were performed on samples from Profile A and C to evaluate species abundance and diversities (Text-figs 4–5).

Since patterns of community structures are often not readily apparent (Clark and Warwick 1994), we have also performed a statistical treatment of our data to better identify and characterize changes in the assemblage structures and relate these to changing environmental conditions. In particular, we have combined the cluster analyses based on the Bray-Curtis Similarity and the non-metric MultiDimensional Scaling (nMDS). This method offers better results than other statistical techniques (e.g., eigenvectors) but is rarely applied to foraminiferal studies (Parker and Arnold 1999). Univariate statistics was used to calculate the Shannon-Wiener Index (H') and the number of species for the three microfossil groups studied for each sample.

In Profile A these indices do not give relevant environmental information because of the relative homogeneity of assemblage compositions and the curves are therefore omitted. In Profile C (Text-fig. 7) the number of benthic species drops drastically to values never exceeding 30 from sample Wag-8 upward. In the same interval the number of planktonic species also decreases to around 5, but increases again to about 10 corresponding to the carbonate build-up. Calcareous nannofossils decrease to 10 species from samples Wag-20 to Wag-22. The Shannon-Wiener Index for the benthic and planktonic foraminifera shows low values from samples Wag-8 to Wag-14 and an opposite trend upward. The H' index for calcareous nannofossils increases from samples Wag-8 to Wag-14 and shows a drastic decrease between sample Wag-19 and Wag-20 (Text-fig. 7).

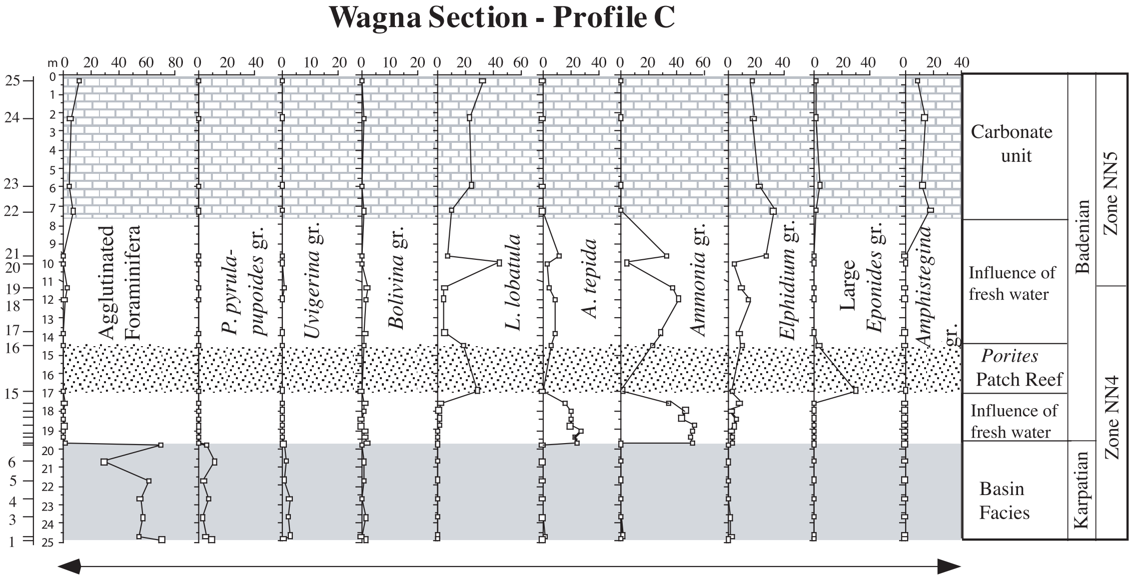
The multivariate statistical analyses, including agglomerative clustering based on the Bray-Curtis Similarity, are shown in Text-figs 8a–c, non-Metric Multidimensional Scaling (nMDS) plots are shown in Text-figs 9a–c.

At the 40% of the Bray-Curtis Similarity four clusters separate for the planktonic and benthic foraminifera (Text-figs 8a–b, 9a–b). At the 63% of the Bray-Curtis Similarity, three clusters separate for the calcareous nannofossils (Text-figs 8c, 9c). Species and groups accounting for the average similarity and dissimilarity in all clusters are listed in order of decreasing contribution in Text-figs 10–12.

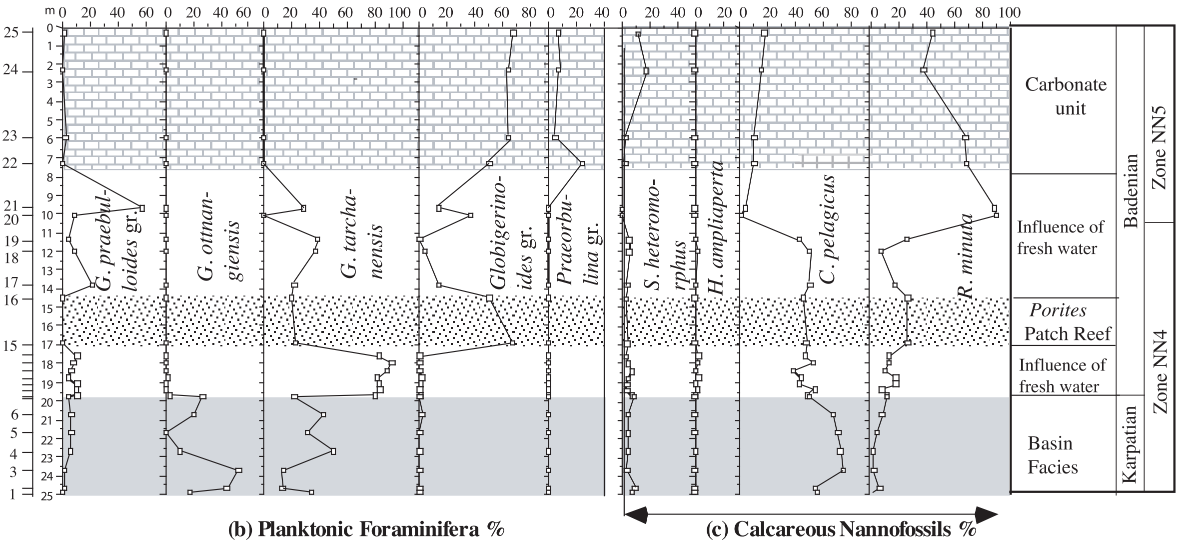
DISCUSSION

Paratethyan microfossil assemblages differ substantially from Mediterranean and oceanic assemblages due to the complex palaeogeographic evolution of this marginal basin (Rögl 1999). Several endemic species and morphotypes of more widely distributed species are present in the Paratethys, especially in the Miocene, making correlations with the world oceans problematic (Rögl and Steininger 1984). The palaeoenvironmental significance of these endemic species and morphotypes is still poorly known. Therefore, to obtain a well constrained palaeoenvironmental interpretation we have compared the percentage curves (Text-figs 5, 6) and the results of the multivariate statistical treatment (Text-figs 8, 9) to better understand our data and have an independent control of our interpretation.

The ecological preferences of the benthic and planktonic foraminifera and calcareous nannofossils are taken from literature data (e.g., among others, McIntyre and Be 1967; Haq and Lohmann 1976; Kuhnt and Kaminski 1990; Cimermann and Langer 1991; Van der Zwaan and Jorissen 1991; Beaufort and Aubry 1992; Jorissen *et al.* 1992; Sgarrella and Montcharmon-Zei 1993; Jones 1994; Spezzaferri 1995; Bernhard *et al.* 1998; Basso and Spezzaferri 2000; Spezzaferri and Ćorić 2001; Spezzaferri 2004).



(a) Benthic Foraminifera %

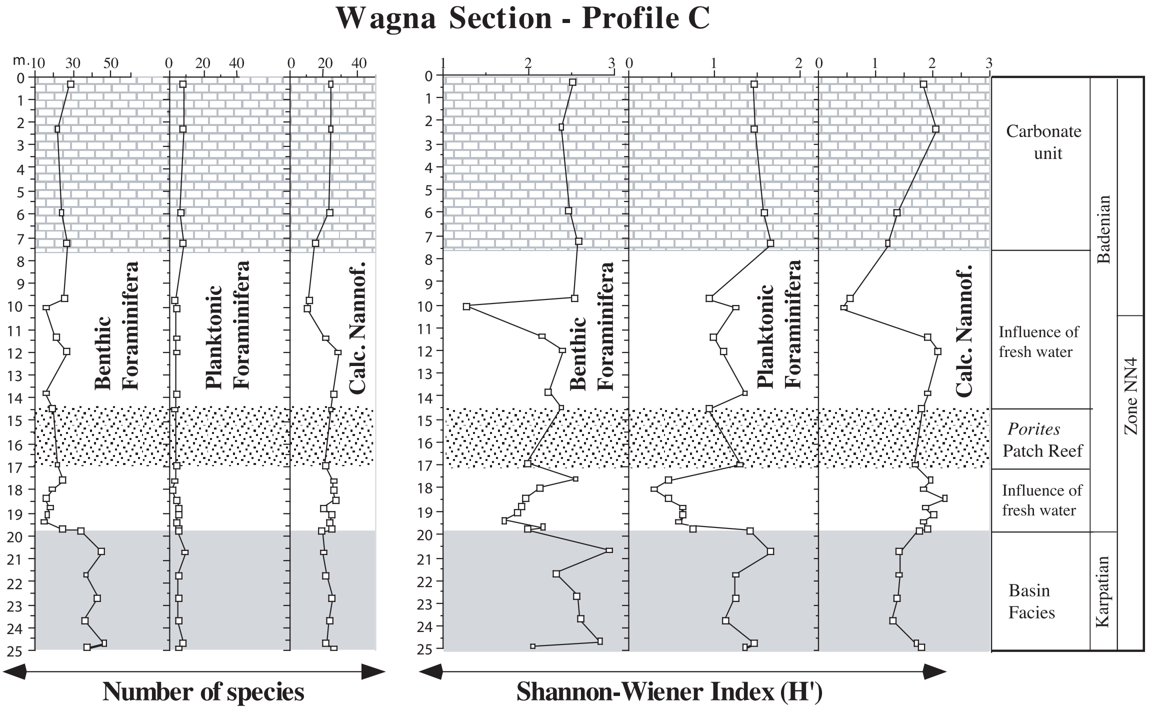


(b) Planktonic Foraminifera % **(c) Calcareous Nannofossils %**

Text-fig. 6. Percent abundance curves of selected a) benthic foraminifera, b) planktonic foraminifera and c) calcareous nannofossils from Profile C

