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ECOLOGY OF KARPATIAN (EARLY MIOCENE) FORAMINIFERS AND CALCAREOUS NANNOPLANKTON FROM LAA AN DER THAYA, LOWER AUSTRIA: A STATISTICAL APPROACH

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Abstract: In this study we present a paleoecological interpretation based on quantitative analysis of middle Karpatian (latest Burdigalian) benthic and planktonic foraminifers and calcareous nannofossils from Hole BL 503 (Wienerberger) drilled at Laa an der Thaya, Lower Austria. Multivariate statistics based on the Bray-Curtis Similarity, non-metric MultiDimensional Scaling (nMDS) and Similarity and Dissimilarity Term Analyses are applied to raw data to identify the ecological gradients subtending the assemblages. Species abundance curves (%) were also plotted. A paleoclimatic curve was obtained using the algebraic sum of planktonic foraminifers warm- and temperate-water indicators (positive) and cool-water indicators (negative) to highlight the paleoclimatic trend during the middle Karpatian. Our data indicate that the sediments drilled at Laa Th. were deposited in water depth not exceeding 200 m, relatively "near shore" in an environment characterized by a generally high concentration of organic matter, suboxic to dysoxic conditions, high nutrient availability, variable salinity and generally cool paleoclimate. On the basis of nannoplankton distribution we also suggest that nutrient availability and upwelling conditions, rather than other ecological factors, control the distribution of calcareous nannoplankton in the Molasse Basin.

Key words: Miocene, Karpatian, Lower Austria, Laa an der Thaya, foraminifers, nannofossils, ecology, statistic.

Introduction

The Mediterranean Sea and the intracontinental Paratethys were formed as new marine realms during the Late Eocene. From the Oligocene through the Miocene the Paratethys underwent a complex evolution that produced deep environmental changes with alternate opening and closing of efficient marine connections with the Indian Ocean on the East and the Mediterranean Sea on the West (Rögl 1999).

This research represents the first attempt at paleoecological reconstruction of part of the Laa Formation drilled and cored (Hole BL 503, Wienerberger) at Laa an der Thaya (Laa Th., hereafter) in the Molasse Basin, Lower Austria, spanning the Middle Karpatian (Latest Burdigalian) (Fig. 1). The type locality of the Laa Fm was established in the brickyard at Brandhuber (now Wienerberger). The sediments consist of blue-gray marl and fine sand becoming greenish upward. Diatom-rich sediments also belonging to the Laa Fm were found in Washerbergzone, 5 km eastern of Laa Th. (Grill 1968). Hole BL 503 was drilled just outside the Wienerberger brickyard. Sediments consist of approximately 2 meters of Quaternary loess with sand passing to yellow brownish sand containing variable amounts of silt down to approximately 6 m. They can be correlated to the upper part of the sequence outcropping in the brickyard and consisting of shallow-water deposits, discordantly overlying the calcareous shales. Karpatian homogeneous gray silt and marl with randomly distributed 1-cm thick fine sandy layers occur from 6 m down to 30 m. These sandy layers are interpreted as distal fans (Rögl., pers. comm.).

Materials and methods

Two hundred grams of sediment for each sample were soaked in gasoline for several hours to desegregate the sediments without damaging the specimens and to retain the original faunal composition. Samples were then soaked in warm water and washed under running water through >250 μm, 250–125 μm and >63 μm mesh sieves. The washed residues were split, according to Rupp (1986), to obtain approximately 300 to 500 hundred specimens per fraction. Specimens of benthic and planktonic foraminifers were picked from the three fractions of one split per sample, identified with a binocular microscope and counted. Smear slides were prepared following Perch-Nielsen (1985) and studied under light microscope with a 1000× magnification. Approximately 350 specimens for each sample were counted.

The raw data (Table 1) were then transformed into percentages over the total abundance and percent abundance curves were plotted (Fig. 2). Species with phylogenetic affinities and similar environmental significance were also grouped to better interpret their distribution patterns (Fig. 3, Table 2).

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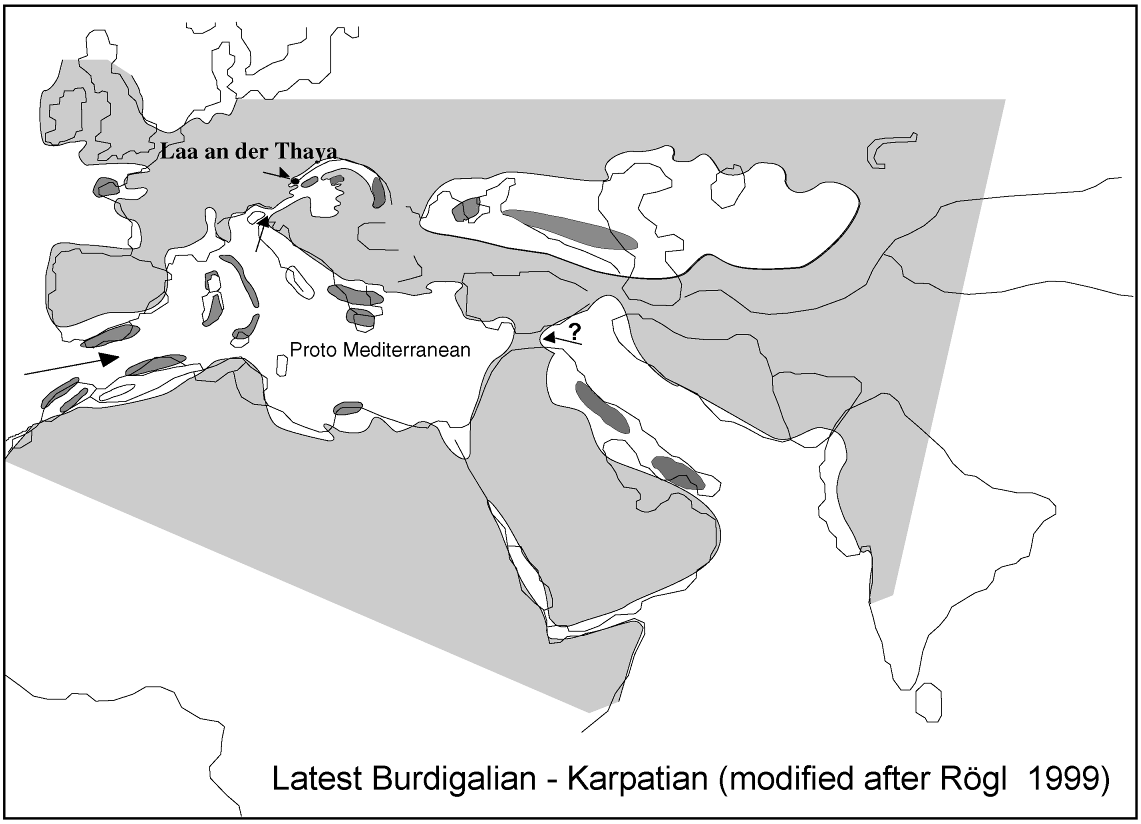

Fig. 1. Paleogeographical map showing the position of Laa an der Thaya during the Karpatian.

Univariate and multivariate statistics are applied to quantitative data using the Software PRIMER 5 (Plymouth Marine Laboratory). Application of this method to planktonic and benthic foraminifers is extensively discussed in Basso & Spezzaferri (2000). However, it was never applied to compare nannofossil and foraminiferal assemblages from the Molasse Basin. Data are 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 are used for hierarchical agglomerative clustering based on the Bray-Curtis Similarity (Figs. 4A–C; Clifford & Stephenson 1975). Group Average Linking is used for benthic and planktonic foraminifers, and Complete Linkage is applied to calcareous nannoplankton assemblages. On the basis of the same similarity matrix, samples are ordered by non-metric MultiDimensional Scaling (nMDS; Figs. 5A–C; 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, are 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. Species and groups accounting for the average similarity and dissimilarity in all clusters are listed in order of decreasing contribution in Tables 3 to 5.

Results

Biostratigraphy

Rögl (1969) studied in detail the foraminiferal biostratigraphy of Laa Th. brickyard. In Hole BL 503, planktonic and benthic foraminifers are relatively well preserved throughout the sequence. Two levels (Samples 15.4 m and 20.9 m) yield a completely pyritized fauna consisting of large globigerinids (e.g. *Globigerina concinna*) and *Globigerinella obesa* group together with *Spiroloculina compressiuscula* and *Virgulinella pertusa*, which are not present in the remaining samples (Table 1*). Bulimina elongata, Valvulineria complanata*, *Praeglobobulimina*, and *Uvigerina* groups peak in correspondence of the pyritized levels (Fig. 2). These levels were previously identified from middle Karpatian sediments in Outer Carpathian basins in Moravia and termed "Virgulinella Horizons" (Vašíček 1951). Reworked specimens were identified, whenever possible, considering their different preservation, and counted separately. Some specimens of selected benthic foraminifers (e.g. *Ammonia* spp.) possibly reworked and present throughout the sequence could not be separated as such as a result of their preservation consistent with the accompanying assemblage (e.g. in Samples 27.8 m and 27.5 m).

