# High-resolution Deep-Water Agglutinated Foraminiferal record across the Paleocene/Eocene transition in the Contessa Road Section (central Italy)

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#### ABSTRACT

The distribution of benthic foraminifera across the Paleocene/Eocene (P/E) Boundary of the Contessa Road section allows us to compare the response of both calcareous hyaline and Deep Water Agglutinated Foraminiferal (DWAF) assemblages to the terminal Paleocene Benthic Extinction Event (BEE). The two groups are contemporaneously affected by the terminal Paleocene events.

Quantitative analysis reveals a sharp change in DWAF assemblages indicating that a major perturbation on the sea floor occurred in coincidence with the P/E Boundary Carbon Isotope Excursion. The record of DWAF, however, indicates a gradual initiation of environmental changes beginning some 750 ky before the CIE with the entrance of shallower water taxa probably in response to the emplacement of saline intermediate water mass mixing surface waters to intermediate depths within the Tethys. This phase intensified in the last 250 ky of the Paleocene and terminated at the P/E boundary when the exit of shallower water taxa is recorded.

#### **INTRODUCTION**

The transition from the Paleocene to the Eocene witnessed the largest extinction event affecting the deep water benthic foraminifera during the last 90 Myr, the so-called Benthic Extinction Event (BEE). About 35-50% of the bathyal to abyssal calcareous benthic foraminiferal species became extinct at this event (Tjalsma & Lohman, 1983; Thomas, 1990; Kennett & Stott, 1991; Pak & Miller, 1992, 1995; Kaiho et al., 1993, 1996; Kaiho, 1994; Ortiz, 1995, Thomas & Shackleton, 1996; Thomas, 1998). Outer neritic foraminiferal faunas (e.g., Speijer, 1994) and abyssal agglutinated foraminifera (e.g., Geroch & Nowak, 1984) suffered lower extinction rates, but faunal changes are still noticable. According to Orue-Extebarria et al. (2001), however, the major turnover of benthic larger foraminifera, which marks the base of the Ilerdian Stage may have been coeval or nearly coeval with the BEE.

The BEE was a global and synchronous phenomenon, caused by significant changes in global climate and oceanic circulation. As a result of profound changes in ocean circulation and the carbon cycle, a large, negative excursion in the carbon isotope record is stratigraphically associated with the BEE in the deep sea. (Kennett & Stott, 1991; Pak & Miller, 1992; Stott, 1992; Koch *et al.*, 1992; Lu & Keller, 1993; Kaiho, 1994; Robert & Kennett, 1994; Bralower *et al.*, 1995; Canudo *et al.*, 1995; Thomas & Shackleton, 1996; Stott *et al.*, 1996, among others). Most authors conclude that the extinctions of calcareous benthic foraminifera were due to a combination of environmental factors, such as decreased oxygenation of bottom waters resulting from an increase in temperature, increased carbonate dissolution, and changes in upwellingdriven productivity patterns (Berggren et al., 1998; Thomas, 1998). The amplitude of the carbon isotope excursion suggests that warming of the bottom waters caused widespread dissociation and subsequent oxidation of isotopically light methane hydrates (Dickens et al., 1995), which would have aggravated low oxygen conditions and carbonate dissolution. At some oceanic localities, changes in the benthic foraminiferal assemblages during the Paleocene-Eocene Thermal Maximum (PETM) reflect increased productivity, while nannofossil evidence suggests lowered productivity (Thomas, 1998; Thomas et al., 2000). This raises the question of whether deep-sea benthic foraminifera benefited from an increased food source in the form of chemosynthetic or methane-oxydizing bacteria that would have flourished as a result of methane release (Thomas, 2003).

The record of the response of calcareous hyaline benthic foraminifera across the Paleocene/Eocene (P/E) boundary interval is now fairly well-established. However, the existence of only a few continuous, well-dated oceanic sequences containing wellpreserved deep water agglutinated foramineral (DWAF) assemblages has prevented a detailed study of this group across this horizon as well as their calibration to the well established chemo-, magneto- and biochronology. In contrast to the calcareous-hyaline species, DWAF were not pushed to extinction at the P/E boundary (Kaminski *et al.*, 1996). Among the "flysch-type" agglutinated foraminifera, the terminal Paleocene extinctions were somewhat less dramatic, with about 34% of the species disappearing in

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Figure 1. Location of the Contessa Road and Contessa Highway sections, near Gubbio. Shaded areas represent the Mesozoic-Cenozoic Apennine belt.