Statistical treatment

Comparison between the Similarity and Dissimilarity Term Analyses of the benthic and planktonic foraminifera (Text-figs 8a, 9a, 10), their abundance curves and their ecological preference suggests that Clusters 1 to 4 of the benthic and planktonic foraminifera are strictly correlated; they contain almost the same set of samples, showing a strict relation between surface and sea-floor processes. Cluster 1 of the benthic and Cluster 1 of the planktonic foraminifera group samples Wag-1 to Wag-25 from Profile A and Wag-1 to Wag-7 from Profile C. It represents the basin facies and is correlated with the sequence stratigraphic cycle TB2.2. Cluster 1 of the benthic foraminifera is dominated by agglutinated and relatively deep-water benthic forms such as *Gaudryinopsis beregoviensis* and *Cribrostomoides* spp., together with low-oxygen species like *Praeglobobulimina pyrula, P. pupoides*, *Valvulineria complanata, Bulimina elongata*, and *Caucasina* spp. (Kuhnt and Kaminski 1990; Spezzaferri *et al.* 2004). Cluster 1 of the planktonic foraminifera is dominated by *Globigerina ottnangiensis*, a cool water indicator (Spezzaferri and Ćorić 2001), *G. praebul-*



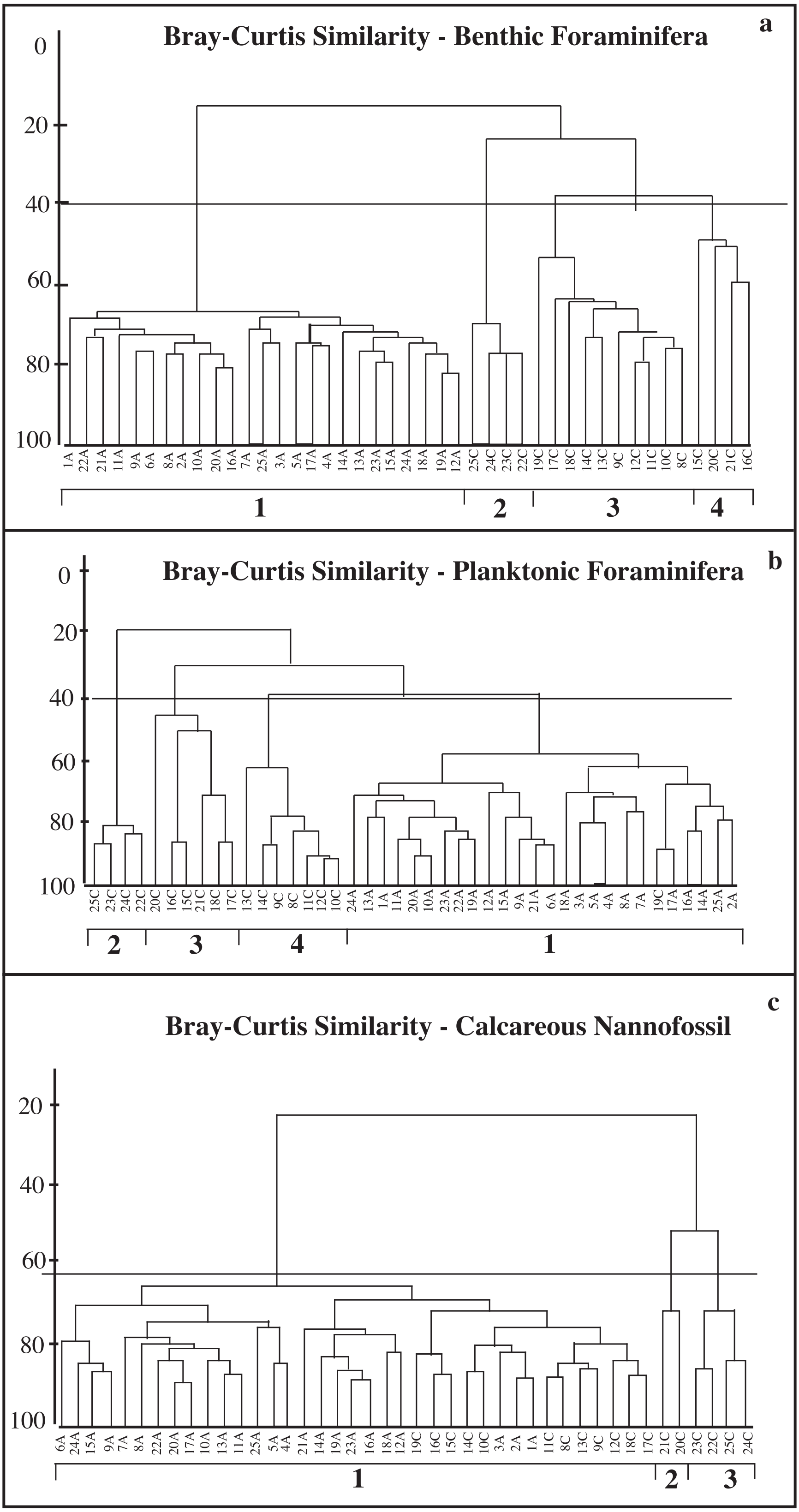
Text-fig. 7. Diversity Indices: Number of Species and Shannon Wiener Index (H') obtained for benthic and planktonic foraminifera and calcareous nannofossils of Profile C

loides and rarer *G. tarchanensis.* This latter species may also be interpreted as a cooler and nutrient-rich surface water indicator (Text-fig. 5a, b).

Cluster 2 of the benthic and Cluster 2 of the planktonic foraminifera group samples from the carbonate unit of Profile C. Cluster 2 of the benthic foraminifera is dominated by *Elphidium,* amphisteginids and *Lobatula*. In modern environments these species occur in shallow water detritic-sandy bottoms or attached, respectively (Sgarrella and Montcharmon-Zei 1993; Basso and Spezzaferri 2000). It represents the fine sand intercalations in the carbonate build-up and corresponds to Cluster 2 of planktonic foraminifera dominated by warm water species like *Globigerinoides* spp., *Praeorbulina* spp. and *Globigerinella obesa* (e.g., Hemleben *et al.* 1989), which may have proliferated during a warming episode (Text-fig. 6a, b).

Clusters 3 and 4 of the benthic and planktonic foraminifera group samples from samples Wag-8 to Wag-21 in Profile C and together they correspond to cycle TB2.3. However, since their palaeoenvironmental significance seems to be slightly different they are here treated separately.

Cluster 3 of the benthic foraminifera is dominated by shallow water species like *Ammonia* spp., *A. tepida*, *Aubignyna perlucida* and *Elphidium* spp. (Text-fig. 6a. b), which are typical of silty-sandy substrata in low-salinity environments (Basso and Spezzaferri 2000; Spezzaferri and Ćorić 2001). In particular, *Ammonia tepida* is also reported from brackish and lagoonal environments, including the terminal Messinian Lago-Mare facies, and is, therefore, considered in the literature as highly tolerant of low salinity (e.g. Cita *et al.* 1980; Spezzaferri *et al.* 1998). Sgarrella *et al.* (1983) and Sgarrella and Montcharmon-Zei (1993) reported this species together with other low salinity tolerant species in poorly diversified assemblages collected in front of river mouths. These lines of evidence suggest that during the intervals between samples Wag-8 and Wag-14 benthic foraminifera were living under low salinity conditions probably related to the presence of braided rivers, as evidenced by the fan delta deposits in the eastern and northern basin margins (Friebe 1993). This interpretation is also supported by the trends of the Number of Species and the Shannon-Wiener Indices (Text-fig. 7). The Shannon-Wiener Index (H') express the degree of species diversity within each sample and can be related to environmental stress (Warwick and Clarke 1995). In particular, diversity declines when sea and fresh water meet, albeit these waters may be highly fertile, productive and support dense populations of some species (Lassere 1992; Spezzaferri *et al.* 2000). The great abundance of the planktonic species *Globigerina*