The sequence is attributed to the middle Karpatian on the basis of the presence of the pyritized levels and on the typical assemblage containing *Uvigerina graciliformis, Pappina*

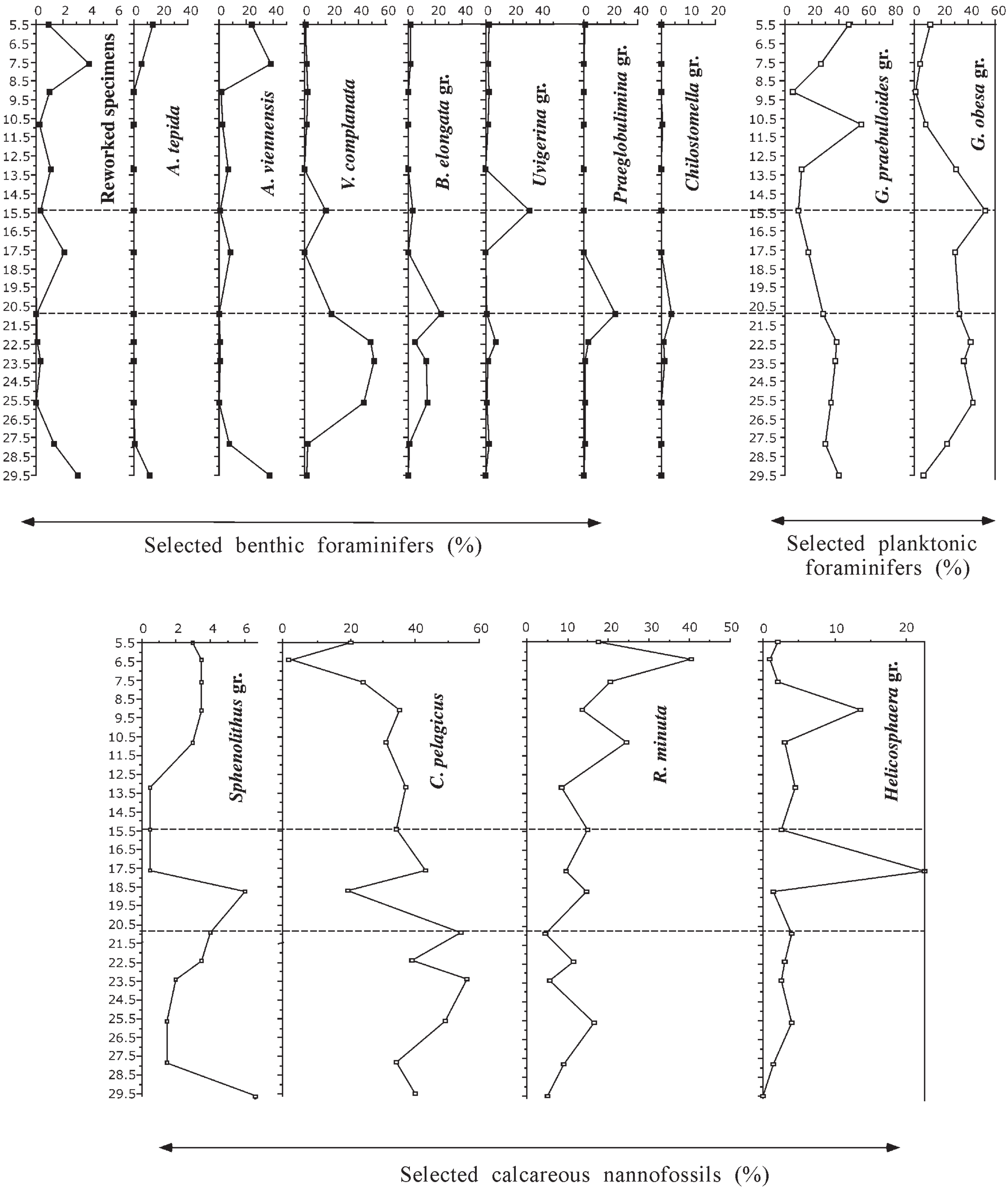

Fig. 2. Abundance curves of selected benthic, planktonic foraminifers and calcareous nannofossil species.

primiformis and *P. breviformis* in the absence of younger species such as *Globigerinoides bisphericus*.

Martini & Müller (1975) studied the calcareous nannofossil content in a few samples from the Karpatian of the Central Paratethys. In Hole BL 503, nannofossil assemblages are relatively well preserved but not rich (from 3–5 specimens/1 field of view to 3–5 specimens/10 fields of view) throughout the section. They are characterized by relatively abundant and constantly present *Calcidiscus leptoporus, Calcidiscus tropicus, Coccolithus pelagicus, C. miopelagicus, Coronocyclus*

Table 1: Distribution of benthic and planktonic foraminifers and calcareous nannofossils in samples from Hole 503, Laa an der Thaya.

Benthic Foraminifera 1

Meters	*Adelosina longirostra*	*Alabamina tangenzialis*	*Alliatina* cf. *excentrica*	*Alliatina tollmanni*	*Ammonia parkinsoniana*	*Ammonia tepida*	*Ammonia viennensis*	*Amphimorphina haueriana*	*Angulogerina angulosa*	*Asterigerinata mamilla*	*Asterigerinata planorbis*	*Astrononion stelligerum*	*Aubignyna perlucida*	*Baggina arenaria*	*Bolivina dilatata* gr.	*Bolivina dilatata maxima*	*Bolivina fastigia*	*Bolivina hebes*	*Bolivina korynoides subtumida*	*Bolivina plicatella*	*Bolivina pokornyi*	*Bolivina sagittula*	*Bulimina elongata* gr.	*Cassidulina carinata*	*Cassidulinoides oblonga*	*Caucasina schischkinskayae*	*Caucasina subulata*	*Chilostomella oolina*	*Chilostomella ovoidea*	*Cibicides tenellus*
5.5–5.6		1	1	1	12	50	86				1		18		5			1				1	5	1	2	17				3
7.6–7.7					2		19						6										1			1				1
9.1–9.2					5	1	9		1	1	1		7	19	16			1		1						18	4			1
10.8–10.9							8						8	16	55										1	42			2	1
13.2–13.3							3						2																	1
15.4–15.5					2		1						3	2	1								6							2
17.6–17.7	2				3		16	2			1	1	2	1		1														4
20.9–21								5						1			1		12		4		94			1		1	13	
22.4–22.5				3	1		4	16	1	1			3	14			12				10		27			9	4		5	
23.4–23.5							3	16	2				3	2			6				9		62			6	8		5	
25.6–25.7					1			7					12	3			5				5		41			5	4			
27.8–27.9		2		1	4	2	15				1		5	4	27						2		1			15	1			
29.5–29.6				1		8	25						6													2cf	1			

Meters	*Cibicidoides* cf. *austriacus*	*Cibicidoides lopjanicus*	*Cycloforina* cf. *contorta*	*Cycloforina gracilis*	*Dentalina boueana*	*Elphidiella heteropora*	*Elphidiella minuta*	*Elphidiella semincisa*	*Elphidiella* sp.	*Elphidiella subnodosa*	*Elphidium angulatum*	*Elphidium* cf. *listeri*	*Elphidium fichtelianum*	*Elphidium macellum*	*Elphidium matzenense*	*Elphidium reussi*	*Elphidium rugosum*	*Elphidium* sp.	*Elphidium subtypicum*	*Elphidium ungeri*	*Escornebovina ? trochiformis*	*Fissurina laevigata*	*Fissurina marginata*	*Fissurina orbignyana*	*Fursenkoina acuta*	*Glabratellina aurantisa*	*Glabratellina patelliformis*	*Globocassidulina globosa*	*Globocassidulina oblonga*
5.5–5.6		4				1	2				1					1							1	1	3			1	4
7.6–7.7		1					1		1																				
9.1–9.2		8								1	2cf		1		1cf	1						1							
10.8–10.9		1					1									1				1cf							1	1	
13.2–13.3		7		1			2		1		3					1					1							2	
15.4–15.5		2	4							1		1				1									3			1	
17.6–17.7		6									2	1				3			2							1cf			
20.9–21																									1			1	
22.4–22.5		3			3																				3				
23.4–23.5					2			1	1																				1
25.6–25.7		1		1																					2			1	
27.8–27.9	2	8	6								1			1cf		1	1	1							2			2	1
29.5–29.6		2						1cf										3										1	