Trinidad – largely the calcareous-cemented forms (Kaminski et al., 1988). However, at abyssal localities in Morocco and the Polish Carpathians and in the Boreal northern Norwegian Sea (Morgiel & Olszewska, 1981; Geroch & Nowak, 1984; Nagy et al., 1997), even fewer extinctions are observed, and the P/E event is manifested more by changes in abundance, size, diversity, and shifts in the proportions of agglutinated foraminiferal morphogroups (Kaminski et al., 1996; Bàk et al., 1997; Nagy et al., 1997). This group therefore could allow a better comparison of pre- and post-extinction faunas in terms of the evolution of sea floor paleoenvironments and bottom water masses. In this paper we address some paleoecological and paleoceanographic aspects in the distribution of DWAF across the P/E Boundary in the Contessa Road section. We present new data on faunal parameters and expand the stratigraphic interval previously studied by Galeotti et al. (2000). The Contessa Road section offers the unique opportunity to compare the distribution of calcareous plankton (foraminifera and nannofossils) and benthic foraminifera (calcareous hyaline and agglutinated), and stable isotopes and calibrate this record to the magnetostratigraphy across the Paleocene/Eocene boundary transition (Galeotti et al., 2000).

# GEOLOGICAL AND STRATIGRAPHICAL SETTING

In the Umbria-Marche Basin the P/E boundary is contained within the pelagic red limestones of the Scaglia Rossa Formation which has be proven to be suitable for precisely correlating the Paleogene biostratigraphy to the geomagnetic polarity history. Previous studies on magnetostratigraphy and biostratigraphy in the Gubbio area enabled the first calibration of the geomagnetic reversal for most of the Paleogene interval (Lowrie *et al.*, 1982; Napoleone *et al.*, 1982). Geochemical analysis from the Contessa Highway section reported a carbon isotope record including a negative shift in  $\partial^{13}$ C values across the P/E boundary (Corfield *et al.*, 1991). However, minor tectonic disturbance and/or the presence of covered intervals have hampered a detailed study of the P/E transition in this classical Tethyan setting. A 1 m-thick covered interval occurs slightly below the last occurrence of *Morozovella velascoensis* in the Contessa Highway section, which prevents a continuous sampling across the P/E boundary. This interval is, in turn, represented by a slump in the Bottaccione section (see Cresta *et al.*, 1989).

The Contessa Road section (Figs. 1-2), previously studied by Luterbacher (1964), Lowrie et al. (1982), and Galeotti et al. (2000), is apparently the only section where a continuous and undisturbed sequence can be collected across the P/E boundary in the Gubbio area. Owing to its paleobathymetrical setting and completeness, it offers a unique opportunity to study the evolution of intermediate-deep water masses across the P/E in the western Tethys. The available magneto-, bio-, and chemostratigraphic record allows for a good chronological control of the observed events. The section starts just below the K/P boundary and continues up to the varicoloured marls and limestones of the Scaglia Variegata Formation. A magnetostratigraphic record of the Contessa Road section was published by Lowrie et al. (1982) who, however, did not study the interval below the major fault recognised within Chronozone C25N. Reconstruction of the displacement produced by this fault allowed Galeotti et al. (2000) to extend the available magnetostratigraphy of the section down to the upper part Chron C26n. In this paper,



**Figure 2**. Stratigraphic position of the studied interval with respect to lithology and magnetostratigraphy of the Contessa Road section (modified from Galeotti *et al.,* 2000).

we consider the onset of the sharp carbon isotopic excursion at 30.30 m as the Paleocene/Eocene (P/E) boundary, in accordance with the International Subcommission on Paleogene Stratigraphy (Luterbacher *et al.*, 2000). This level marks the onset of the Paleocene/Eocene thermal maximum and also coincides with the benthic extinction event (BEE) in calcareous benthic foraminifera.

The P-E transition is represented by a sequence of limestones and marly limestones with some marly layers ranging from 0.5 to 10 cm in thickness. Galeotti et al. (2000) reported the occurrence of carbonate impoverished beds occurring at 30.30 m above the K/P boundary and marking the P/E boundary (Fig. 3). The clay marker observed in the U-M basin is reminescent of clay beds, also described as the Carbonate Dissolution Interval (CDI), observed in correspondence to the Paleocene-Eocene Thermal Maximum (PETM) at Zumaya and Caravaca (Canudo et al., 1995; Ortiz, 1995), Trabakua (Coccioni et al., 1995; Orue-Extebarria et al., 1996) and Alamedilla (Lu et al., 1996) in Spain. A similar decrease in carbonate content occurs also at different DSDP (401, 550) and ODP (690) Sites (The Shipboard Scientific Party, 1979, 1985) across the P/E interval. Increased CaCO<sub>3</sub> dissolution over a wide depth and geographical range in the deep oceans was associated with the large, short term carbon isotope excursion observed in deep as well as surface waters and in the continental records (see Thomas & Shackleton, 1996 for a review). The Paleocene/Eocene CDI from the Zumaya and Caravaca (Canudo et al., 1995; Ortiz, 1995), Trabakua (Orue-Extebarria et al., 1996) and Alamedilla (Lu et

*al.*, 1996) sections in Spain is associated with a large negative excursion in the carbon isotope record, corresponding to the well known Carbon Isotope Excursion (CIE), occurring worldwide at the P/E boundary transition. Accordingly, a ~2‰ negative excursion in bulk  $\partial^{13}$ C values is observed in correspondence with the 0.4 m-thick interval containing the CaCO<sub>3</sub>-impoverished beds (Fig. 3).