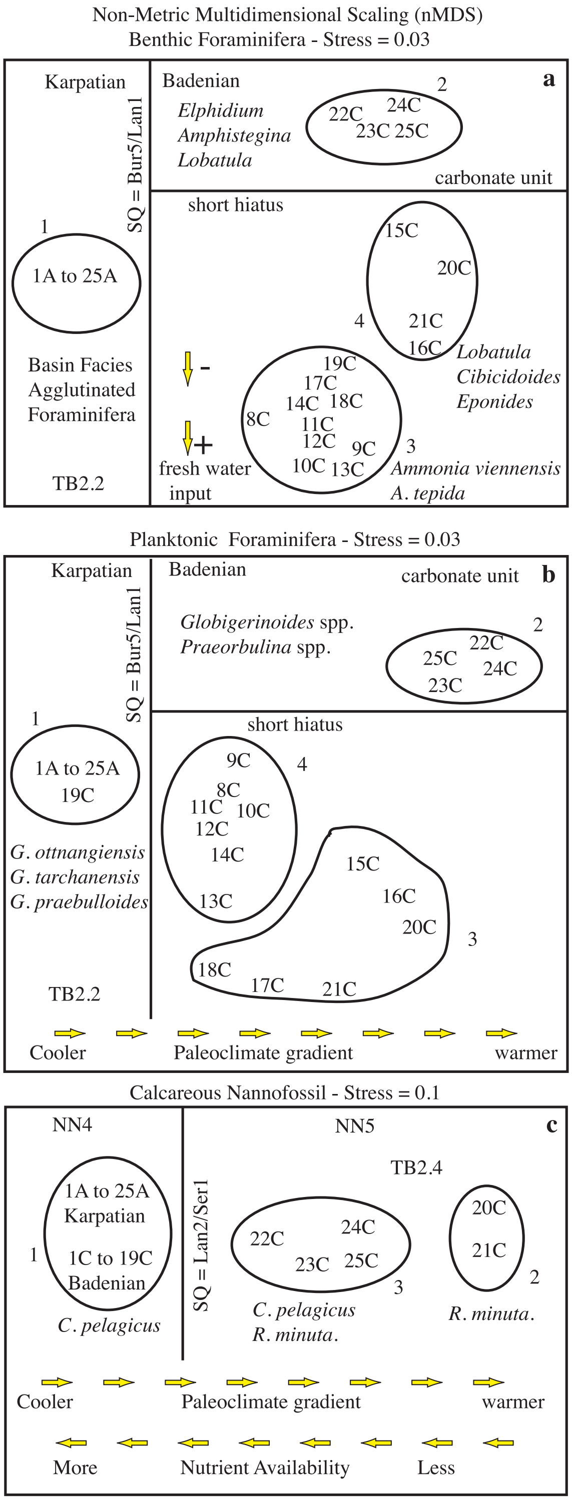


Text-fig. 8. Hierarchical agglomerative clustering based on the Bray-Curtis Similarity of A. benthic foraminifera, B. planktonic foraminifera and C. calcareous nannofossils *tarchanensis* in this interval also suggests its possible preference for nutrient rich waters (Text-figs 6b, 11).

Cluster 3 of the planktonic foraminifera is dominated by *Globigerinoides* spp., *Globigerina praebulloides* and *G. tarchanensis.* The co-occurrence of *Globigerinoides* spp. and a high abundance of *G. praebulloides* (Text-figs 6b, 11) suggests a more temperate climate and possibly high nutrient availability. *Globigerina praebulloides* is, in fact, considered as an indicator of upwelling of cooler and nutrient-rich waters (e.g., Kroon 1988). However, the cluster includes samples Wag-15 and Wag-16 from the *Porites* patch reef yielding benthic foraminiferal assemblages dominated by large eponinids (including *Eponides* cf. *repandus*) and *Lobatula* spp. with rare *Ammonia* spp. (Text-figs 6a, 10). Eponinids are reported to be abundant on circalittoral detritic bottoms, whereas the *Lobatula* gr. prefers to live attached (Cimermann and Langer 1991; Sgarrella and Montcharmon-Zei 1993). These indications are in agreement with a shallow water reef environment, with detrital sediment and characterized by *Porites* colonies. Since it was not possible to trace this horizon over long distances, based on the presence of several other similar restricted horizons in the area, we have interpreted this level as a patch reef deposit.

Cluster 4 of the benthic foraminifera groups samples dominated by *Lobatula* spp., *Cibicides lopjanicus* and the shallow water *Elphidium* spp., with only low percentages of the *Ammonia* group. The Dissimilarity Term Analysis also reveals that this cluster differs from Clusters 1 to 3 in the presence of large eponinids, which occur together with *Porites* in samples Wag-15 and Wag-16 (Text-figs 6a, 10). These samples cluster together with samples Wag-20 and Wag-21 (Text-figs 8a, 9a). Therefore, we interpret Cluster 4 as representing the *Porites* patch reef but also a facies transitional to the overlying carbonate unit characterized by algal prairies where *Lobatula* and *C. lopjanicus* found ideal attachment sites, and by a detritic silty-sandy substratum allowing proliferation of *Elphidium* and *Ammonia*. Cluster 4 of the planktonic foraminifera is dominated by *Globigerina tarchanensis* and *G. praebulloides* (Text-fig. 11). The co-occurrence of high abundances of *Ammonia* spp. at the sea floor and *G. tarchanensis* at the surface suggest a similar response to environmental conditions.

In the calcareous nannofossils, the comparison between the Similarity and Dissimilarity Term Analyses (Text-figs 8c, 9c, 12) and their ecological preferences indicates that Cluster 1 groups samples dominated by *Coccolithus pelagicus* (Text-fig. 6c). The preference of *C. pelagicus* for cool-water temperatures is well known. It is indicated as a stenothermal species adapted to water temperatures ranging from 1.7°C to 18°C. This r-strate-



Text-fig. 9. NonMetric MultiDimensional Scaling (nMDS) of A) benthic foraminifera, B) planktonic foraminifera and C) calcareous nannofossils. The nMDS plot has no dimensions and no axes and can be arbitrarily scaled, located, rotated or inverted. It gives simply the relationship of samples relative to each other. SQ from Rögl *at al.* (2007) and Hohenegger *at al.* (2009)

Cluster 1		**Average similarity = 64.15**		
	Avg. Ab.	**Avg. Sin**	**Contrib.%**	**Cum%**
G. beregoviensis	164.60	26.52	41.35	41.35
P. pyrula-pupoides gr.	65.00	10.23	15.95	57.30
V. complanata	31.00	4.22	6.58	63.88
B. elongata gr.	27.76	3.77	5.88	69.76
A. haueriana	15.32	2.35	3.67	73.43
N. commune	12.88	1.67	2.61	76.04
Caucasina gr.	11.40	1.65	2.58	78.62
Cribrostomoides gr.	14.92	1.65	2.57	81.19
Cluster 2		**Average similarity = 66.97**		
	Avg. Ab.	**Avg. Sin**	**Contrib.%**	**Cum%**
Elphidium gr.	91.50	17.84	26.63	26.63
L. lobatula	92.00	16.10	24.05	50.68
Amphistegina gr.	56.50	10.54	15.73	66.42
Pseudogaudryna gr.	25.75	4.03	6.02	72.44
C. digitalis	27.75	3.99	5.96	78.40
R. semiporata	18.25	3.13	4.67	83.07
R. spinulosa	20.75	3.08	4.60	87.67
H. dutemplei	22.25	2.70	4.03	91.70
Cluster 3		**Average similarity = 65.34**		
	Avg. Ab.	**Avg. Sin**	**Contrib.%**	**Cum%**
A. viennensis	44.30	28.50	43.62	43.62
A. tepida	25.80	13.50	20.66	64.28
A. perlucida	19.10	10.20	15.61	79.88
Elphidium gr.	7.50	3.39	5.19	85.07
A. parkinsoniana	4.60	1.65	2.53	87.60
H. dutemplei	3.40	1.18	1.81	89.41
C. lopjanicus	3.80	1.16	1.77	91.18
Cluster 4		**Average similarity = 39.49**		
	Avg. Ab.	**Avg. Sin**	**Contrib.%**	**Cum%**
L. lobatula	53.25	17.85	45.21	45.21
C. lopjanicus gr.	26.75	8.04	20.36	65.57
Elphidium gr.	25.50	3.93	9.96	75.53
A. viennensis	25.75	3.51	8.89	84.42
H. dutemplei	4.50	1.23	3.10	87.52
A. parkinsoniana	9.50	1.07	2.72	90.24

	Average dissimilarity = 68.76				
	Group 2	**Group 4**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
Elphidium gr.	91.50	25.50	11.41	16.59	16.59
Amphistegina gr.	56.50	1.25	9.07	13.19	29.79
L. lobatula	92.00	53.25	7.95	11.56	41.34
C. digitalis	27.75	0.00	4.48	6.51	47.86
Pseudogaudryna gr.	25.75	0.00	4.20	6.10	53.96
A. viennensis	0.50	25.75	3.93	5.71	59.67
R. spinulosa	20.75	0.50	3.51	5.10	64.77
Eponinids	8.25	20.50	3.42	4.97	69.74
C. lopjanicus gr.	8.00	26.75	3.29	4.79	74.52
R. semiporata	18.25	1.50	2.87	4.17	78.69

	Average dissimilarity = 92.70				
	Group 2	**Group 3**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
L. lobatula	92.00	3.50	16.28	17.56	17.56
Elphidium gr.	91.50	7.50	15.38	16.59	34.15
Amphistegina gr.	56.50	0.00	10.28	11.09	45.24
A. viennensis	0.50	44.30	8.03	8.66	53.90
C. digitalis	27.75	0.00	4.96	5.35	59.25
A. tepida	0.00	25.80	4.72	5.09	64.34
Pseudogaudryna gr.	25.75	0.00	4.65	5.02	69.36
R. spinulosa	20.75	0.80	3.85	4.15	73.51
A. perlucida	0.00	19.10	3.50	3.78	77.29
R. semiporata	18.25	0.20	3.43	3.70	80.99

	Average dissimilarity = 70.10				
	Group 4	**Group 3**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
L. lobatula	53.25	3.50	16.41	22.44	22.44
A. viennensis	25.75	44.30	10.13	13.86	36.30
C. lopjanicus gr.	26.75	0.70	7.78	10.65	46.95
A. tepida	4.00	25.80	6.87	9.40	56.35
Elphidium gr.	25.50	7.50	5.44	7.45	63.80
Eponinids	20.50	0.00	5.44	7.44	71.24
A. perlucida	2.50	19.10	5.18	7.09	78.32
A. parkinsoniana	9.50	4.60	2.47	3.38	81.70

	Average dissimilarity = 95.76				
	Group 2	**Group 1**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
G. beregoviensis	0.00	164.60	18.61	19.44	19.44
L. lobatula	92.00	0.72	10.47	10.93	30.37
Elphidium spp.	91.50	0.68	10.38	10.84	41.21
P. pyrula-pupoides gr.	0.00	65.00	7.39	7.72	48.93
Amphistegina gr.	56.50	0.00	6.43	6.72	55.65
V. complanata	0.00	31.00	3.52	3.68	59.32
C. digitalis	27.75	0.00	3.13	3.26	62.59
B. elongata gr.	0.00	27.76	3.11	3.25	65.84
Pseudogaudryna gr.	25.75	0.00	2.92	3.05	68.89
R. spinulosa	20.75	0.16	2.43	2.53	71.42
R. semiporata	18.25	0.00	2.14	2.23	73.65
H. dutemplei	22.25	13.28	2.00	2.09	75.74
P. bulloides	0.00	15.64	1.77	1.85	77.59
A. haueriana	0.00	15.32	1.75	1.83	79.43
Cribrostomoides gr.	0.00	14.92	1.71	1.79	81.22