Benthic Foraminifera 2

Meters	*Globulina gibba*	*Grigelis pyrula*	*Hansenisca soldanii*	*Gyroidinoides laevigatus*	*Gyroidinoides umbonatus*	*Hanzawaia boueana*	*Heterolepa dutemplei*	*Lagena clavata*	*Lagena hispida*	*Lagena isabella*	*Lagena laevis*	*Lagena semistriata*	*Lenticulina calcar*	*Lenticulina gibba*	*Lenticulina inornata*	*Lenticulina melvilli*	*Lenticulina orbicularis*	*Lobatula lobatula*	*Melonis pompilioides*	*Miliolids* sp.	*Neoeponides bradyi*	*Nodosaria longiscata*	*Nonion commune*	*Nonionella* cf. *stella*	*Nonionella* sp.	*Oridorsalis umbonatus*	*Pappina breviformis*	*Pappina primiformis*	*Pappina* sp.	*Pararotalia aculeata*
5.5–5.6					2				1		1			1				1	1		3		20				17	4		
7.6–7.7						1													1				3							
9.1–9.2	1	1			3		5	1		1								2	1				8	1			392			
10.8–10.9					5	1	8								2	1cf		2					9				176	3		
13.2–13.3															1								7				1			
15.4–15.5						1									9	2			1	4			11				2			
17.6–17.7						3	9								2			2		2			4				103	2		
20.9–21				1	2	3					1				3							1	11	11	2	4	3	4	6	
22.4–22.5					2	18	1								20	2		1					18			15	4			
23.4–23.5		1			1	7	2					1		1	4	1	1						20			15	1	6		2
25.6–25.7			1	2	2	12							1cf		4								8			13	4	2		
27.8–27.9						5		1							10	1		2					9				41			
29.5–29.6																							7				1			

Meters	*Planularia moravica*	*Plectofrondicularia digitalis*	*Plectofrondicularia inaequalis*	*Plectofrondicularia raricosta*	*Porosononion granosum*	*Porosononion* sp.	*Praeglobobulimina pupoides*	*Praeglobobulimina pyrula*	*Protelphidium roemeri*	*Pseudonodosaria aequalis*	*Pullenia bulloides*	*Pyrgo* juven.	*Quinqueloculina buchiana*	*Quinqueloculina triangularis*	*Reussella spinulosa*	*Riminopsis boueanum*	*Rosalina semiporata*	*Semivulvulina pectinata*	*Sigmoilinita tenuis*	*Siphonodosaria verneuili*	*Sphaeroidina bulloides*	*Spiroloculina badenensis*	*Spiroloculina canaliculata*	*Spiroloculina compressiuscula*	*Spiroloculina excavata*	*Spirorutilus carinatus*	*Stilostomella adolphina*	*Stilostomella advena*	*Stilostomella consorbina*
5.5–5.6					42		2								1							1							4
7.6–7.7					3										1														
9.1–9.2					2	1		1	2cf	1								3		2							1		
10.8–10.9					1													5								2			1
13.2–13.3																1		1			1					1			
15.4–15.5									1				7	1				6					1		1	2			4
17.6–17.7		1			3				1			1	3		1		2	3	1		1								3
20.9–21	1		1	1			23	68		1								2		1		2		4					
22.4–22.5		1		3	1		6	12		1		1				1		1		7		2	1				3		2
23.4–23.5					1		1	2		1	1							2		5		4				1	3		1
25.6–25.7			1	1	2			3		2								3	1	2		2				2	1		1
27.8–27.9	1				6			1	1		1							6							5	2		1	
29.5–29.6					3																								

Table 1: *Continued*

Benthic Foraminifera 3

Meters	*Stilostomella scabra*	*Stilostomella spinescens*	*Textularia* cf. *candeiana*	*Textularia laevigata*	*Textularia pala*	*Triloculina gibba*	*Triloculina neudorfensis*	*Uvigerina acuminata*	*Uvigerina graciliformis*	*Uvigerina parviformis*	*Uvigerina pygmoides*	*Valvulinera complanata*	*Virgulinella pertusa*	*Virgulopsis tuberculatus*	Total benthic
5.5–5.6			13	3					8			2			351
7.6–7.7			2	1						1		1			50
9.1–9.2									12			16			551
10.8–10.9			3						5			7	1	1	372
13.2–13.3													6	1	44
15.4–15.5									54			26		2	165
17.6–17.7			1				1								197
20.9–21								2			1	79	21		393
22.4–22.5								27	13			276			560
23.4–23.5	1	2		1	1	1		5	2		1	236			460
25.6–25.7								2				130			292
27.8–27.9			1						5			5		4	208
29.5–29.6			3	1								1		1	67

Planktonic Foraminifera

Meters	*Beella clavacella*	*Cassigerinella globulosa*	*Globoquadrina larmeui*	*Paragloborotalia acrostoma*	*Globigerina diplostoma*	*Globigerina bollii lentiana* gr.	*Globigerina bulloides*	*Globigerina* cf. *concinna*	*Globigerina concinna*	*Globigerina praebulloides* gr.	*Globigerina regularis*	*Globigerina tarchanensis*	"*Globigerina*" *dubia*	"*Globigerina*" *ottnangiensis*	*Globigerinella obesa* gr.	*Globigerinella siphonifera*	*Globigerinita glutinata*	*Globigerinita juvenilis*	*Globigerinoides trilobus*	*Paragloborotalia inaequiconica*	Not identified	*Tenuitellinata angustiumbilicata*	*Turborotalita* aff. *quinqueloba*	*Zeaglobigerina woodi*	Total Planktonic
5.5–5.6						1				33				19	8			2				3	3		69
7.6–7.7						5				7				8	1			1				4			26
9.1–9.2				1	1	27	5			159		3	1	15	32			3			10	6		1	264
10.8–10.9		1				13				50				13	7			1				3			88
13.2–13.3	1							11	3	6		1	1	5	15				2			4			49
15.4–15.5						8			4	11	7			20	56										106
17.6–17.7				1			1			16				4	12		1					4	1		40
20.9–21	1	1	1			25	4	29	15	87	3			36	109						13				324
22.4–22.5						59			13	246			1	47	268						12				646
23.4–23.5		1				75			7	198	2	1		45	191			1				3			524
25.6–25.7						50			2	143		1		37	184				1		6				423
27.8–27.9						14	3		3	27		2		17	24	1		4	1	2			2		100
29.5–29.6				1		5				12				7	2					1		2			30

Calcareous Nannoplankton

Samples	*Braarudosphaera bigelowii*	*Calcidiscus leptoporus*	*Calcidiscus macintyrei*	*Calcidiscus premacintyrei*	*Calcidiscus tropicus*	*Coccolithus miopelagicus*	*Coccolithus pelagicus*	*Coronocyclus nitescens*	*Cyclicargolithus floridanus*	*Cycloperfolithus carlae*	*Discoaster* spp.	*Geminilithella rotula*	*Hayella* sp.	*Helicosphaera ampliaperta*	*Helicosphaera carteri*	*Helicosphaera euphratis*	*Helicosphaera intermedia*	*Helicosphaera mediterranea*	*Helicosphaera obliqua*	*Helicosphaera paleocarteri*
5.5		13	2		9	1	40	3	13	1	1		1		2				1	
6.6		7	2		10	1	22	2	14		1				1					1
7.6		12		1	11	3	44	4	7	1		2			1					
9.1	1	10			5	2	55	1	9	1		1	2	2	18	1	1			
10.8	1	10	1	1	1	1	51	1	4			1		1	4					
13.2	1	16	1		11	3	57		20	2			3	1	5					
15.4		12		2	17		54		12	1		1	5	1	2	1				
17.6		12		1		1	63	5	6	1				4	27				7	
18.7		15	1		13	1	39	2	14			2	3		1					
20.9	1	9	1	1	6	1	74	2	13	1		3	3	1	4	1				
22.4		13	1		7		59	1	11	1			1	1	2					
23.4	1	14	1	2	6	1	76	3	5	1					2			1		
25.6	1	6		1	8	2	69	1	11	1			1		5					
27.8	1	12		1	13	3	54	4	12	1	1	2	2	1	1					
29.5		13		2	18	4	60	3	8	2		3	2							