The distribution of calcareous plankton well fits with the position of the CIE and the magnetostratigraphic record across the P/E boundary. The main bioevents in calcareous nannofossil assemblages observed in the surveyed interval are, from bottom to top: the First Occurrence (FO) of Discoaster multiradiatus marking the NP8/NP9 and CP7/CP8 zonal boundaries of Martini (1971) and Okada & Bukry (1980), respectively, at 27.37 metres above the Cretaceous/Paleogene (K/P) boundary; the FO of Rhomboaster bramlettei, which marks the NP9/NP10 zonal boundary of Martini at 30.30 metres above the K/P boundary; the First Occurrence of Discoaster diastypus which marks the CP8/CP9a of Okada & Bukry (1980) at 32.00 metres above the K/P boundary.

Among planktic foraminifera, the disappearance of *Globanomalina pseudomenardii* allows to place the P4/P5 zonal boundary of Berggren *et al.* (1995) at 27.90 metres above the K/P boundary, just below the boundary between Chrons C25n/C24r. The last occurrence of *Morozovella velascoensis* marks the P5/P6 zonal boundary of Berggren *et al.* (1995) at 31.50 and falls within the lower fifth of Chron C24r following the magnetostratigraphy given in Lowrie *et* 



**Figure 3**. Oxygen and carbon isotope record (bulk rock) and biostratigraphy of the studied interval in the Contessa Road section (from Galeotti *et al.*, 2000). Different biozonal schemes according to their authors are reported as: 1) Martini (1971); 2) Okada & Bukry (1980); 3) Berggren *et al.* (1995); 4) Berggren & Miller (1989).

*al.* (1982). We refer to Galeotti *et al.* (2000) for a detailed description of the calcareous plankton events and biostratigraphy. Among calcareous hyaline benthic foraminifera, the last occurrence of *Gavelinella beccariiformis* allows to place the BB1/BB2 zonal boundary of Berggren & Miller (1989) between 30.30 and 30.60 m.

The sedimentation rate of the 17 m-thick C24R (Lowrie *et al.*, 1982) is estimated to be around 6.6 m/Myr, if the Geomagnetic Polarity Time Scale of Cande & Kent (1995) is followed.

#### MATERIAL AND METHODS

The present study focuses on a 12 m-thick interval which includes the P-E transition (Fig. 2). A qualitative survey of calcareous hyaline forms has been conducted on a few marly layers to identify the stratigraphic level of the BEE. Calcareous hyaline forms were studied from washed residues (>125  $\mu$ m) obtained from the less indurated samples to check the record of marker species defining the position of the BEE. Washed residues were obtained by immerging about 150 g of sample in Rewoquat soap after gentle crushing. Quantitative analysis of DWAF was carried out on acid residues from 22 samples. Samples were dried, weighted and soaked in a hydrochloric acid solution (5%). After acid digestion, samples were washed over a 63  $\mu$ m screen and dried. A suitable split with approximately 200-400 specimens was obtained from the fraction greater than 63  $\mu$ m with a microsplitter. From these splits all specimens were picked, counted and mounted on micropaleontological slides for quantitative analysis. Agglutinated taxa were grouped into seven morphogroups (Fig. 4), largely following Severin (1983), Jones & Charnock (1985), Bernhard (1986), Koutsoukos et al. (1990), Tyszka (1994), and Nagy et

MORPHOGROUP	LIFE POSITION	FEEDING STRATEGY	MORPHOLOGY	GENUS		
<b>—Ĭ</b> —	ERECT EPIFAUNAL	DEPOSIT OR SUSPENSION FEEDER	TUBULAR	Hyperammina Kalamopsis Rhabdammina Rhizammina		
1	EPIFAUNAL	HERBIVOROUS OR ACTIVE DEPOSIT FEEDER	DISCOIDAL COILED	Ammodiscus Glomospira Glomospirella Lituotuba Paratrochamminoides Trochamminoides		
	EPIFAUNAL OR SHALLOW INFAUNAL	DEPOSIT FEEDER	GLOBULAR	Cribrostomoides Lagenammina Recurvoides Repmanina Saccammina Thalmannamina		
	EPIFAUNAL OR SHALLOW INFAUNAL	HERBIVOROUS OR DEPOSIT FEEDER	PLANOCONVEX	Praecystammina Trochammina		
	INFAUNAL TO EPIFAUNAL	DEPOSIT FEEDER	ROUNDED PLANISPIRAL	Haplophragmoides Reticulophragmium		
<b>&gt;&gt;</b>	INFAUNAL DEPOSIT FEEDER TAPER		TAPERED	Arenobulimina Dorothia Remesella Tritaxia		
<b>}</b>	INFAUNAL	DEPOSII FEEDER	TAPERED	Ammabaculifes Clavulinoides Reophax Subreophax Gerochammina Scherochoreila Aschermocella Karrerulina Pseudobolivina		

**Figure 4**. Inferred life position and feeding strategy of DWAF genera from the P/E transition of the Contessa Road section. According to test morphology each genus is allocated into seven morphogroups following Severin, (1983), Jones & Charnock (1983, Bernhard (1986), Koutsoukus *et al.* (1990), Tyszka (1994), and Nagy (1995). Adapted from Nagy (1995).