	Average dissimilarity = 95.96				
	Group 4	**Group 1**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
G. beregoviensis	0.00	164.60	24.94	25.99	25.99
P. pyrula-pupoides gr.	0.00	65.00	9.92	10.34	36.33
L. lobatula	53.25	0.72	8.24	8.59	44.92
V. complanata	0.00	31.00	4.73	4.92	49.84
B. elongata gr.	0.25	27.76	4.12	4.30	54.14
C. lopjanicus gr.	26.75	0.00	4.01	4.18	58.32
A. viennensis	25.75	0.32	3.70	3.86	62.18
Elphidium gr.	25.50	0.68	3.53	3.68	65.85
Eponinids	20.50	0.00	2.91	3.03	68.88
A. haueriana	0.00	15.32	2.36	2.46	71.34
Cribrostomoides gr.	0.00	14.92	2.31	2.41	73.75
P. bulloides	0.75	15.64	2.30	2.40	76.14
Textularia gr.	0.00	12.40	1.92	2.00	78.15
H. dutemplei	4.50	13.28	1.73	1.81	79.95

	Average dissimilarity = 94.14				
	Group 3	**Group 1**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
G. beregoviensis	0.00	164.60	27.48	29.19	29.19
P. pyrula-pupoides gr.	0.00	65.00	10.94	11.62	40.82
A. viennensis	44.30	0.32	7.46	7.93	48.74
V. complanata	2.60	31.00	4.77	5.07	53.81
B. elongata gr.	1.40	27.76	4.34	4.61	58.42
A. tepida	25.80	0.20	4.34	4.61	63.03
A. perlucida	19.10	0.64	3.13	3.33	66.36
A. haueriana	0.20	15.32	2.57	2.73	69.09
P. bulloides	0.40	15.64	2.57	2.73	71.81
Cribrostomoides gr.	0.10	14.92	2.53	2.69	74.51
Textularia gr.	0.30	12.40	2.08	2.21	76.72
H. dutemplei	3.40	13.28	1.97	2.09	78.81
N. commune	1.50	12.88	1.90	2.01	80.82

Text-fig. 10. Bray-Curtis Similarity and Dissimilarity of benthic foraminifera. List of species and statistical parameters in Clusters 1–4. The Similarity Term Analysis indicates the species responsible for the similarity among clusters. The Dissimilarity Term Analysis reveals why a cluster differs from the others in term of species composition. Avg.Ab. = Average abundance of single species in the groups of samples analysed; Avg.Sim. = Average similarity; Avg.Dis. = Average dissimilarity; Contrib.% = Percentage contribution of the single species to the total similarity; Cum% = Summary of the percentage contribution of the single species gist form indicates higher nutrient levels and eutrophic conditions. Recent studies of Cachao and Moita (2000) have also demonstrated that this species responds positively to riverine plumes and to upwelling regimes, indicating its preference for nutrient-rich waters. Higher percentages of C. *pelagicus* were also documented in the Karpatian sediments of the Austrian Molasse Basin (Spezzaferri and Ćorić 2001) and the lowermost part of the Middle Miocene (clastic sequence of the Lower Badenian) from the Roggendorf-1 borehole in the Austrian Molasse Basin (Ćorić and Rögl 2004).

Cluster 1 includes the same set of samples grouped in Clusters 1 and 3 of the benthic and planktonic foraminifera. Cluster 2 groups samples dominated by *Reticulofenestra minuta* (Text-fig. 6c), whose ecological preference is still not well known. Small reticulofenestrids dominate nannoplankton assemblages along continental margins (Haq 1980). They were used for the palaeoecological interpretation of Lower/Middle Miocene sediments from the Roggendorf-1 borehole in the Austrian Molasse Basin (Ćorić and Rögl 2004). Blooms of *R. minuta* (up to 90%) in the Lower Badenian sediments of the Vienna Basin (Ćorić and Hohenegger 2008) were interpreted as indicators of a warmer, better-stratified water column in contrast to Karpatian assemblages dominated by *Coccolithus pelagicus.* High abundances of small reticulofenestrids were also documented by Tomanová and Švábenická (2007) in the Carpathian Foredeep in Moravia in the Lower Badenian strata. Comparing the abundance trends of *C. pelagicus* and *R. minuta* with those of foraminifera (e.g. the warm water *Globigerinoides* group, Text-figs 6b) we interpret *R. minuta* as a warmer-water and relatively low nutrients proxy. This cluster also includes the samples representing the transition to the carbonate build-up (Wag-20 and 21). Cluster 3 groups samples dominated by both *C. pelagicus* and *R. minuta* and corresponds to Cluster 2 of the benthic and planktonic foraminifera.

Comparing these observations with the bio- and cyclostratigraphy of the Wagna section we can interpret the vertical line in the nMDS plots of the benthic and planktonic foraminifera (Text-fig. 9a, b) to be the Karpatian-Badenian transition, equated to the "Styrian Discordance" and thus to sequence boundary Bur1/Lan5 (Rögl *et al.* 2007; Hohenegger *at al.* 2009). The same line also represents the fresh water input gradient in the nMDS plot of the benthic foraminifera. The horizontal line represents the passage to the carbonate unit devel-

Cluster 1		**Average similarity = 48.95**		
	Avg. Ab.	**Avg. Sin**	**Contrib.%**	**Cum%**
G. ottnangiensis	33.00	25.19	51.45	51.45
G. tarchanensis	10.42	9.20	18.79	70.24
T. quinqueloba	7.12	7.51	15.35	85.59
G. obesa gr.	4.73	3.35	6.84	92.42
Cluster 2		**Average similarity = 74.96**		
	Avg. Ab.	**Avg. Sin**	**Contrib.%**	**Cum%**
Globigerinoides gr.	32.25	56.74	75.69	75.69
Praeorbulina gr.	6.75	9.37	12.50	88.19
G. obesa gr.	5.50	8.52	11.37	99.56
Cluster 3		**Average similarity = 46.28**		
	Avg. Ab.	**Avg. Sin**	**Contrib.%**	**Cum%**
Globigerinoides gr..	3.17	22.81	49.29	49.29
G. tarchanensis	2.83	14.83	32.05	81.34
G. preabulloides gr.	1.67	7.04	15.20	96.54
Cluster 4		**Average similarity = 73.51**		
	Avg. Ab.	**Avg. Sin**	**Contrib.%**	**Cum%**
G. tarchanensis	53.86	64.58	87.85	87.85
G. preabulloides gr.	5.86	6.41	8.72	96.57

	Average dissimilarity = 85.75				
	Group 2	**Group 3**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
Globigerinoides gr.	32.25	3.17	52.37	61.08	61.08
Praeorbulina gr.	6.75	0.00	12.88	15.02	76.10
G. obesa gr.	5.50	0.17	9.67	11.28	87.37
G. tarchanensis	0.00	2.83	5.24	6.11	93.49
	Average dissimilarity = 85.07				
	Group 3	**Group 4**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
G. tarchanensis	2.83	53.86	68.78	80.85	80.85
G. preabulloides gr.	1.67	5.86	5.75	6.76	87.61
Globigerinoides gr.	3.17	0.43	4.58	5.38	92.99
	Average dissimilarity = 93.51				
	Group 2	**Group 1**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
Globigerinoides gr.	32.25	0.04	32.80	35.08	35.08
G. ottnangiensis	0.00	33.00	27.11	28.99	64.07
G. tarchanensis	0.00	10.42	9.92	10.61	74.67
T. quinqueloba	0.00	7.12	7.90	8.4	83.12
Praeorbulina gr.	6.75	0.00	7.12	7.6	90.73
	Average dissimilarity = 74.92				
	Group 1	**Group 4**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
G. tarchanensis	10.42	53.86	36.77	49.07	49.07
G. ottnangiensis	33.00	0.57	23.47	31.32	80.39
T. quinqueloba	7.12	0.43	6.54	8.72	89.12
G. preabulloides gr.	3.19	5.86	3.20	4.28	93.39
	Average dissimilarity = 84.77				
	Group 3	**Group 1**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
G. ottnangiensis	0.00	33.00	40.57	47.87	47.87
G. tarchanensis	2.83	10.42	12.91	15.24	63.10
T. quinqueloba	1.00	7.12	12.77	15.06	78.16
G. obesa gr.	0.17	4.73	5.96	7.03	85.20
Globigerinoides gr.	3.17	0.04	5.74	6.77	91.97
	Average dissimilarity = 94.08				
	Group 2	**Group 4**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
G. tarchanensis	0.00	53.86	48.34	51.38	51.38
Globigerinoides gr.	32.25	0.43	30.03	31.92	83.30
Praeorbulina gr.	6.75	0.14	0.00	6.83	90.14

Text-fig. 11. Bray-Curtis Similarity and Dissimilarity of planktonic foraminifera. List of species and statistical parameters in Clusters 1–4 oped in a different environmental setting. We interpret the horizontal line in the nMDS plot of the planktonic foraminifera (Text-fig. 9b) to be the passage to the carbonate platform equated to a short hiatus (Text-fig. 4). The palaeotemperature gradient is shown in the lower part of the nMDS. We finally interpret the vertical line on the left side of the nMDS plot of the calcareous nannofossils to represent the passage from Zone NN4 to NN5 equated to sequence boundary Lan1/Ser2 of Hardenbol *et al.* (1998) and the two horizontal lines at the base of the nMDS plot to be the nutrient availability and palaeotemperature gradients.