Samples	*Helicosphaera scissura*	*Helicosphaera* sp.	*Helicosphaera walbersdorfensis*	*Orthorhabdus serratus*	*Pontosphaera* spp.	*Reticulofenestra ampliumbilicus*	*Reticulofenestra haqii*	*Reticulofenestra minuta*	*Reticulofenestra pseudoumbilicus* 5–7	*Reticulofenestra pseudoumbilicus* >7	*Reticulofenestra* sp.	*Rhabdosphaera* sp.	*Sphenolithus heteromorphus*	*Sphenolithus moriformis*	*Sphenolithus* sp.	*Syracosphaera pulchra*	*Tetralithoides symeonidesii*	*Thoracosphaera heimii*	*Thoracosphaera saxea*	*Thoracosphaera* sp.	*Triquetrorhabdulus milowii*	*Umbilicosphaera jafarii*	Reworked Specimens
5.5		1	1		2	1	26	35	7	3	5			2	3	4	1	1	6	5	1	9	147
6.6							23	81	15	4	1	2		6	1			1	3	2			124
7.6			2		4		16	41	13	6	7	1	2	1	3	1		4	3	5	2	2	165
9.1		4	1	1	7		18	27	8	7	3	2	1	2	2					1		5	143
10.8	1						17	49	9	7	4	1		3	3			1	3	15	4	6	135
13.2	1	2			1		12	17	17	8	4		1			2	1	3		1	5	5	162
15.4	1				3	1	15	30	8	8	2	1		1		4		5		2	3	8	112
17.6		3	4	1	4	1	14	19	10	3	2	1		1		3				1		6	77
18.7			2		5	1	18	29	7	8	5		1	11		1	1			2	7	11	115
20.9		1	1				13	9	10	10	6	2		7				2	1	1	4	11	143
22.4			3		5		22	23	13	5	5			7		2		3		3	3	9	96
23.4			2		5		17	11	12	12	4			4		4					5	11	77
25.6		1	2		6		21	33	6	3	2		1	2		7	1			2	2	5	155
27.8			1	2	3		19	18	14	5	5	1			2	2		1		2	12	4	127
29.5				1	1	1	17	10	6	7	5			11	1	1	1	4	3	12		5	118

nitescens, Cyclicargolithus floridanus, Helicosphaera ampliaperta, H. carteri, Pontosphaera spp., *Reticulofenestra haqii, R. minuta, R. pseudoumbilicus*, together with other minor components listed in Table 1. Reworking strongly affected this group (up to 45 %). Clearly reworked specimens are excluded from the statistical treatment. The occurrence of *H. ampliaperta* and *Sphenolithus heteromorphus* and absence of *Sphenolithus belemnos* indicate the presence of the H. ampliaperta-S. heteromorphus Interval Zone (MNN4a) of Fornaciari et al. (1996) corresponding to the upper part of Zone NN4 of Martini (1971).

Ecology of foraminifers and calcareous nannoplankton

The paleoclimatic-paleoecological significance of Miocene foraminifers and calcareous nannoplankton are deduced from their latitudinal abundance patterns, oxygen and carbon isotopic composition of tests and from comparison of these parameters with those of the modern counterparts. In particular, the paleoecological significance of benthic foraminifers is based on Rögl (1969), Rupp (1986), DeStigter et al. (1988); Nishi (1990), Cimerman & Langer (1991), Murray (1991), Jorissen et al. (1992), Sgarrella & Moncharmont-Zei (1993), Kaiho (1994), Culver et al. (1996), Gupta (1997), Bernhard et al. (1998), Debenay et al. (1998), Basso & Spezzaferri (2000). The paleoecology of the most relevant benthic foraminiferal species identified at Laa Th. is shown in Table 2.

Following Spezzaferri (1995) and Rögl (pers. comm. 2001) planktonic foraminifers were grouped according to their paleoclimatic significance as follows: the warm water indicators are *Globoquadrina larmeui, Globigerinoides trilobus, Paragloborotalia acrostoma*; the temperate water indicators are *Globigerinella obesa, Globigerinella regularis, Globigerinella siphonifera, Globigerina concinna, Paragloborotalia inaequiconica, Zeaglobigerina woodi.* The cool water indicators are *Globigerina praebulloides* group, *"Globigerina" ottnangiensis, "Globigerina" dubia, Globigerina bollii lentiana, Tenuitellinata angustiumbilicata, Turborotalita quinqueloba, Globigerinita juvenilis* and *Globigerinita glutinata*. The abundance trends of paleoclimatic indices were plotted in Fig. 3.

The paleoecological interpretation of the calcareous nannoplakton assemblages is more problematic because this group of microfossils includes coccolithophorids (e.g., *C. pelagicus*) and other incertae-sedis forms such as *Discoaster* and *Helicosphaera.* Our paleoecological interpretation is based mainly on variations in the relative abundances of *C. pelagicus, R. minuta,* and *Sphenolithus* and *Helicosphaera* groups. *Coccolithus pelagicus* is considered a good paleoclimatic indicator (Haq 1977). In modern oceans it prefers cold and nutrient rich surface waters with temperature between 7 and 14 °C (McIntyre & Be 1967). Haq & Lohmann (1976) suggested that this species migrated from the tropics towards the poles during the middle Cenozoic changing its ecological preference. Rahman & Roth (1990) interpreted the relatively high abundances of *C. pelagicus* as related to intense upwelling, and an unstable stratified water column. High abundance of *C. pelagicus* in the middle Miocene subtropical sediments of the Vienna Basin point to a strong influence of nutrient availability (Fuchs & Stradner 1977). Gartner et al. (1983/84) suggested that the size

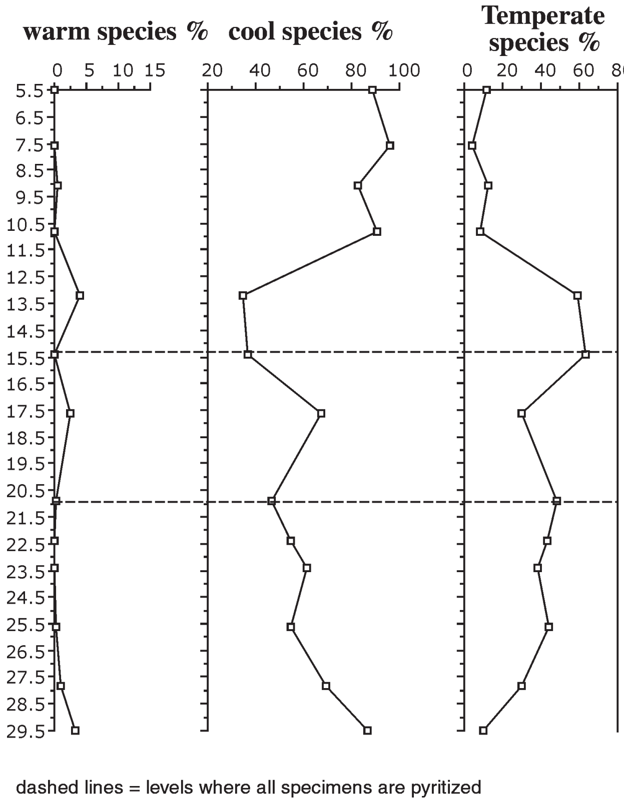

Fig. 3. Planktonic foraminiferal climatic indicators.

of the coccoliths is associated with seasonal fluctuations in nutrients and temperature and that changes in relative abundance of small *R. minuta* (<3 μm) can be a signal of changes in nutrient dynamics. Investigations on living specimens of *H. carteri* from the Atlantic Ocean (McIntyre & Be 1967; Okada & McIntyre 1979) and Pacific Ocean (Okada & Honjo 1973) demonstrated that this species can tolerate temperature ranges from 5 °C to 30 °C (Okada & McIntyre 1979). However, it is more common in tropical and subtropical waters. Perch-Nielsen (1985) remarked that the *Sphenolithus* and *Helicosphaera* groups (in particular, *H. ampliaperta*), most commonly occur in hemipelagic sediments and are generally absent in pelagic sediments. The *Helicosphaera* group is also interpreted as an upwelling-preferring species (Perch-Nielsen 1985).

Statistical treatment

Since patterns of community structures are often not readily apparent (Clark & Warwick 1994), we have performed the statististical treatments of our data to better identify and characterize changes in the assemblage structures and relate these to changing environmental conditions.

Benthic Foraminifers: At 45% of the Bray-Curtis Similarity 3 Clusters separate (Figs. 4A, 5A). Cluster 1 groups Sample 7.6 m and 29.5 m. Six species and/or groups account for the 90.24 % of the average similarity within this group. Cluster 2 groups Samples 20.9 m, 25.6 m, 22.4 m, and 23.4 m. Seven species and/or groups account for 80.70 % of the average similarity within this group. Cluster 3 groups Samples 15.4 m, 5.5

Table 2: Ecological preference of selected benthic foraminifers. Oxic, Suboxic A-C, and dysoxic indicators are as in Kaiho (1994). Terms “epipelic”, “endopelic” and “epiphytic” from Ramade (1993).