*al.* (1995). The number of species per sample and the percentages of epifaunal, shallow infaunal, and infaunal forms were calculated. Bulk rock Carbon and Oxygen isotope analysis was conducted on 22 samples from 26.50 to 34.50 m above the K/P boundary. Samples were analysed at the Centro di Studio per il Quaternario e l'Evoluzione dell'Ambiente of the La Sapienza University of Rome following the conventional procedure of McRea (1950). We refer to Galeotti *et al.* (2000) for a more detailed description of the isotope analysis and results.

#### RESULTS

Calcareous benthic foraminiferal assemblages are relatively rich in the studied interval, though poorly preserved. Analysis of washed residues reveals a very high planktic/benthic ratio ranging from 97 to 99%. P/B ratios are higher above the CIE (about 99%) than below it (97-98%).

A typical bathyal Paleocene assemblage is present up to 30.30 m where the last occurrences of Gavelinella beccariiformis, Pullenia coryelli, and Cibicides hyphalus are observed. These taxa are generally documented from the pre-BEE Paleocene worldwide (Tjalsma & Lohmann, 1983; Berggren & Miller, 1989; Thomas, 1989, 1992; Speijer et al., 1995; Oreu-Extebarria et al., 1996; Thomas, 1998). Up to this level, these species are quite common, therefore allowing us to recognise the level of the BEE within Zone P5 and Zone NP10. Many of the typical Velasco (and some Midway) elements are present below the BEE. From 30.60 m onwards assemblages dominated by large-sized Cibicidoides, including biconvex specimens referable to C. pseudoperlucidus and relatively flattened specimens not classified at the species level, are present, indicating that a faunal turnover occurs