SUMMARY AND CONCLUSION

During the Karpatian (cycle TB2.2), the water depth in the Styrian Basin did not exceed 300 m (Hohenegger 2004) as testified by the agglutinated benthic foraminiferal fauna (Spezzaferri *et al.* 2004). Cool conditions with relatively high nutrient input prevailed in the basin, suggested by the high abundance of cool water indicators e.g., *Globigerina ottnangiensis* (Spezzaferri and Ćorić 2001), *G. praebulloides*. *Globigerina tarchanensis* is consequently interpreted as high nutrient preferring species based on its abundance trend consistent with the evidence of nutrient-enriched waters. The “Styrian Tectonic Phase” produced the tilting of the “Steirischer Schlier” and the angular unconformity (“Styrian Discordance”). The corresponding hiatus spans an interval of about 400 ky (Rögl *et al.* 2007). At the beginning of the Badenian the sea ingressed again into the Styrian Basin (cycle TB2.3), but the water depth remained relatively shallow, not exceeding 50–100 m (Hohenegger 2004). The shallow water assemblages which proliferated at this time were dominated by *Ammonia* spp. and *Elphidium* spp. and reflected fresh water input from adjacent rivers, the evidence for which can be found in the sediments cropping out in the surrounding areas (Friebe 1993). Riverine plumes induced high productivity in the basin throughout calcareous nannofossil Zone NN4; however, they probably decreased in the interval corresponding to the development of the *Porites* patch reef. During this interval environmental condition became favourable to corals and the associated foraminiferal assemblages (e.g., *Eponides* spp.), while the higher abundance of *Globigerinoides* spp. indicated enhanced warming. This episode was probably very short and newly established riverine input resulted in the decline of the *Porites* patch reef, favouring the more tolerant low salinity species *Ammonia* spp. and *Elphidium* spp.

A sedimentation gap marked the passage from nannofossil Zone NN4 to NN5. The environmental change in this interval is clearly reflected in the inverse abundance trends of *Coccolithus pelagicus* and *Reticulofenestra minuta* (Text-fig. 6c). *Coccolithus pelagicus* became rare, responding to a warmer climate and lower nutrient availability. *Reticulofenestra minuta* became abundant and is therefore interpreted as a warmer-water and lower-nutrient proxy by comparison with the abundance trends of *C. pelagicus* and foraminifera (e.g., the *Globigerinoides* group – warm water indices). The carbonate unit was the sedimentary expression of a tropical-like climate and environment.

Cluster 1		**Average similarity = 77.94**		
	Avg. Ab.	**Avg. Sin**	**Contrib.%**	**Cum%**
C. pelagicus	162.14	45.34	58.17	58.17
H. carteri	48.81	11.19	14.36	72.53
R. minuta	34.81	6.88	8.82	81.35
S. heteromorphus	22.11	4.68	6.00	87.35
S. moriformis	10.14	2.16	2.77	90.12
Cluster 2		**Average similarity = 91.27**		
	Avg. Ab.	**Avg. Sin**	**Contrib.%**	**Cum%**
R. minuta	315.00	88.70	97.18	97.18
Cluster 3		**Average similarity = 76.74**		
	Avg. Ab.	**Avg. Sin**	**Contrib.%**	**Cum%**
R. minuta	198.75	45.60	59.42	59.42
C. pelagicus	47.75	10.68	13.92	73.34
H. carteri	23.75	5.48	7.14	80.48
R. haqii	20.75	4.56	5.94	86.42
S. heteromorphus	29.25	3.39	4.41	90.83

	Average dissimilarity = 35.45				
	Group 3	**Group 2**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
R. minuta	198.75	315.00	16.31	46.02	46.02
C. pelagicus	47.75	9.00	5.45	15.36	61.39
S. heteromorphus	29.25	0.50	4.03	11.37	72.75
H. carteri	23.75	4.00	2.78	7.83	80.58
R. haqii	20.75	11.00	1.61	4.54	85.12
H. waltrans	9.50	2.50	0.99	2.79	87.90
Thoracosphaera gr.	6.75	0.00	0.95	2.68	90.58
	Average dissimilarity = 58.34				
	Group 3	**Group 1**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
R. minuta	198.75	34.81	23.88	40.92	40.92
C. pelagicus	47.75	162.14	16.61	28.46	69.38
H. carteri	23.75	48.81	3.82	6.55	75.93
S. heteromorphus	29.25	22.11	3.46	5.93	81.87
R. haqii	20.75	6.81	2.06	3.53	85.40
H. waltrans	9.50	0.00	1.38	2.36	87.76
S. moriformis	5.00	10.14	1.00	1.71	89.46
S. pulchra	0.25	5.95	0.82	1.41	90.87
	Average dissimilarity = 83.44				
	Group 2	**Group 1**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
R. minuta	315.00	34.81	41.45	49.67	49.67
C. pelagicus	9.00	162.14	22.63	27.12	76.79
H. carteri	4.00	48.81	6.65	7.97	84.76
S. heteromorphus	0.50	22.11	3.21	3.84	88.60
S. moriformis	0.50	10.14	1.42	1.71	90.31

Text-fig. 12. Bray-Curtis Similarity and Dissimilarity of calcareous nannofossils. List of species and statistical parameters in Clusters 1–3

Acknowledgement

This study is part of Project P-13743-Bio and Project P-14366-Geo focused on the paleoecology of the marine Miocene in Austria and paleoenvironments of the Eastern Alps, respectively. Thanks to J. Hohenegger and P. Pervesler (Vienna) and their students, R. Roetzel (Vienna) and A. Kroh (Graz) who helped during the sampling campaign. We also thank T. Suttner for drawing the profiles of the Wagna Section. The manuscript was reviewed by K. Holcová, B. Olszewska and the editor I. Walaszczyk.

REFERENCES

Abdul Aziz, H., Di Stefano, A., Foresi, L.M., Hilgen, F.J., Iaccarino, S.M., Kuiper, K.F., Lirer, F., Salvatorini, G. and Turco, E., 2008. Integrated stratigraphy and 40Ar/39Ar chronology of early Middle Miocene sediments from DSDP Leg 42A, Site 372 (western Mediterranean). *Palaeogeography, Palaeoclimatology, Palaeoecology,* **257**, 123–138.

Andreyeva-Grigorovich, A. S., Kovac M., Halásová, E. and Hudácková, N. 2001. Litho- and biostratigraphy of the Lower and Middle Miocene sediments of the Vienna Basin (NE part) on the basis of calcareous nannoplankton and foraminifers. *Scripta Facultatis Scientiarum Naturalium Universitatis Masarykianae Brunensis, Geology*, **30**, 27–40.

Auer, J. 1996. Biostratigraphische und magnetostratigraphische Untersuchungen im Grenzbereich Unter- und Mittelmiozän (Karpatium/Badenium) der Paratethys, Ziegelei Aflenz/Wagna, Steirisches Beken, Steiermark, Oesterreich. *Dissertation Formal -und Naturwissenschafliche Fakultät*, Universität Wien pp. 1–138. [unpublished]

Basso, D. and Spezzaferri, S. 2000. The distribution of living (stained) benthic foraminifera in Iskenderun Bay (Eastern Turkey): a statistical approach. *Bollettino Società Paleontologica Italiana*, **39**, 359–370.

Beaufort, L. and Aubry, M.-P. 1992. Paleoceanographic implications of a 17-M.Y.-long record of high latitude Miocene calcareous nannoplankton fluctuations. *Proceeding of the Ocean Drilling Program, Scientific Results*, **120**, 539–549.

Bernhard, J.M., Sen Gupta, B.K. and Borne, P.F. 1998. Benthic foraminiferal proxy to estimate dysoxic bottom-water oxygen concentrations: Santa Barbara Basin, U.S. Pacific continental margin. *Journal of Foraminiferal Research*, **27**, 301–310.

Cachao, M. and Moita, M.T. 2000. *Coccolithus pelagicus*, a productivity proxy related to moderate fronts off Western Iberia. *Marine Micropaleontology*, **39**, 131–155.

Cimerman, F. and Langer, M.R. 1991. Mediterranean Foraminifera, pp. 1–119, Slovenska Academia Znanosti in Umetnosti; Ljubljania.

Cita, M.B., Vismara-Shilling, A. and Bossio, A. 1980. Stratigraphy and paleoenvironment of the Cuevas del Almazora Section (Vera Basin). A re-interpretation. *Rivista Italiana Paleontologia e Stratigrafia*, **86**, 215–240.

Clarke, K.R. and Warwick, R.M. 1994. Changes in marine communities: an approach to statistical analysis and interpretation, pp. 1–144, Plymouth Marine Laboratory; Plymouth.

Clifford, H.T. and Stephenson, W. 1975. An introduction to numerical classification, pp. 1–229. Academic Press; New York.

Ćorić, S. and Rögl, F. 2004. The Early to Middle Miocene section of Roggendorf 1 and the position of the Grund Formation (Molasse Basin, Lower Austria). *Geologica Carpathica*, **55**, 165–178.

Ćorić, S. and Hohenegger, J. 2008. Quantitative analyses of calcareous nannoplankton assemblages from the Baden-Sooss section (Middle Miocene of Vienna Basin, Austria). *Geologica Carpathica*, **59**, 447–460.

Ćorić, S. and Švábenická, L. 2004. Calcareous nannofossil biostratigraphy of the Grund formation (Molasse Zone, Lower Austria). *Geologica Carpathica*, **55**, 147–153.

Ebner, F. and Sachsenhofer, R.F. 1991. Die Entwicklungsgeschichte des Steirischen Tertiärbeckens. *Mitteilungen der Abteilung für Geologie und Paläontologie am Landesmuseum Joanneum*, **49**, 1–96,

Fenninger, A. and Hubmann, B. 1997. Palichnologie an der Karpatium/Badenium-Grenze des Steirischen Tertiärbeckens (Österreich). *Geologisch-Paläontologische Mitteilungen*, *Innsbruck*, **22**, 71–83.

Field, J.G., Clarke, K.R. and Warwick, R.M. 1982. A practical strategy for analyzing multispecies distribution patterns. *Marine Ecology Progess Series*, **8**, 37–52.