Species	**Environment (when known)**	**Preferred depth range (m) when known**	**Preferred substratum (when known)**	**Living strategy (when known)**	**Comments**
Ammonia beccarii/viennensis	Infralitoral, rarely circalitoral (Inner shelf)	Down to 100 m, more abundant 0–50 m	Fine infralit. sand, detritic circal/red algae	Epipelic or shallow endopelic	Salinity >33 ‰
Amphimorphina haueriana	Shelf		Mud-silt		
Ammonia tepida	Infralitoral, rarely circalitoral (Inner shelf)	Down to 100 m, more abundant 0–50 m	Muddy sand, sandy mud, detritic circalitoral	Epipelic or shallow endopelic	Low salinity (<33 ‰), river mouths, low energy
Aubignyna perlucida	Infralitoral, rarely circalitoral (Inner shelf)	Down to 100 m, more abundant 0–50 m	Fine infralit. sand, detritic circal/red algae	Epipelic	Salinity >33 ‰
Baggina arenaria	Shelf		Silt		
Bolivina dilatata	Infralitoral-bathyal (inner shelf to bathyal)	Abundant from 50 to 200	Mud	Shallow endopelic	Low oxygen, tolerant of low food availability
Bolivina hebes-plicatella-pokornyi gr.	Inner shelf to bathyal (inner shelf to bathyal)	Abundant from 50 to 200	Mud	Shallow endopelic or epiphytic	Low oxygen, tolerant of low food availability
Bulimina elongata gr.	Infra-upper circalitoral (inner shelf to bathyal)	Abundant down to 80–100 m	Mud and muddy sand	Endopelic	River mouths, high organic matter, low oxygen
Caucasina schischkinskayae	Infra-upper circalitoral (inner shelf to bathyal)	Abundant down to 80–100 m	Mud and muddy sand	Endopelic	River mouths, high organic matter, low oxygen
Chilostomella ovoidea		50 down to 2000 m	Mud	Endopelic	Dysoxic
Cibicidoides lopjanicus	Shelf to bathyal		Hard substrates	Epiphytic	Oxic
Elphidium sp.	Inner shelf	0–50 m	Mud and sand	Epiphytic	Oxic
Hanzawaia boueana	Inner shelf	0–50	Hard substrates?	Epiphytic	Oxic
Lenticulina gr.	Infralitoral to bathyal (outer shelf and bathyal)	From 20 m down			Suboxic B
Nonion commune	Shelf	0–180 m	Mud and silt	Epipelic-Endopelic	Salinity 30–35 ‰
Oridorsalis umbonatus	Usually bathyal	Usually from 600 m downward	Mud	Endopelic (3 cm and below)	River mouth, high Corg, high nutrients (upw), Temp. down to 4 °C
Pappina sp.	Shelf		Clay-silt	Endopelic	Low oxygen, high Corg?
Porosononion granosum	Infra-circalitoral	0–100 m	Sand with Cymodocea		Low salinity, river mouths, high energy
Praeglobobulimina gr.	Circalitoral to bathyal	80–800			Dysoxic
Spiroloculina compressiuscula	Shelf	0–40	Sediment and/or algae	Clinging	May be present in lagoons
Textularia gr.	Shelf to bathyal	0–500	Hard substrates and sand?	Clinging	May be present in lagoons
Uvigerina gr.	Shelf to bathyal	100 to >4500 m, rarely shallower than 100 m	Mud	Shallow endopelic, rarely epiphytic	Suboxic B, and high organic matter
Valvulinera sp.	Circalitoral to epibathyal	Abundant between 40–100 m	Mud		Low oxygen (dysoxic?), high organic matter
Virgulinella pertusa			Mud		Dysoxic

Epiphytic = living on algae or on seagrass
Epipelic = living in the superficial layer of sediment
Endopelic = living inside the sediments

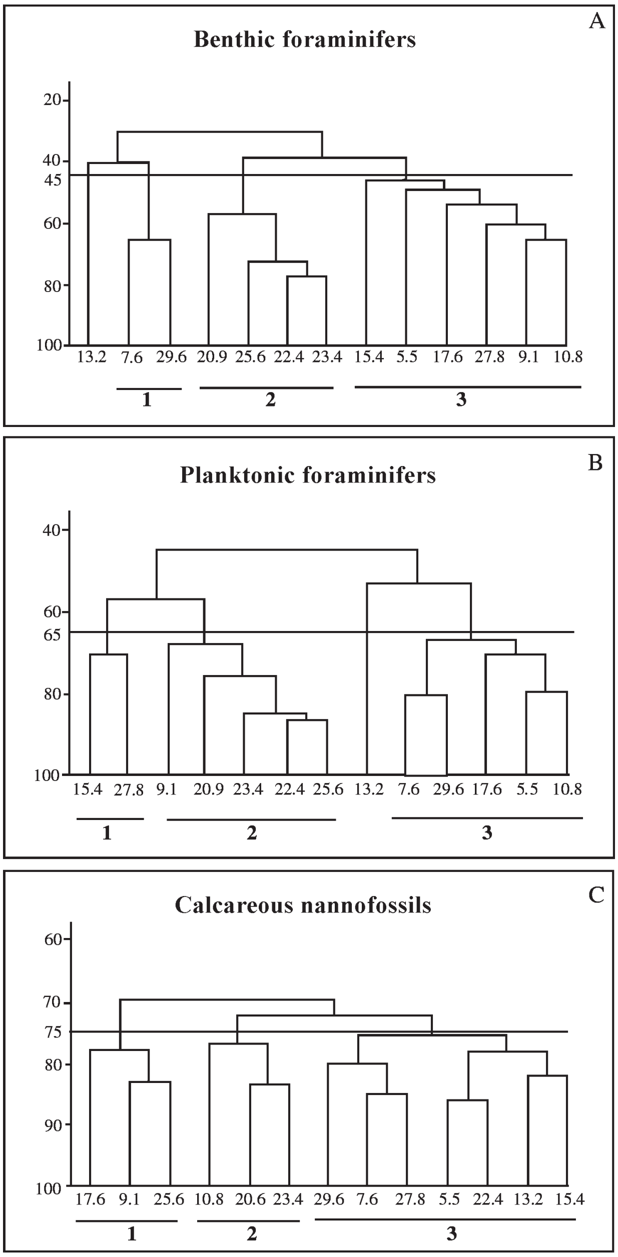

Fig. 4. Hierarchical agglomerative clustering based on the Bray-Curtis Similarity of (A) benthic foraminifers; (B) planktonic foraminifers; (C) calcareous nannofossils.

m, 17.6 m, 27.8 m, 9.1 m, and 10.8 m. Twelve species and/or groups account for 80.54 % of the average similarity within this group.

Planktonic Foraminifers: At 65% of the Bray-Curtis Similarity 3 Clusters separate (Figs. 4B, 5B). Cluster 1 groups Samples 15.4 m and 27.8 m. Four species and/or groups account for 96.82 % of the average similarity within this group. Cluster 2 groups Samples 9.1 m, 20.9 m, 23.4 m, 22.4 m, 25.6 m. Four species and/or groups account for 93.75 % of the average similarity within this group. Cluster 3 groups Samples 7.6 m, 29.5 m, 17.6 m, 5.5 m, 10.8 m. Five species and/or groups account for 80.54 % of the average similarity within this group.

Calcareous Nannofossils: At 75% of the Bray-Curtis Similarity 3 Clusters separate (Figs. 4C, 5C). Cluster 1 groups Samples 17.6 m, 9.1 m, and 25.6 m. Seven species and/or groups account for 83.87 % of the average similarity within

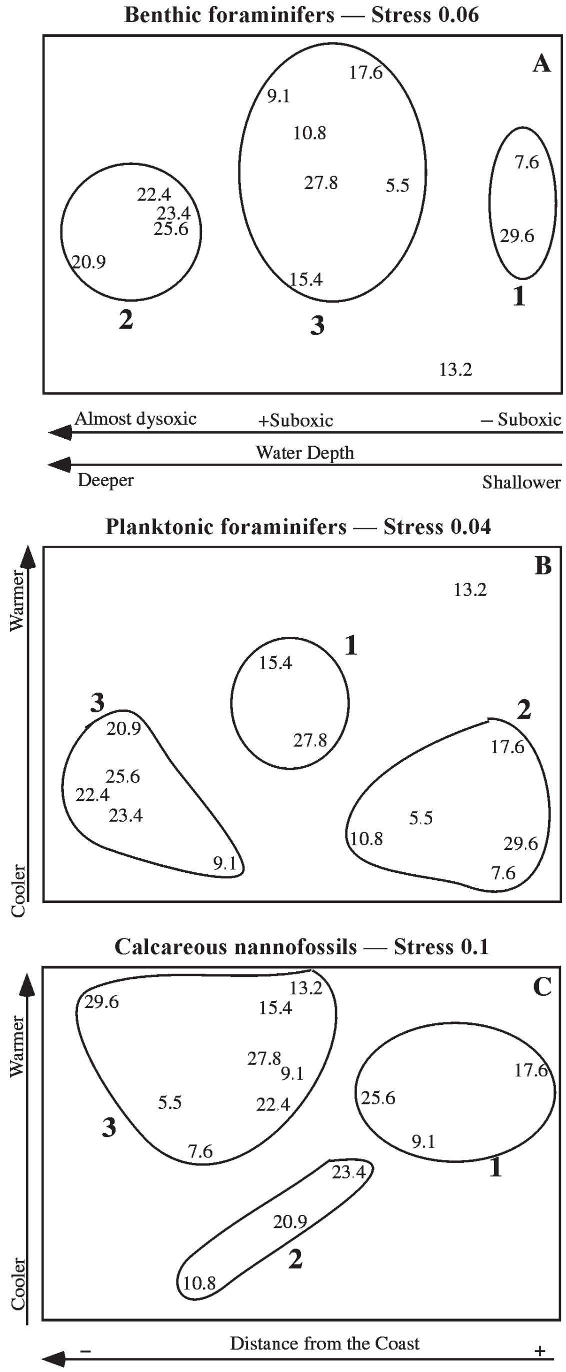

Fig. 5. Non-metric MultiDimensional Scaling (nMDS) plots of (A) benthic foraminifers; (B) planktonic foraminifers; (C) calcareous nannofossils. The order of the group in the nMDS is the order of the same groups in the dendrograms of Fig. 6A–C. Sample position in nMDS and dendrogram may not correspond because of the ordination procedure in the nMDS plot. The stress represents the distortion involved in compressing the data from a multidimensional space into a smaller number of dimensions.

this group. Cluster 2 groups Samples 10.8 m, 20.9 m, and 23.4 m. Eight species and/or groups account for 81.92 % of the average similarity within this group. Cluster 3 groups Samples 29.5 m, 7.6 m, 27.8 m, 5.5 m, 22.4 m, 13.3 m, and 15.4 m. Eight species and/or groups account for 81.12 % of the average similarity within this group.