# **Table 1**. Distribution of DWAF species across the P/E Boundary in the Contessa Road section.

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Species/Samples	CR 23,45	CR 24,00	CR 24,50	CR 25,00	CR 25,50	CR 27,40	CR 28,20	CR 28,50	CR 29,00	CR 29,30	CR 29,60	CR 29,80	CR 30,20	CR 30,50	CR 30,99	CR 31,25	CR 31,60	CR 32,00	CR 32,55	CR 32,90	CR 33,45	CR 34,00
Ammobaculites sp.	-	-			-	-	-	-		-	-	-	-	14	6	11	11	9	-	2		2
Ammodiscus cretaceus								1	1			2	1	3	-	2	3			_		1
Ammodiscus glabratus	1		1	1		1			1		2							3	4			2
Ammodiscus peruvianus							1															
Ammodiscus tenuissimus		2		1							1			1		1	2	3	5	5	2	3
Arenobulimina sp.			1	14						6	13	5				2	1	2	1	2	3	2
Aschemocella grandis	3		1	16		2	5	1			2	1	2	1		2	1	1	2	2	3	
Aschemocella carpathica									4		1										1	
Cribrostomoides trinitatensis									1	2	1					1	2	1	1	1		
Dorothia retusa	1			14			7	7	4		7		1									
Gerochammina conversa	_					1																
Glomospira glomerata		2	1				3		3			1										
Glomospira gordialis	-	1	<u> </u>	1								<u> </u>							2			<u> </u>
Glomospira irregularis	3	1					1				2				3	1	2	4	5	1	2	
Glomospira serpens								1	1				1									
Glomospira ?	_									1		2				1	2			1		1
Glomospirella biediai				5			2	1		1		1	4									
Glomospirella gaultina	1	2	12			2					2			2		3	2	5	3	2		5
Haplophragmoides kirki	1				<u> </u>			1		2	1							1				2
Haplophragmoides porrectus		1		4	1	1	<u> </u>	1	1	4	1					<u> </u>					$\vdash$	<u> </u>
Haplophragmoides walteri			4	2	1	1	1									<u> </u>			3	1		
Hormosinella distans		-	<u> </u>	<u> </u>	.	<u> </u>	<u> </u>		2	-						<u> </u>			1		$\vdash$	<u> </u>
Hyperammina sp.	 				1	-	-	4		6		-	_				-		-			
internal mould (R. indivisa?)	18	14	3	3	11	2	7	15	14	6	11	5	5	77	13	46	70	30	26	40	33	20
Kalamopsis grzybowskii		1			1				1						2	6	2					1
Karrerulina coniformis							1	7	9	7	8	3	9				2					
Karrerulina horrida	_						3	1	1	3	4	2	10				1	1		1		
Lagenammina sp.	6	2	3	8	2	4	6	2	5	3	5	2	4	2	3	11	8	7	5	6	6	2
Litutotuba lituiformis												2	4	4				1		1		1
Litutotuba vermetiformis																2		1			1	2
Lituotuba sp.		1	1				1		1		1						2	2	4	4	5	1
Paratrochamminoides heteromrphus	-																	3	4		1	
Paratrochamminoides olszewskii	3	_	5	2	3	4	4	2				1	13	12	3	3	7	14	10	16	18	18
Praecystammina globigeriniformis	12	8	11	6	6	18		10	2	12	1	2	12		4	2	5	7	5	9	12	5
Pseudobolivina lagenaria	8	5	4		8	4	1	3		3		1	1		2	<u> </u>						<u> </u>
Pseudobolivina munda	3		<u> </u>	1	4	4		2				6	5		2							<u> </u>
Pseudobolivina sp.1	1	1			3			1				<u> </u>										<u> </u>
Pseudobolivina sp.2	8		2	<u> </u>	6	4	8	2		8				_	13	<u> </u>	1	1		<u> </u>		<u> </u>
Pseudobolivina sp.3	1						1	2		6		4	1	2	9	<u> </u>				<u> </u>		<u> </u>
Recurvoides nucleosus			<u> </u>				1		1			<u> </u>										<u> </u>
Recurvoides sp.				7	2	4	-	2		2		_				2	1	1	2	1		<u> </u>
Remesella varians			1			1	2		1	6	16	5				2	1	1		2	3	<u> </u>
Pseudonodosinella troyeri	-	1			-														-			
Reophax elongatus							<u> </u>				1							3	5	2		4
Reophax spp.	-					1	1		2		40	2	10	10	3	2	3	5	3	4	3	5
Repmanina charoides		2		1	9	10	8	2	1	9	12	2	16	19	75	34	40	41	18	30	28	22
Reticulophragmium jarvisi	1	2		3		1	2	1	3	1	3	4	4			<u> </u>			1	3	6	2
Rhabdammina spp.	1	15	3	101	9	13	10	13	12	2	5	26	4		405	457	105	4 7 7	450	2	1	0.7
Knizammina inalvisa	112	146	144	124		201	12/	1/1	297	195	90	183	139	90	135	15/	105	1//	150	182	187	85
<i>Knizammina</i> sp.	12	25	14	24	80	13	2		35	24	23		39	30	30	17	12	11	/	20	37	<u> </u>
Saccammina grzybowskii				1			-		2			2			8	<u> </u>		<u> </u>	2			<u> </u>
Saccammina placenta	2		3		1	2		2		1	2	-							-			<u> </u>
Saccammina sphaerica	1				-		10	2				5	00	3	3			4	5	11	12	4
Scherochorella minuta	8		1	8	5	11	10	1	00	10	6	9	23		3	3	3	2		1		1
Spiroplectammina spectablis	5	3	50				3	25	26	18	24	24	17				1		2			1
Subreophax pseudoscalaris	2		2	4	<u> </u>	2	<u> </u>				-	-	44		-	<u> </u>			-			-
Subreophax scalaris	-				10		-	-		8	2	4	14		3		-	10	2	6	8	5
Subreephax ci. spiendidus	5	-	6	4	19	8	5	5	2	40	6	12	20	1		3	5	13	5		$\vdash'$	7
Subreophax ci. subhodulosus	5	2	1		<u> </u>	<u> </u>	9	3		10	4			18		<u> </u>						3
Thaimannammina sp.				3	<u> </u>	<u> </u>	<u> </u>		2			3			4	<u> </u>				3	5	<u> </u>
Truaxia aspera	+	-	-	-	-	-	<u> </u>	2	1	2	3	<u> </u>				<u> </u>				<u> </u>	$\vdash$	<u> </u>
Trochammina quadriloba			<u> </u>	<u> </u>	5	<u> </u>	-			2						<u> </u>			_		$\vdash$	<u> </u>
Trochammina deformis						-		-		4			1			<u> </u>			3		$\vdash$	<u> </u>
Trochammina spp.			3		-		1	2	1	<u> </u>		4			-	-		-	2	-		
Trochamminoides dubius		1	5	4	2	2	-				-	-	2	6		2	3	5	-	2		3
Trochamminoides proteus	-		8	16	10	<u> </u>	4	2		2	8	2	4	5	3	2	1	4	3	1	4	4
Trochamminoides septatus	13	1	14	1	1	1	12	I	1 I	13	I I	I I	11	13	1	1	1	I I	1	I I	14	12