Friebe, J.G. 1990. Lithostratigraphische Neugliederung und sedimentologie der Ablagerungen des Badenium (Miozän) um die Mittelsteirische Schwelle (Steirische Becken, Österreich). *Jahrbuch der Geologisches Bundesandstalt, Wien*, **133**, 223–257.

Friebe, J.G. 1991. Neotektonik an der Mittelsteirischen Schwelle (Österreich): "Die Steirische Phase", *Zentralblatt für Geologie und Paläontologie, Stuttgart Teil 1*, **1,** 41–54.

Friebe, J.G. 1993. Sequence Stratigraphy in a Mixed Carbonate-Siliciclastic Depositional System (Middle Miocene; Styrian Basin, Austria). *Geologische Rundschau,* **82**, 281–294.

Haq, B.U. 1980. Biogeographic history of Miocene calcareous nannoplankton and paleoceanography of the Atlantic Ocean. *Micropaleontology*, **26**, 414–443.

Haq, B.U. and Lohmann, G.P. 1976. Early Cenozoic calcareous nannoplankton biogeography of the Atlantic Ocean. *Marine Micropaleontology*, **1**, 119–194.

Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, T., Gracianski, P.C., de and Vail, P.R. 1998. Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins. In: P.C., de Gracianski, J., Hardenbol, T., Jacquin, and P.R. Vail (Eds), Mesozoic and Cenozoic sequence stratigraphy of European basins. SEPM Special Publication, **60**, 3–13. Tulsa.

Hemleben, C., Spindler, M. and Anderson, O.R. 1989. Modern Planktonic Foraminifera, pp. 1–363. Springer; New York.

Hiden, H. and Stingl, K. 1998. Neue Ergebnisse zur Stratigraphie und Paläogeographie der "Eibiswalder Schichten" (Miozän, Weststeirisches Becken, Österreich): Die Otolithenfauna der Tongrube Gasselsdorf. *Geologisch-Paläontologische Mitteilungen, Innsbruck*, **23**, 77–85.

Hohenegger, J. 2004. Estimation of environmental paleogradient values based on presence/absence data: a case study using benthic foraminifera for paleodepth estimation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **217**, 115–130.

Hohenegger, J., Rögl, F., Ćorić, S., Pervesler, P., Lirer, F., Roetzel, R. Scholger, R. and Stingl, K. 2009. The Styrian Basin: A key to the Middle Miocene (Badenian/Langhian) Central Paratethys transgression. *Austrian Journal of Earth Sciencs*, **102**, 102–103.

Jones, R.W. 1994. The Challenger Foraminifera, pp. 1–151. The Natural History Museum, Oxford University Press; London.

Jorissen, F.J., Barmawidjaja, D.M., Puskaric, S. and Van der Zwaan, G.J. 1992. Vertical distribution of benthic foraminifera in the northern Adriatic Sea: The relation with the organic flux. *Marine Micropaleontology* **19**, 131–146.

Kollmann, K. 1965. Jungtertiär im Sterischen Becken. *Mitteilungen der Geologischen Gesellschaft in Wien*, **57**, 479–632.

Krainer, B. 1988. Bericht 1987 über die geologische Aufnahme auf Blatt 204 Arnfels. *Jahrbuch der Geologischen Bundesandstalt, Wien*, **131**, 622–623.

Krainer, B. 1989. Bericht 1988 über die geologische Aufnahme auf Blatt 204 Arnfels. *Jahrbuch der Geologischen Bundesandstalt, Wien*, **133**, 204–205.

Kroon, D. 1988. The planktic δ^{13}C record, upwelling and climate. In: Brummer G.J.A., Kroon, D. (Eds), Planktonic foraminifers as tracer of ocean-climate history, pp. 335–346. VU Uitgeverij; Amsterdam.

Kruskal, J.B. 1977. Multidimensional scaling and other methods for discovering structures. In: K., Enslein, A. and Ralston, H.S. Wilf (Eds), Statistical methods for digital computers, pp. 296–339. John Wiley; New York.

Kuhnt, W. and Kaminski, M.A. 1990. Paleoecology of Late Cretaceous to Paleocene deep-water agglutinated foraminifera from the North Atlantic and western Tethys. In: Ch. Hemleben, M.A., Kaminski, W., Kuhnt, and D.B. Scott (Eds), Paleoecology, biostratigraphy, paleoceanography and taxonomy of agglutinated foraminifera. NATO ASI Series, Series C: Mathematical and Physical Sciences, Kluwer Academic Publishers, Dordrecht, **327,** 433–506.

Lassere, P. 1992. The role of biodiversity in marine ecosystems. *International Union Biological Science Press, Monograph*, **8**, 105–130.

Martini, E. 1971. Standard Tertiary and Quaternary Calcareous Nannoplankton Zonation. Proceedings of the II Planktonic Conference, pp. 739–785, Ed. Tecnoscienza; Roma.

McIntyre, A. and Be, A.W.H. 1967. Modern Coccolithophoridae of the Atlantic Ocean. I. Placoliths and cribriliths. *Deep Sea Research*, **14**, 561–597.

Parker, W.C. and Arnold, A.J. 1999. Quantitative methods of data analysis in foraminiferal ecology. In: B.K., Sen Gupta (Ed.), Modern Foraminifera, pp. 71–92. Kluver Academic Publisher; Dordrecht.

Perch-Nielsen, K. 1985. Cenozoic calcareous nannofossils. In: H.M., Bolli, J.B., Saunders, K. Perch-Nielsen (Eds), Plankton Stratigraphy, pp. 427–555. Cambridge University Press; Cambridge.

Popov, S.V., Akhmet'ev M.A., Zaporozhets, N.I., Voronina, A.A. and Stolyarov, A.S. 1993. Evolution of Eastern Paratethys in the Late Eocene-Early Miocene. *Stratigraphy and Geological Correlation*, **1**, 572–600.

Rögl, F., Ćorić, S., Hohenegger, J., Pervesler, P., Roetzel, R., Scholger, R., Spezzaferri, S. and Stingl, K. 2005. The Styrian tectonic phase – A series of events at the Early/Middle Miocene boundary revised and stratified (Styrian Basin, Central Paratethys). Regional Committee on Mediterranean Neogene Stratigraphy, pp. 191–192. Vienna.

Rögl, F., Ćorić, S., Hohenegger, J., Pervesler, P., Roetzel, R., Scholger, R., Spezzaferri, S. and Stingl, K. 2006. The Styrian tectonic phase – A series of events at the Early/Middle Miocene boundary revised and stratified in the Styrian Basin. European Geosciences Union (EGU8), A-10733.

Rögl, F., Ćorić, S., Hohenegger, J., Pervesler, P., Roetzel, R., Scholger, R., Spezzaferri, S. and Stingl, K. 2007. Cyclostratigraphy and transgressions at the Early/Middle Miocene (Karpatian/Badenian) boundary in the Austrian Neogene basins (Central Paratethys). *Scripta Facultatis Scientiarun Naturalium Universitatis Masarykianae Brunensis, Geology,* **36**, 7–13.

Rögl, F. 1999. Mediterranean and Paratethys. Facts and hypothesis of an Oligocene to Miocene paleogeography (short overview). *Geologica Carpathica*, **50**, 339–349.

Rögl, F. 2001. Mid-Miocene Circum-Mediterranean paleogeography. *Berichte des Institutes der Edwissenschaften Karl-Franzens-Universität Graz,* **4**, 49–59.

Rögl, F. and Steininger, F. 1984. Neogene Paratethys, Mediterranean and Indo Pacific Seaways. In: P., Brencheley (Ed.), Fossil and Climate, pp. 171–200. Wiley and Sons Ltd; New York.

Rögl, F., Spezzaferri, S. and Ćorić, S. 2002. Micropaleontology and biostratigraphy of the Karpatian-Badenian transition (Early-Middle Miocene boundary) in Austria (Central Paratethys). *Courier Forschungsinstitut Senckenberg,* **237**, 47–67.

Sachsenhofer, R.F. 1996. The Neogene Styrian Basin: An overview. *Mitteilungen der Gesellschaft der Geologie und Bergbaustudenten in Österreich,* **41**, 19–32.

Schell, F. 1994. Die Geologie der südlichen Windischen Büheln (Raum Arnfels-Leutschach-Langegg), pp. 1–207. Unpublished Ph. D. thesis Karl Franzen University Graz.

Sgarrella, F., Barra D. and Improta, A. 1983. The benthic foraminifers from the Gulf of Policastro (Southern Tyrrhenian Sea, Italy). *Bollettino Società Naturalisti Napoli,* **92**, 67–114.

Sgarrella, F. and Moncharmon-Zei, M. 1993. Benthic foraminifera in the Gulf of Naples (Italy): systematic and autoecology. *Bollettino Società Paleontologica Italiana*, **32**, 145–264.

Spezzaferri, S. 1995. Planktonic foraminiferal paleoclimatic implications across the Oligocene-Miocene transition in the oceanic record (Atlantic, Indian and South Pacific). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **114**, 43–74.

Spezzaferri, S. 2004. Foraminiferal biostratigraphy and paleoecology of the Grund Formation. *Geologica Carpathica*, **55**, 155–164.

Spezzaferri, S. Basso, D. and Koral, H. 2000. Holocene paleoceanographic evolution of the Iskenderun Bay, South-Eastern Turkey, as a response to river mouth diversions and human impact. *Mediterranean Marine Science*, **1**, 19–43.

Spezzaferri, S. and Ćorić, S. 2001. Ecology of Karpatian (Early Miocene) foraminifera and calcareous nannoplankton from Laa an der Thaya, Lower Austria: a statistical approach. *Geologica Carpathica*, **52**, 361–374.

Spezzaferri, S., Cita, M.B. and McKenzie, J.A. 1998. The Miocene/Pliocene boundary in the Eastern Mediterranean: Results from site 967 and 969. *Proceedings of the Ocean Drilling Program, Scientific Results*, **160**, 9–28.