Discussion

Benthic and planktonic foraminifers and calcareous nannoplankton can provide important information not only concerning biostratigraphy, but can be used also as proxies and tracers of the water mass to reconstruct ancient paleoenvironments.

Paleobathymetry

An approximate water depth for the Laa Formation is assessed through the Plankton/Benthos Ratio, 100P/(P+B) (Fig. 6). According to Murray (1976) we identify an inner shelf environment (values not exceeding 20 %), a middle shelf environment (values 20–40 %) and an outer shelf environment (values 40–60 %). Comparing the preferred depth distribution of living benthic foraminifers (Table 2, and data in the literature) we assume a water depth between 100 and 200 m for the sediment deposited at Laa Th. The shallower water depth observed in Fig. 6 and corresponding to Samples 10.8 and 17.6 may be due to reworking and/or re-deposition of shallower water species. The fine-sandy sediments from the top of the section down to about 8 m (Fig. 2) correlate with the shallow-water deposit observed by Rögl (pers. comm.) outside the Wienerberger brickyard and therefore, sediments from Laa Th. represent a shallowing upward sequence as also indicated by the 100P/(P+B) of Figure 6.

The distribution of calcareous nannoplankton supports our bathymetric reconstruction. The *Helicosphaera* group is interpreted in the literature as "near shore" species (Perch-Nielsen 1985). Its trend in Figure 2 shows increased abundances in correspondence of the samples recording the shallower benthic foraminiferal assemblage and the lowest values of the 100P/(P+B) at 10.8 m and 17.6 m.

Paleoclimatology

Planktonic foraminifers are used to reconstruct the paleoclimatic trend during the investigated part of the Karpatian. The climatic trend deduced from the curve in Figure 7 suggests that cool conditions prevailed during the investigated interval. The coolest conditions are recorded in the upper part of the sequence (from Sample 10.8 m upward). The trend is interrupted by a relatively warmer/temperate episode in its upper middle part (Samples 13.2 and 15.4 m). Increasing abundance of *R. minuta* also indicates climatic stress from the bottom to the top of the section (Fig. 2; Rahman & Roth 1990). Absence of warm water taxa such as *Discoaster* group and low abundance of *S. heteromorphus* also implies cool surface waters in the Paratethys during the investigated interval (Zone MNN 4a p.p.).

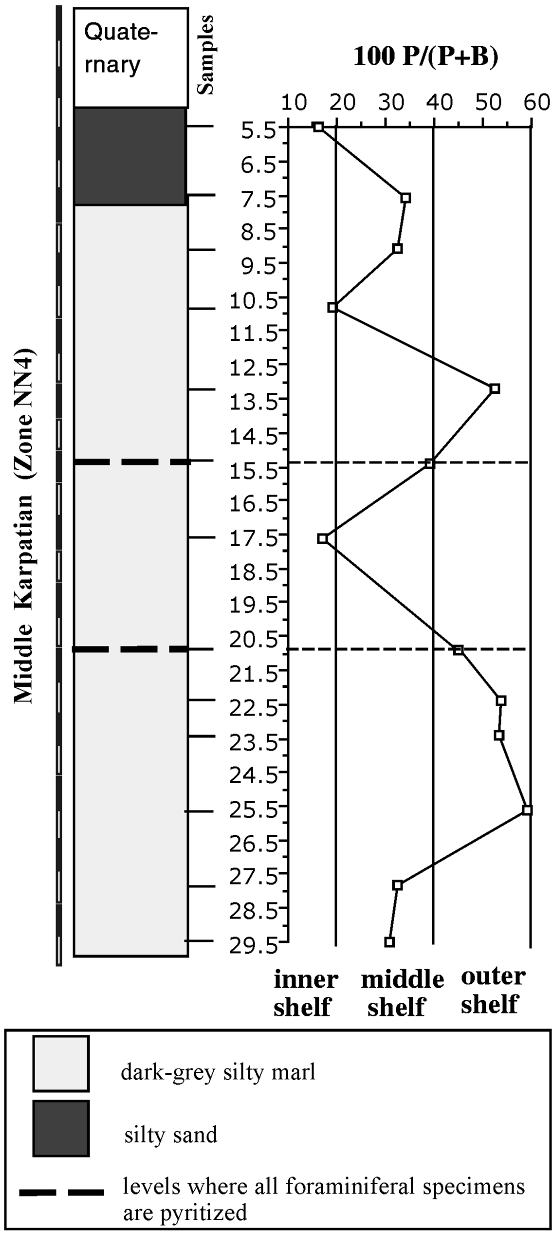

Fig. 6. Plankton/Benthos Ratio (100P/(P+B), and interpretation of paleodepth plotted vs. the simplified lithology of Hole BL 503. P = planktonic foraminifers, B = benthic foraminifers.

Paleoenvironmental reconstruction

a — Benthic Foraminifers: Comparison between Similarity and Dissimilarity Term Analyses of benthic foraminifers and their ecological preference (Table 2 to 5, Fig. 5A) suggests that Cluster 1 groups samples containing the shallower, relatively more oxygenated, and higher salinity assemblages (*Ammonia* spp., *Aubignyna perlucida, Porosononion* gr.). *Ammonia tepida* and *Porosononion* are known in the literature to be high salinity-tolerant species, abundant in the inner neritic environment with water depth not exceeding 50–100 m (e.g., Basso & Spezzaferri 2000). Cluster 2 groups samples contain-

Table 3: Bray Curtis Similarity and Dissimilarity of benthic foraminifers. List of species and statistical parameters in Cluster 1–3. The Similarity Term Analysis indicates the species responsible for the similarity among clusters. The Dissimilarity Term Analysis reveals why a cluster differs form 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.

Cluster 1	**Average similarity = 44.59**			
	Avg. Ab.	**Avg. Sim.**	**Contrib.%**	**Cum%**
A. viennensis	22.00	32.48	46.34	46.34
A. perlucida	6.00	10.26	14.63	60.98
Textularia gr.	3.50	5.13	7.32	68.29
N. commune	5.00	5.13	7.32	75.61
Porosononion gr.	3.00	5.13	7.32	82.93
A. tepida	5.50	5.13	7.32	90.24

Cluster 2	**Average similarity = 57.28**			
	Avg. Ab.	**Avg. Sim.**	**Contrib.%**	**Cum%**
V. complanata	180.25	28.23	49.29	49.29
B. elongata gr.	56.00	9.12	15.92	65.21
N. commune	14.25	2.46	4.29	69.50
O. umbonatus	11.75	2.06	3.60	73.10
A. haueriana	11.00	1.72	3.00	76.10
H. boueana	10.00	1.38	2.40	78.51
Pappina gr.	7.50	1.26	2.20	80.70

Cluster 3	**Average similarity = 34.82**			
	Avg. Ab.	**Avg. Sim.**	**Contrib.%**	**Cum%**
Pappina gr.	123.33	11.84	34.00	34.00
N. commune	10.17	2.47	7.08	41.08
A. viennesis	22.50	2.45	7.04	48.12
C. schischkinskayae	15.33	1.78	5.11	53.23
B. dilatata-sagittula-fastigia gr.	17.67	1.70	4.88	58.12
Uvigerina gr.	14.00	1.33	3.82	61.94
Miliolid gr.	7.00	1.26	3.61	65.54
A. perlucida	7.17	1.25	3.60	69.14
V. complanata	9.33	1.11	3.19	72.33
C. lopjanicus	4.83	1.03	2.95	75.28
S. pectinata	3.83	0.93	2.67	77.95
Elphidium gr.	4.00	0.90	2.59	80.54