Table 2. Mor	hogroup sc	heme adopted	in this study.
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Genus	Morphology	Inferred Life Position				
Saccorhiza	Tubular					
Rhizammina	Tubular (branching)	Erect Epifaunal				
Rhabdammina						
Ammosphaeroidina	Rounded trochospiral					
Trochammina	Planoconvex trochospiral					
Glomospira	Irregular					
Lituotuba	Flattened streptospiral					
Ammodiscus		Surficial Enifounal				
Glomospirella	]	Sumcial Epiraunai				
Haplophragmoides	Flattened planispiral					
Paratrochamminoides						
Trochamminoides						
Rzehakina	Flattened					
Recurvoides	Globular (stroptospiral)	Shallow Infaunal				
Thalmannammina	Giobulai (streptospiral)					
Aschemocella	Globular					
Saccammina	Globular (monothalamous)					
Karrerulina		-				
Pseudobolivina	Lanceolate					
Spiroplectammina						
Tritaxia	Tapered					
Karrerulina	Elongate tapered					
Ammobaculites		Doon Infaunal				
Gerochammina						
Dorothia	]					
Hormosinella	Elongate subcylindrical					
Kalamopsis	]					
Reophax	]					
Subreophax						

between 30.30 m and 30.60 m. Moreover, a reduction in diversity is observed across the CIE.

The calcareous benthic foraminiferal assemblage exhibits a predominance of epifaunal morphotypes. Infaunal morphotypes among the hyaline taxa are quite rare (<10%) in the 125-630  $\mu$ m fraction throughout the studied interval and show a trend to decrease above the BEE.

DWAF assemblages are rich and well diversified in the acid residues, and preservation is generally good. Seventy-three species representing 35 genera have been identified (Tab. 2). Many of the identified species have a scattered distribution throughout the studied interval. *Rhizammina indivisa* steadily dominates the DWAF assemblages (Tab. 2, Fig. 5a, b). Other taxa showing percentages higher than 5% are *Repmanina, Spiroplectammina, Praecystammina,* and *Rhabdammina.* 

Across the BEE and CIE, a succession of discrete biostratigraphical events within DWAF assemblages is recorded as follows: *Karrerulina coniformis* and *K. horrida* first occur at 28.20 m, *Reophax elongatus* first occurs at 29.60 m coincident with the last occurrence of *Cribrostomoides trinitatensis*. As already reported by Kaminski *et al.* (1996), these taxa show stratigraphically comparable FOs and LOs at other sites, and may be considered accessory biostratigraphic markers for the Late Paleocene – Early Eocene transition. The genus *Bulhohaculites* first appears at 30.50 m and *Pseudobolivina* decreases dramatically in abundance at 31 m, and finally disappears at 32 m.

Below the carbon isotope excursion, assemblages are well diversified with about 30 species per sample on average (Fig. 6). At the base of the interval recording the negative shift of  $\partial^{13}$ C values, a drop in diversity to a minimum of 18 species is observed (Fig. 6). Washed residues from the clay layer showing the lowest  $\partial^{13}$ C values at 30.30 m yielded a depauperate DWAF fauna, likely a consequence of diagenetic alteration. Lowermost Eocene assemblages show a gradual recovery of diversity which is completed in the first meter above the CIE. The observed decrease in diversity corresponding to the CIE is preceded by large fluctuations in the relative abundance of morphogroups (Fig. 6) and the proportion of epifaunal and infaunal taxa (Fig. 7).

In particular, the uppermost Paleocene is characterised by increasing proportions of tapered/ flattened morphotypes mainly due to increased abundances of the infaunal opportunistic *Spiroplectammina spectabilis* from the middle part to the top of calcareous nannofossil Zone NP9, i.e., in the lower half of planktic foraminiferal Zone P5. The same interval is characterised by the first occurrence of mid-bathyal taxa such as *Tritaxia aspera* and more generally of agglutinated species with calcareous cement (Figs. 5 a,b). Tubular forms are represented by a greater proportion of *Rhabdammina* fragments

#### DWAF across the Paleocene/Eocene transition in the Contessa Road Section



**Figure 5 a,b**. Vertical distribution of DWAF genera across the P/E boundary in the Contessa Road section. Note that numerical scales are not the same for all species.

Just above the minimum in  $\partial^{13}$ C record (i.e., in the lower part of calcareous nannofossil Zone NP10 and in the upper part of planktic foraminiferal Zone P5), a bloom of the infaunal globular morphotype (mainly due to increasing abundance of *Repmanina charoides*) is observed, followed by an increase in the discoidal coiled morphotype (mainly *Ammodiscus* and *Paratrochamminoides*) (Figs. 5b and 6). Post-CIE DWAF assemblages are characterised by reduced proportions of deep infaunal taxa and higher relative abundances of shallow infaunal forms. Tubular forms consist almost entirely of small *Rhizammina* fragments, whereas the large tubular taxa are rare.