Spezzaferri, S., Ćorić, S., Hohenegger, J. and Rögl, F. 2002. Basin-scale paleobiogeography and paleoecology: An example from Karpatian (Latest Burdigalian) benthic and planktonic foraminifera and calcareous nannofossils from the Central Paratethys. *Geobios*, **24**, 241–256.

Spezzaferri, S., Rögl, F., Ćorić, S. and Hohenegger, J. 2004. Paleoenvironmental changes and agglutinated foraminifera across the Karpatian/Badenian (Early/Middle Miocene) boundary in the Styrian Basin (Austria, Central Paratethys). In: M., Bubik, M.A. and Kaminski (Eds), Proceedings VI International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, **8**, 423–459.

Stille, H. 1924. Grundfragen der vergleichenden Tektonik, pp. 1–443. Borntraeger; Berlin.

Švábenická, L. and Ctyroká, J. 1999. Biostratigraphic correlation (Foraminifers and Nannofossils) of the Karpatian and lower Badenian sediments in the Alpine-Carpathian Foredeep (Moravia and Lower Austria). *Biuletyn Panstwowego Instytutu Geologicznego*, **387**, 187–188.

Švábenická, L. 1993. Bericht 1992 über die biostratigraphische Bearbeitung von kalkigen Nannoplankton auf Blatt 22 Hollabrunn. *Jahrbuch der Geologischen Bundesandstalt, Wien,* **136**, 639–640.

Švábenická, L. 2000. Bericht 1999 über Untersuchungen an kalkigen Nannoplankton auf den Blättern 22 Hollabrunn und 23 Hadres. *Jahrbuch der Geologischen Bundesandstalt, Wien,* **142**, 388–389.

Švábenická, L. 2002. Calcareous nannofossils of the upper Karpatian and lower Badenian deposits in the Carpathian Foredeep, Moravia (Czech Republic), *Geologica Carpathica,* **53**, 197–210.

Tari, G.C. 1996. Extreme crustal extension in the Raba River extensional corridor (Austria/Hungary). *Mitteilungen der Gesellschaft der Geologie und Bergbaustudenten in Österreich*, **41**, 1–17.

Tomanová, P. and Švábenická, L. 2007. Lower Badenian biostratigraphy and paleoecology: a case study from the Carpathian Foredeep (Czech Republic). *Geologica Carpathica,* **58**, 333–352.

Van der Zwaan, G.J. and Jorissen, F.J. 1991. Biofacial patterns in river-induced shelf anoxia. In: R.V. Tyson and T.H. Pearson (Eds), Modern and Ancient Continental Shelf Anoxia. *Geological Society*, *London, Special Publications*, **58**, 65–82**.**

Warwick, R.M. and Clarke, K.R. 1991. A comparison of methodes for analysing changes in benthic community structure. *Journal of the Marine Biological Association U.K.*, **71**, 225–244.

Manuscript submitted: 25th April 2009
Revised version accepted: 15th October 2009

Appendix 1

Distribution of benthic foraminifera in Profile C from the Wagna section. Specific and generic concepts are retained following Spezzaferri *et. al.* (2004)

Age	Meters	Samples	*Ammomarginulina brevilingulata*	*Allomorphina trigona*	*Alveolophragmium obliquicameratum*	*Ammomarginulina matchigarica*	*Ammonia parkinsoniana*	*Ammonia tepida*	*Ammonia viennensis*	*Amphicorina badenensis*	*Amphimorphina haueriana*	*Amphistegina bogdanowiczi*	*Amphistegina mamilla*	*Angulogerina angulosa*	*Asterigerinata mamilla*	*Asterigerinata planorbis*	*Astrononion stelligerum*	*Aubignyna perlucida*	*Bathysiphon filiformis*	*Bigenerina nodosaria*	*Bolivina dilatata*	*Bolivina fastigia*	*Bolivina hebes*	*Bolivina plicatella*	*Bolivina pokornyi*	*Bolivina sagittula*	*Budashevaella laevigata*	*Budashevaella wilsoni*	*Bulimina elongata* gr.	*Bulimina striata*	*Cassidulina laevigata*	*Caucasina subulata*
B.	0.3	25							2			1	37			29								1								
	2.3	24											65			1					3											
	5.9	23											42		1								1									
	7.3	22										5	76			3					3		1									
	9.7	21					30	8	72				1			20		2			1								1	1		
	10.1	20					5	1	4				1									1										
	11.4	19						7	44		1			1		1		18						1		2						1
	12	18					7	10	62		1							19						3								
	13.8	17						17	36									9						1		1			3			
	14.5	16					2	7	24									7			1											
	16.9	15					1		3				3					1														
	17.6	14					6	23	32								1	17			1			1					2			
	18	13					4	18	28								1	14								1			1			1
	18.4	12						32	35									23											2			1
	18.8	11					6	26	52									44											3			1
	19.1	10					6	45	46									10					1	1					2			1
	19.4	9					4	37	49									28						1		1						
	19.7	8		1			13	43	59									9			4		1						1			
K.	19.8	7			1	5				1	21			4					21		1							1	22			9
	20.7	6	1		4			1		3	10			9				1	11		3								9			11
	21.7	5	2			6				2	22			8				1	68		5								52			26
	22.7	4			1	1					2			2				1	25		2		1				1	2	10		1	6
	23.7	3				3			2		1			2					41		3		1		1		2		38			7
	24.7	2	2		1	3	7				5			2				2	86	1	1							2	9		2	12
	24.9	1	9	1		2					8			1				1	3						8		4		12			4

Age	Meters	Samples	*Cibicides* cf. *refulgens*	*Cibicides lopjanicus*	*Cibicides lopjanicus* gr.	*Cibicidoides ungerianus*	*Coryphostoma digitalis*	*Cornuspira involvens*	*Cribrostomoides moravicus*	*Cribrostomoides* sp. 1	*Cribrostomoides* spp.	*Cribrostomoides subglobosus*	*Cribrostomoides vasiceki*	*Discorbinoides* sp.	*Elphidiella minuta*	*Elphidium angulatum*	*Elphidium crispum*	*Elphidium fichtelianum*	*Elphidium flexuosum*	*Elphidium macellum*	*Elphidium reussi*	*Elphidium* sp.	*Elphidium subumbilicatum*	*Eponides* gr.	*Fissurina laevigata*	*Fissurina saccula*	*Fursenkoina acuta*	*Gaudryinopsis beregoviensis*
B.	0.3	25		11	2		26	4						1			21	41					10	6				
	2.3	24			21		55	9									59	20					2	9				
	5.9	23			5		14	13									7	19		6			41	13				
	7.3	22			4		16	33									87	23					30	5	1			
	9.7	21			22									2	1	4	9	4	1	38	16	10	5					
	10.1	20			8									1			1	5	1				2				1	
	11.4	19			3	3					1				1		4			3			4					
	12	18	2	1											1		7	2		1	6	8	2					
	13.8	17		4	4										2		2					9						
	14.5	16			29												6			2		6		5				
	16.9	15	4	6	48	4									1		1	1		3	1			77				
	17.6	14	10	19													3			2	3		5					
	18	13	2	4																	1		1					
	18.4	12		3																1	6							
	18.8	11		2																2	4							
	19.1	10		2		1															2		1					
	19.4	9		1															1		5							
	19.7	8		2																2	3		1					
K.	19.8	7		3							18																3	223
	20.7	6		7					1		20	1															2	40
	21.7	5		4					1		32							2							2		7	261
	22.7	4		1					1	4	38	2	2	1														154
	23.7	3								2	33												2					79
	24.7	2		2							40	1			1		5				4					2	4	89
	24.9	1		3							57														2		1	259

Appendix 1 c.d.

Age	Meters	Samples	*Glabratellina* sp.	*Globocassidulina globosa*	*Globocassidulina oblonga*	*Globulina gibba*	*Gyroidinoides umbonatus*	*Hansenisca soldanii*	*Hanzawaia boueana*	*Haplophragmoides laminatus*	*Haynesina depressula*	*Heterolepa dutemplei*	*Hyperammina elongata*	*Hyperammina granulosa*	*Lagena clavata*	*Lagena gracilicosta*	*Lagena laevis*	*Lagena semistriata*	*Lagena striata*	*Lapugyna schmidi*	*Lenticulina gibba*	*Lenticulina inornata*	*Lobatula lobatula*	*Melonis pompilioides*	Miliolids	*Neoeponides bradyi*	*Nonion commune*	*Pappina primiformis*	*Pararotalia aculeata*
B.	0.3	25	1									9								4			138		1		2		6
	2.3	24										48			1								105			2			3
	5.9	23					1					9			3								81				1		
	7.3	22				1						23											44			2	3		
	9.7	21						2				7											25						
	10.1	20	1								2												88						1
	11.4	19							1														7				1		
	12	18									1	4											8	1		5	1		
	13.8	17										3											9				5		
	14.5	16	1						1			6								2			27				4		1
	16.9	15	4									5			1								73				15		2
	17.6	14					1				1	1											5				2		
	18	13									2										1		1						
	18.4	12		1			1				3	3											2	1			2		
	18.8	11									3	2					1						3				1		
	19.1	10					1				1	9															1		
	19.4	9					1					4														1			
	19.7	8			1		2				4	8										1		1			2		
K.	19.8	7		1	1			2				5	5	4						2		1					7	3	
	20.7	6			1			2	2	1		66	3		1	2			2				1				6		
	21.7	5		2	6			2	4	3		5	7	3				2		1		3					34	4	
	22.7	4			2		2	3	1	3		39	3	20						1		3					4	2	
	23.7	3			6		3		1		1	2	3	3								2					9	1	
	24.7	2					1	1		3		22	23				1			1		4	1	1			7	3	
	24.9	1		2	1		1	1					3	12						1		3	2				6		