	Average dissimilarity = 80.42				
	Group 3	**Group 1**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
Pappina gr.	123.33	0.50	27.7	35.08	35.08
A. viennensis	22.50	22.00	5.88	7.43	42.51
Uvigerina gr.	14.00	0.50	5.09	6.44	48.95
B. dilatata-sagittula-fastigia gr.	17.67	0.00	4.60	5.81	54.75
C. schischkinskayae	15.33	1.50	3.68	4.66	59.41
A. tepida	8.83	5.50	3.12	3.95	63.36
V. complanata	9.33	1.00	2.86	3.61	66.97
Miliolids	7.00	0.00	2.84	3.58	70.55
Porosononion gr.	9.17	3.00	2.08	2.63	73.19
Lenticulina gr.	4.67	0.00	1.78	2.25	75.43
N. commune	10.17	5.00	1.69	2.13	77.56
B. arenaria	7.00	0.00	1.59	2.01	79.58
S. pectinata	3.83	0.00	1.28	1.62	81.20

	Average dissimilarity = 81.45				
	Group 3	**Group 2**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
V. complanata	9.33	180.25	23.21	28.49	28.49
Pappina gr.	3.33	7.50	14.23	17.47	45.97
B. elongata gr.	2.00	56.00	7.81	9.58	55.55
Praeglobobulimina gr.	0.67	28.75	4.03	4.95	60.50
A. viennensis	2.50	1.75	2.92	3.58	64.08
Uvigerina gr.	4.00	13.25	2.42	2.97	67.05
B. dilatata-sagittula-fastigia gr.	7.67	6.00	2.11	2.59	69.64
C. schischkinskayae	5.33	5.25	1.81	2.23	71.87
O. umbonatus	0.00	11.75	1.66	2.03	73.90
A. haueriana	0.33	11.00	1.44	1.77	75.67
A. tepida	8.83	0.00	1.16	1.43	77.10
H. boueana	1.67	10.00	1.16	1.42	78.52
Porosononion gr.	9.17	1.00	1.16	1.42	79.94

	Average dissimilarity = 92.25				
	Group 1	**Group 2**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
V. complanata	1.00	180.25	35.95	38.90	38.90
B. elongata gr.	0.50	56.00	12.11	13.10	52.00
Praeglobobulimina gr.	0.00	28.75	6.14	6.64	58.64
A. viennesis	22.00	1.75	4.42	4.79	63.43
O. umbonatus	0.00	11.75	2.48	2.68	66.11
Uvigerina gr.	0.50	13.25	2.20	2.38	68.49
A. haueriana	0.00	11.00	2.19	2.37	70.86
H. boueana	0.50	10.00	1.98	2.14	73.00
N. commune	5.00	14.25	1.80	1.95	74.95
Lenticulina gr.	0.00	9.25	1.75	1.89	76.84
Pappina gr.	0.50	7.50	1.54	1.67	78.51
B. hebes-plicatella-pokornyi gr.	0.00	7.00	1.42	1.53	80.05
Chilostomella gr.	0.00	6.00	1.22	1.32	81.36
B. dilatata-sagittula-fastigia gr.	0.00	6.00	1.19	1.28	82.65
A. tepida	5.50	0.00	1.17	1.27	83.92
V. pertusa	0.00	5.25	1.17	1.26	85.18

ing an almost dysoxic, high organic matter-preferring assemblage dominated by *V. complanata, B. elongata, Praeglobobulimina* gr. (Fig. 2, Table 2). In muddy sediments the redox boundary normally falls within a few centimeters of the sea floor in those environments where the overlying bottom water is well oxygenated. Therefore, the presence of an oxygen-limited component of the fauna should not automatically indicate bottom water dysoxia (Murray 2001). However, at Laa Th. oxygen-limited components of the fauna also include species living within 0–3 cm of sediments (e.g. *Uvigerina* gr. in Sample 15.4 m, Figs. 2, 5A, Table 2) indicating that dysoxia also extends into the lower part of the water column. *Bulimina elongata* and *Oridorsalis umbonatus* commonly occur off shore in front of river mouths (Sgarrella & Moncharmont-Zei 1993), where high organic matter content may reflect fresh water influence. This cluster also contains *V. complanata* which indicates water depth from 50 to 200 m (Rupp 1986). The presence of typical bathyal benthic forms like *O. umbonatus* (Table 3) may be explained by the "telescoping effects" (Alve 1990; Sen-Gupta & Machain-Castillo 1993). Fauna typical for deeper environments may occur at relatively shallower water depths in marginal seas or enclosed basins controlled by ecological factors like organic matter fluxes, oxygen concentration, substratum, etc. Finally, Cluster 3 groups samples containing assemblages intermediate between the previous two. The high abundance of *Pappina* gr., a genus related to *Uvigerina,* seems to indicate intermediate suboxic conditions here. According to these data we can interpret the lines at the bottom of the nMDS plot (Fig. 5A) as the oxygenation and the water depth gradients respectively.

b — Planktonic Foraminifers: The Similarity and Dissimilarity Term Analyses of planktonic foraminifers (Table 4) suggest that Cluster 1 groups samples containing a relatively temperate assemblage with the highest abundance of *G. obesa* (temperate-water indicator) recorded in the sequence (contribution to the total similarity of 44.38 %). Cluster 2 groups samples containing an intermediate assemblage with *G. obesa* contributing to the total similarity for the 40 % and *G. concinna* contributing for the 3.5 %. Cluster 3 groups samples containing the coolest assemblage and low abundance of *G. obesa*. According to these data we can interpret the line at the left hand side of the nMDS to be the temperature gradient (Fig. 5B).

c — Calcareous Nannoplankton: The Similarity and Dissimilarity Term Analyses of calcareous nannoplankton (Table 5) suggest that Cluster 1 groups samples containing high nutrient and coastal assemblages characterized by the *C. pelagicus, R. minuta,* and *Helicosphaera* groups. Cluster 2 groups samples containing assemblages with characteristics intermediate between Cluster 1 and 3 with *C. pelagicus* and *R. minuta* contributing about 45 % to the total similarity. Cluster 3 groups samples containing a relatively more pelagic assemblages. *Coccolithus pelagicus* and *R. minuta* contribute for about the 42.4 % to the total similarity. According to these data we can

Table 4: Bray Curtis Similarity and Dissimilarity of planktonic foraminifers. List of species and statistical parameters in Cluster 1–3.

Cluster 1	**Average similarity = 58.84**			
	Avg. Ab.	**Avg. Sim.**	**Contrib. %**	**Cum %**
G. praebulloides gr.	168.40	30.55	44.38	44.38
G. obesa gr.	156.80	21.85	31.75	76.12
G. bollii lentiana	47.20	7.69	11.16	87.29
"G." ottnangiensis gr.	36.40	6.56	9.53	96.82
Cluster 2	**Average similarity = 57.28**			
	Avg. Ab.	**Avg. Sim.**	**Contrib. %**	**Cum %**
G. obesa gr.	40.00	23.30	37.50	37.50
"G." ottnangiensis gr.	18.50	16.50	26.56	64.06
G. praebulloides gr.	20.50	10.68	17.19	81.25
G. bollii lentiana	11.00	7.77	12.50	93.75
Cluster 3	**Average similarity = 52.14**			
	Avg. Ab.	**Avg. Sim.**	**Contrib. %**	**Cum %**
G. praebulloides gr.	23.80	25.19	44.95	44.95
"G." ottnangiensis gr.	10.20	13.56	24.20	69.15
G. obesa gr.	6.00	5.81	10.38	79.52
T. angustiumbilicata	3.20	5.80	10.35	89.87
G. bollii lentiana	4.80	4.05	7.23	97.10

	Average dissimilarity = 79.77				
	Group 3	**Group 1**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib. %**	**Cum %**
G. praebulloides gr.	23.80	168.40	30.26	37.93	37.93
G. obesa gr.	6.00	156.80	28.71	35.99	73.92
G. bollii lentiana	4.80	47.20	8.44	10.59	84.50
"G." ottnangiensis gr.	10.20	36.40	5.31	6.65	91.15
	Average dissimilarity = 54.41				
	Group 3	**Group 2**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib. %**	**Cum %**
G. obesa gr.	6.00	40.00	22.65	41.62	41.62
G. praebulloides gr.	23.80	20.50	9.43	17.34	58.96
"G." ottnangiensis gr.	10.20	18.50	6.12	11.25	70.21
G. bollii lentiana	4.80	11.00	4.88	8.97	79.19
G. regularis	0.00	4.00	2.63	4.83	84.01
G. concinna gr.	0.00	3.50	2.33	4.28	88.29
T. angustiumbilicata	3.20	0.00	2.14	3.94	92.23
	Average dissimilarity = 64.37				
	Group 1	**Group 2**			
	Avg. Ab.	**Avg. Ab.**	**Avg. Dis.**	**Contrib.%**	**Cum%**
G. praebulloides gr.	168.40	20.50	27.44	42.63	42.63
G. obesa gr.	156.80	40.00	20.48	31.82	74.45
G. bollii lentiana	47.20	11.00	6.33	9.83	84.28
"G." ottnangiensis gr.	36.40	18.50	3.29	5.11	89.39
G. concinna gr.	13.20	3.50	2.51	3.90	93.29

Table 5: Bray Curtis Similarity and Dissimilarity of calcareous nannofossils. List of species and statistical parameters in Cluster 1–3.