#### DISCUSSION

#### A. Significance of Faunal Trends

Previous studies of benthic foraminiferal assemblages from the Scaglia Rossa formation (Kuhnt, 1990, Kuhnt & Kaminski, 1996; Galeotti, 1998; Galeotti *et al.*, 2000; Galeotti *et al.*, 2002) have shown that DWAF assemblages include elements of mixed calcareous and agglutinated bathyal assemblages (*Spiroplectammina* spp., *Remesella varians*, *Tritaxia* spp.) and elements of a purely agglutinated flysch type fauna (*Aschemocella grandis*, *Rhizammina indivisa*, *Rhabdammina* sp., *Paratrochamminoides* spp., *Subreophax scalaris*, and *Recurvoides* spp.). According to these authors,



**Figure 6**. Relative abundance of DWAF morphogroups across the P/E boundary in the Contessa Road section. Note the scale break.

such a taxonomic composition, associated with a low calcareous hyaline vs. agglutinated ratio of the benthic foraminiferal assemblages, is indicative of a lower bathyal depositional environment, at a paleodepth of 1500-2000 m. The high proportions of tubular branched morphotypes in the studied material (Fig. 6) well fits with this interpretation. In modern environments, tubular erect morphotypes (such as Rhizammina and Rhabdammina) are typically well distributed in bathyal environments with increasing abundance towards lower bathyal depth (Jones & Charnock, 1985). Moreover, Rhizammina indivisa, which markedly dominates the assemblages in the Paleocene-Eocene of the Contessa Road, shows greatest abundance in lower bathyal to abyssal environments according to Olsson & Nyong (1984) and Kaminski & Kuhnt (1995). The high diversity in DWAF assemblages is indicative of a rather stable environment during the late Paleocene. DWAF assemblages are dominated by epifaunal morphotypes (Fig. 6) suggesting that oligotrophic conditions predominate on the sea-floor.

By comparing the record of agglutinated forms to that of calcareous taxa it emerges that the sea-floor perturbance testified by DWAF distribution is correlative to the BEE as indicated by the disappearance of *G. beccariiformis* between 30.30 and 30.60 m. However, important changes in the taxonomic composition of DWAF are observed below the CIE. In particular, below the dissolution interval, CIE, and BEE, an increase in species diversity is observed. This increase is caused by the appearance of shallower water (typically bathyal) taxa such as *Dorothia retusa*, *Tritaxia aspera*, and *Remesella varians*, and more generally of calcareous-cemented agglutinated species. Moreover, the species Spiroplectammina spectabilis displays a double peak in abundance in the ~ 5 m interval below the BEE. This species is known to be an opportunistic "disaster species", and shows synchronous peaks in abundance above the K/P boundary in Gubbio, southern Spain, and at ODP Site 959 off West Africa (Kuhnt & Kaminski, 1998, Kuhnt et al., 1998). In some Boreal areas such as the Central North Sea basin and southern Norwegian Sea, the uppermost Paleocene is characterised by an acme of this species just below uppermost Paleocenelowermost Eocene Coscinodiscus-bearing sediments which are virtually barren of foraminifera (Gradstein et al., 1994). The first peak of S. spectabilis at 24.50 m is synchronous with the first appearance of Trochammina spp. ~ 5 m below the BEE. A similar increase in Trochammina spp. has been found in the uppermost Paleocene in the outer neritic Esna Shales of Egypt (Kaminski, Berggren & Cetean, in prep.), where this group dominates the agglutinated foraminiferal assemblages in the uppermost Paleocene "dissolution facies". The second peak in S. spectabilis is broader, beginning between 28.20 and 28.50 m. A maximum in Subreophax spp. coincides with the upper part of this peak, and encompasses the CIE interval. In the modern ocean, Subreophax is known to be an opportunistic form and is presently recolonising area of the South China Sea affected by the 1991 Mt. Pinatubo volcanic ashfall (Hess et al. 2001).

These faunal changes are indicative of a gradual initiation of the paleoecological/paleoceanographic changes eventually leading to the BEE, which are also reflected by a gradual decrease in our bulk carbonate  $\partial^{13}$ C values within planktic foraminiferal zones P4-P5. A gradual decline in  $\partial^{13}$ C values prior to the rapid