Age	Meters	Samples	*Planostegina costata*	*Plectofrondicularia digitalis*	*Plectofrondicularia raricosta*	*Popovia* cf.	*Porosononion granosum*	*Praeglobobulimina pyrula-pupoides* gr.	*Pseudogaudryina mayeriana*	*Pseudogaudryina karreriana*	*Pseudogaudryina sturi*	*Pullenia bulloides*	*Reophax pilulifer*	*Reticulophragmium karpaticum*	*Reticulophragmium venezuelanum*	*Reussella spinulosa*	*Rosalina semiporata*	*Saracenaria arcuata*	*Semivulvulina deperdita*	*Semivulvulina pectinata*	*Sigmoilopsis foeda*	*Siphonodosaria consobrina*	*Siphonodosaria perscripta*	*Siphonodosaria verneuilii*	*Spirorutilus carinatus*	*Textularia aplanata*	*Textularia laevigata*	*Textularia pala*	*Trifarina bradyi*	*Uvigerina graciliformis*	*Valvulineria complanata*	*Varidentella sp.*
B.	0.3	25	6						30	4	8					7	10		6									1				1
	2.3	24							15		4					18	13		3										1			
	5.9	23							10		1					39	29		1		1	1							1			
	7.3	22	2						13		18					19	21		1					1			1		1			
	9.7	21					3					3													1							
	10.1	20																														
	11.4	19																							2					1		
	12	18			1							2				1						3			1						1	
	13.8	17																				3									1	
	14.5	16					1										3					1										
	16.9	15														2	3															
	17.6	14					1									3	1						1		1						5	
	18	13														1	1					1									1	1
	18.4	12																													3	
	18.8	11										2				1									1						3	
	19.1	10																													7	
	19.4	9																						1							2	
	19.7	8														2									1	2	1			1	3	
K.	19.8	7		1				25				3							1		1				1	1	1			1	6	
	20.7	6		1	2	3	2	41				11	3	2	2			1	1		1	5				3	4			5	42	
	21.7	5						19				1									1					1	1			4	20	
	22.7	4						36				27		2	1						1				2	4	5			12	63	
	23.7	3					1	7				4	1	1	2										1	3	5			6	39	
	24.7	2						23				30	1		1					1		2		1	1	1	8			14	43	
	24.9	1					2	46				6		5	1				2		1	2				2				3	32	1

Appendix 2

Distribution of planktonic foraminifera in Profile C from the Wagna section. Specific and generic concepts are retained following Spezzaferri (1995).

Age	Samples	*Globigerina bollii lentiana*	*Globigerina* cf. *concinna*	*Globigerina dubia*	*Globigerina globosa*	*Globigerina ottnangiensis*	*Globigerina preabulloides* gr.	*Globigerina tarchanensis*	*Globigerinella obesa* gr.	*Globigerinoides bisphericus*	*Globigerinoides quadrilobatus*	*Globigerinoides ruber*	*Globigerinoides* sp.	*Globigerinoides subsacculifer*	*Globigerinoides trilobus*	*Globorotalia bykovae*	*Paragloborotalia siakensis*	*Praeorbulina circularis*	*Praeorbulina sicana*	*Praeorbulina* spp.	*Praeorbulina transitoria*	*Tenuitellinata angustiumbilicata*	*Turborotalita quinqueloba*	*Not identified planktonic foram.*
	25						1		9	9	4			2	36			3		2				10
	24								3	6				3	20	1		1	1	2				9
	23						1		6	3	5				16				2		2			3
	22								4	5	1			1	18			3	2	9				7
	21						4	2			1													
	20						1				1				3							1		5
	19						2	16	1														9	14
Baden.	18						2	8			1												3	8
	17						3	3							2								3	3
	16							2		1					4									3
	15							2	1	3					3									
	14						5	38	1															2
	13						2	21																
	12						5	66	3														1	
	11					1	4	62	4						1								1	4
	10						10	74	4			1											1	
	9						6	49	3										1					
	8		2			3	9	67	2				1											
	7					21	4	17	6														27	4
	6	5		1		13	4	27	5						1		1						4	2
Karp.	5				1		4	18	4														18	13
	4					2	1	9	1														3	2
	3					76	3	20	11														13	21
	2	1		2		54	16	16	14													1	5	13
	1	1				5		10	9														2	2

Appendix 3

Distribution of calcareous nannofossils in Profile C from the Wagna section.

Age	Zones	Meters	Samples	*Braarudosphaera bigelowii*	*Calcidiscus premacintyrei*	*Calcidiscus carlae*	*Calcidiscus leptoporus*	*Calcidiscus tropicus*	*Coccolithus miopelagicus*	*Coccolithus pelagicus*	*Coronocyclus nitescens*	*Cyclicargolithus floridanus*	*Discoaster adamanteus*	*Discoaster deflandrei*	*Discoaster exilis*	*Discoaster variabilis*	*Helicosphaera ampliaperta*	*Helicosphaera carteri*	*Helicosphaera euphratis*	*Helicosphaera granulata*	*Helicosphaera intermedia*	*Helicosphaera mediterranea*	*Helicosphaera minuta*	*Helicosphaera obliqua*	*Helicosphaera pacifica*	*Helicosphaera perch-nielseniae*	*Helicosphaera scissura*	*Helicosphaera vedderi*	*Helicosphaera* sp.	*Helicosphaera walbersdorfensis*	*Helicosphaera waltrans*
B.	NN5	0.3	25		2		1	1	1	65		1						32	1	1									1	1	11
		2.3	24	1				1	2	55					1	2		25	3	1											14
		5.9	23		3			1	1	35		1						20	2		1	1							1		7
		7.3	22		3				1	36								18								1		2			6
		9.7	21							15		1		1				7	1									2	1	1	5
		10.1	20	1						3								1		1											
	NN4	11.4	19				1		6	146							3	18	3	3									1		
		12	18		1	1			7	182	4	1		1			5	30	1			1					16	3	1		
		13.8	17		1				3	182	3	3					2	25									8	1	1	1	
		14.5	16		1		1	1	3	153				1				20		2			1						1	1	
		16.9	15				1		4	165		1					1	27	1								1			1	
		17.6	14	3				1	12	156		1					7	52	1	2						2	3			2	
		18	13				1		5	187							7	39		1						1	2	2			
		18.4	12		1				7	133	2	4		1			3	54					1			1	2				
		18.8	11						8	165		1					9	58									1			1	
		19.1	10				1	1	4	142			1	1			3	44	1	1						1	3			2	
		19.4	9						10	185		3					7	40									1			2	
		19.7	8					1	8	175		2					3	50		1							1	1		1	
K.		19.8	7				1		7	165	1	1						52		1											
		20.7	6			1	2		14	235	1	1	1				1	23													
		21.7	5						9	236		8		1				7	1	1					1						
		22.7	4		1		1		6	248		9					2	5		1									1		
		23.7	3				2	2	3	245		6		1				18	1	1		1									
		24.7	2		3				7	207		4						48	1	1									1		
		24.9	1				2		7	188		8						45	1					1		1	1	1			

Age	Zones	Meters	Samples	*Lithostromation perdurum*	*Helicosphaera* sp.	*Helicosphaera walbersdorfensis*	*Helicosphaera waltrans*	*Pontospher discopora*	*Pontosphaera multipora*	*Pontosphaera* sp.	*Reticulofenestra haqii*	*Reticulofenestra minuta*	*R. pseudoumbilicus* 5-7µm	*R. pseudoumbilicus* >7µm	*Reticulofenestra* sp.	*Reticulofenestra gelida*	*Rhabdosphaera sicca*	*Sphenolithus compactus*	*Sphenolithus conicus*	*Sphenolithus heteromorphus*	*Sphenolithus moriformis*	*Sphenolithus* sp.	*Syracosphaera pulchra*	*Thoracosphaera heimii*	*Thoracosphaera saxea*	*Thoracosphaera* sp.	*Triquetrorhabdulus millowii*	*Triquetrorhabdulus* sp.	*Umbilicosphaera jafari*
B.	NN5	0.3	25		1	1	11				23	168	4		1	1		1		45	3			2	4	1			3
		2.3	24				14				17	136	5			3		2	1	60	12		1	6	1	5			4
		5.9	23		1		7				14	246	3	1	1	3	1			7	4			3		2			2
		7.3	22				6				29	245	4	1						5	1			1	2				
		9.7	21		1	1	5				3	320																	1
		10.1	20								19	310	1							1	1								3
	NN4	11.4	19		1			2			9	88	7	2		11			1	18	11		6				1	1	7
		12	18		1			1	1		13	28	14	4		5		1		19	7		12		6	1			3
		13.8	17		1	1			1	1	11	63	8	7		9		1		11	7	1	10		1	2			2
		14.5	16		1	1				1	6	89	10	3		13				9	5		8	1	1	1			7
		16.9	15			1					4	93	5	2		13				12	4		5	5	1	1			2
		17.6	14			2			3	1	8	45	7	1	1	4				9	5		4	1	2	2			
		18	13					1		1	10	47	8	1	1	9		1		14	9	2	4	1		1	2		1
		18.4	12						2		11	36	4	7		15		1	1	22	19		9	1	1	2	2		3
		18.8	11			1			1	2	7	70	10	1		6		1		15	9		12		1				1
		19.1	10			2			4		11	62	10	2		5				11	7		13	2		1			3
		19.4	9			2			1		11	28	8	1		3		2		12	10	1	6	1	3	2	2	2	
		19.7	8	2		1					8	42	9	1		6		3	1	23	9		12			1	1	1	2
K..		19.8	7								8	38	5	2	1	7		1	1	28	11		6			1			
		20.7	6							1	4	30	8			4		1		15	6		2		2		1		
		21.7	5						1	1	7	17	6	1		8			1	15	11	1			2	3		1	
		22.7	4		1					1	3	6	13	2		5			1	14	16		2	1	2	2	2	1	1
		23.7	3							1	3	7	4	2		5		2		12	7		3		1	3		2	
		24.7	2		1					1	4	24	5	1		3		9	1	35	20	2	1	1		1			
		24.9	1								4	8	1	1		1		9	5	24	21	2	2	2		2	2	1	1