Cluster 1	Average similarity = 77.50			
	Avg. Ab.	Avg. Sim.	Contrib.%	Cum%
C. pelagicus	62.33	28.83	37.20	37.20
R. minuta	26.33	10.83	13.98	51.18
R. haqii	17.67	7.67	9.89	61.08
Helicosphaera gr.	26.67	7.17	9.25	70.32
C. leptoporus	9.33	3.67	4.73	75.05
C. floridanus	8.67	3.50	4.52	79.57
R. pseudoumbilicus 5–7 µm	8.00	3.33	4.30	83.87

Cluster 2	Average similarity = 74.57			
	Avg. Ab.	Avg. Sim.	Contrib.%	Cum%
C. pelagicus	67.00	29.33	39.29	39.29
R. haqii	15.67	7.17	9.60	48.88
R. minuta	23.00	4.83	6.47	55.36
R. pseudoumbilicus 5–7 µm	10.33	4.67	6.25	61.61
C. leptoporus	11.00	4.67	6.25	67.86
R. pseudoumbilicus >7 µm	9.67	4.00	5.36	73.21
U. jafarii	9.33	3.83	5.13	78.35
Helicosphaera gr.	6.33	2.67	3.57	81.92

Cluster 3	Average similarity = 78.00			
	Avg. Ab.	Avg. Sim.	Contrib.%	Cum%
C. pelagicus	52.57	24.02	30.79	30.79
R. minuta	24.86	9.06	11.61	42.40
R. haqii	18.14	7.65	9.81	52.21
C. leptoporus	13.00	6.13	7.86	60.07
C. tropicus	12.29	4.92	6.30	66.37
C. floridanus	11.86	4.73	6.06	72.44
R. pseudoumbilicus 5–7 µm	11.14	4.33	5.55	77.98
R. pseudoumbilicus >7 µm	6.00	2.45	3.14	81.12

	Average dissimilarity = 26.57				
	Group 3	Group 1			
	Avg. Ab.	Avg. Ab.	Avg. Dis.	Contrib.%	Cum%
Helicosphaera gr.	4.43	26.67	5.58	20.98	20.98
C. pelagicus	52.57	62.33	2.70	10.16	31.14
R. minuta	24.86	26.33	2.46	9.26	40.40
C. tropicus	12.29	4.33	2.01	7.56	47.96
R. haqii	18.14	17.67	1.07	4.03	51.99
R. pseudoumbilicus 5–7 µm	11.14	8.00	1.07	4.03	56.02
C. floridanus	11.86	8.67	1.04	3.90	59.91
Sphenolithus gr.	5.43	3.67	0.94	3.53	63.45
C. leptoporus	13.00	9.33	0.92	3.45	66.89
T. milowii	3.71	0.67	0.83	3.13	70.03
Pontosphaera spp.	2.71	5.67	0.76	2.86	72.89
Thoracosphaera sp.	4.29	1.33	0.76	2.86	75.75
T. heimii	3.00	0.00	0.75	2.82	78.57
S. pulchra	2.29	3.33	0.69	2.60	81.16

	Average dissimilarity = 26.20				
	Group 3	Group 2			
	Avg. Ab.	Avg. Ab.	Avg. Dis.	Contrib.%	Cum%
R. minuta	24.86	23.00	4.51	17.21	17.21
C. pelagicus	52.57	67.00	4.29	16.39	33.59
C. tropicus	12.29	4.33	1.99	7.58	41.17
Thoracosphaera sp.	4.29	5.33	1.52	5.81	46.98
C. floridanus	11.86	7.33	1.49	5.68	52.66
R. haqii	18.14	15.67	1.02	3.91	56.56
U. jafarii	6.00	9.33	1.02	3.90	60.47
R. pseudoumbilicus >7 µm	6.00	9.67	0.96	3.68	64.14
R. pseudoumbilicus 5–7 µm	11.14	10.33	0.92	3.50	67.64
Sphenolithus gr.	5.43	6.00	0.88	3.36	71.00
T. milowii	3.71	4.33	0.75	2.86	73.86
C. leptoporus	13.00	11.00	0.71	2.72	76.58
Helicosphaera gr.	4.43	6.33	0.69	2.63	79.21
Pontosphaera spp.	2.71	1.67	0.64	2.45	81.66

	Average dissimilarity = 27.56				
	Group 1	Group 2			
	Avg. Ab.	Avg. Ab.	Avg. Dis.	Contrib.%	Cum%
Helicosphaera gr.	26.67	6.33	5.08	18.45	18.45
R. minuta	26.33	23.00	4.61	16.73	35.18
C. pelagicus	62.33	67.00	3.06	11.09	46.27
R. pseudoumbilicus >7 µm	4.33	9.67	1.33	4.84	51.11
Thoracosphaera sp.	1.33	5.33	1.28	4.64	55.75
C. floridanus	8.67	7.33	1.06	3.83	59.58
Pontosphaera spp.	5.67	1.67	1.06	3.83	63.41
U. jafarii	5.33	9.33	1.00	3.63	67.04
T. milowii	0.67	4.33	0.92	3.33	70.36
R. haqii	17.67	15.67	0.83	3.02	73.39
C. tropicus	4.33	4.33	0.83	3.02	76.41
Sphenolithus gr.	3.67	6.00	0.81	2.92	79.33
S. pulchra	3.33	1.33	0.78	2.82	82.16

interpret the line at the left side of the nMDS plot as the temperature gradient and the line at the bottom of the nMDS plot as the distance from the coast (Fig. 5C). *Coccolithus pelagicus* and *R. minuta*, are interpreted as high nutrient indicators. Their abundance curves show a vicariant trend (Fig. 2) and therefore, we suggest that high availability of nutrients characterized the entire studied interval.

Comparing the nMDS plots of the investigated microfossil groups and the abundance curves in Figure 2 and 7 we observe good correspondence of ecological factors. For example, sample 13.2 and 15.4 record the warmest assemblages and sample 10.8 one of the cooler assemblage in the three nMDS plots (Fig. 5A–C). The distance from the coast gradient (Fig. 5C) does not necessarily match the water depth gradient (Fig. 5A). Shallow waters can, infact, extend very far from the coast (as in the Adriatic Sea).

Conclusion

Our data indicate that the sediments drilled at Laa Th. were deposited in a water depth not exceeding 200 m, relatively "near shore" in an environment characterized by a generally high concentration of organic matter, suboxic to dysoxic conditions, high nutrient availability and variable salinity. Generally cool conditions prevailed throughout the investigated interval with a temperate episode in its middle part.

We speculate that high nutrient availability possibly related to the presence of river mouths, or alternatively to coastal and wind-related upwelling of cool water, induced high productivity at the surface and high accumulation of organic matter at the bottom. Oxygen depletion probably account for an increased bacterial activity in reducing microenviron-

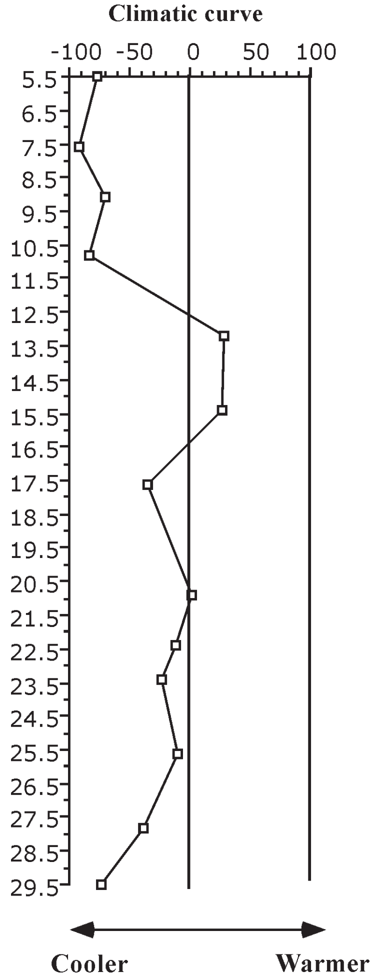

Fig. 7. Climatic curve based on planktonic foraminifers. The curve is derived from the algebraic sum of percentage abundance of temperate (positive) and cool (negative) indices as proposed by Cita et al. (1977) and successively applied by Spezzaferri & Premoli Silva (1991) and Spezzaferri (1995). Since truly warm-water species are rare, we consider the temperate group to be indicative of relative warming.

ments with consequent pyritization of microfossils in the two levels at 15.4 and 20.9 m. We also suggest that nutrient availability and upwelling conditions, rather than other ecological factors, control the distribution of calcareous nannoplankton in the Molasse Basin.

Finally deposition near the coast and relatively shallow water depth resulted in high percentages of reworked (Paleogene and Cretaceous) nannofossil forms (up to 45 %).

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