<sup>13</sup>C excursion occurring in coincidence with the PETM is also observed at other Tethyan localities such as in Alamedilla (Lu et al., 1996; Pardo et al., 1999) and Kaurtakapy (Pardo et al., 1999) and in the Zumaya section (Schmitz et al., 1997). In the Contessa Road section, This "prelude" to the BEE starts at 24.50 m above the K/ $\dot{P}$  boundary, i.e., about 5 metres below the onset of the CIE. Assuming a constant sedimentation rate of 6.6 m/myr across the P/E boundary in the Contessa Road section (see above) this event pre-dated the BEE and CIE by about 750 kyr. Interestingly, the same taxa that make their first occurrence or increase in abundance in correspondence to the pre-BEE change, have been shown to disappear temporarily and/or to markedly decrease in abundance from the shallower settings of the Trabakua Pass (Coccioni et al., 1995, Orue-Extebarria et al., 1996) and Caravaca (Ortiz, 1995) sections at the same stratigraphic level. In particular, at Caravaca, a gradual decline eventually leading to the disappearance of Tritaxia trilatera, Gaudryina pyramidata and Dorothia retusa is observed prior to the BEE. Taxa declining in the middle bathyal setting of Caravaca either appear or show increased abundances in the same interval in the Contessa Road section. These taxa evidently underwent a downward migration from upper-middle bathyal settings (200-1000 m) to lower bathyal (1000-2000) settings in the latest Paleocene in the Western Tethys. Accordingly, in the same interval, the first occurrences of Karrerulina coniformis, Bulbobaculites sp., and an increase in Remesella varians are observed. These taxa are either rare or absent in older intervals in the lower bathyal-abyssal Scaglia Rossa of the Umbria Marche Basin (Kuhnt, 1990) but they do occur in the Paleocene of the Tethyan shallower water setting of Possagno, northern Italy (Galeotti, personal observations). According to Ortiz (1995) the gradual change observed in Caravaca occurred over a period of 250 kyr and culminated in a 4‰ shift in  $\partial^{13}$ C. The faunal events observed in the Contessa Road contemporaneously with the gradual decline among benthic foraminifera observed at Caravaca, which suggests a common cause. Based on differences between the record of the Tethyan Caravaca section and the Boreal Zumaya section, Ortiz (1995) suggested that the oceanographic changes which triggered the BEE exhibited their first manifestation in the Tethys region.

Following this 750 kyr-long "prelude" to the BEE, the DWAF assemblages show a drastic decrease in species diversity and a change in taxonomic composition corresponding to the CIE. The succession of events observed in the Contessa Road section seems to suggest that a rapid P/E boundary event was superimposed over a relatively longer term period of paleoceanographic instability. The paleoecological significance of the event recorded by DWAF in correspondence to the CIE and BEE of calcareous hyaline taxa (i.e., a bloom of Repmanina charoides and of small, finely agglutinated taxa) is not unequivocable. However, it correlates well to patterns observed in several other sections (see Coccioni et al., 1996; Orue Extebarria et al., 1996; Kaminski et al., 1996 with references therein). Repmanina charoides (usually reported as Glomospira) has been suggested to prefer well-oxygenated environments by Kaminski et al.

(1989, 1996) but was found to also occur in modern hydrocarbon seep environments by Kaminski (1988). High abundances of *Repmanina charoides* have been found to occur in oxic-mildly dysaerobic environments by Kuhnt et al. (1996). Kuhnt & Kaminski (1989) noted increased abundances of ammodiscids, in particular *Glomospirella*, in lower Campanian green claystones reflecting dysaerobic conditions in the North Atlantic. As already suggested by Kaminski et al. (1996), such different behaviours might simply indicate that the Ammodiscus-Glomospira-Repmanina group is characteristic of environmentally stressed environments showing an opportunistic behaviour under rapidly changing sea floor conditions independently from dissolved oxygen levels on the sea floor.

Regardless of its paleoecological significance, the bloom of Repmanina charoides seems to be of use for stratigraphic correlation across the P-E transition in deep-water settings. It occurs, in fact just above the BEE observed in the calcareous benthic foraminiferal assemblages, and is likely coeval to the Glomospira-Ammodiscus assemblage described by Kaminski et al., (1996) from the Paleocene-Eocene Talaa Lakrah section in northern Morocco. Moreover, similar assemblages with common Glomospira and Ammodiscus have been described from the lower Eocene of the Alpine Carpathian region (Jurkiewicz, 1967; Morgiel & Szymakowska, 1978; Morgiel & Olszewska, 1981, 1982, Bàk, this volume), the lower part of Zone NP10-NP12 (undifferentiated) in the Schlieren flysch of the Alpine Flysch Zone of Switzerland (Winkler, 1984), and from the Northern Alps in the Salzburg area (Speijer, pers. obs.). Kaminski et al. (1990) reported the range of *Glomospira* to be confined to the lower Eocene at Site 643 in the Norwegian Sea. A bloom of *R. charoides* occurs in the Trabakua Pass section in the Basque basin where it forms 50% of the whole assemblage in the earliest Eocene (Coccioni et al., 1995; Orue-Extebarria et al., 1996). Higher abundance of *Glomospira* representatives (including *R. charoides*) have been reported in calcareous nannofossil Zones NP9 and NP10, and planktic foraminiferal Zone P5 by Bubík (1995) from the Bile Karpaty Unit (West Carpathians).

#### b. Paleoceanography and water mass changes

Several papers have discussed the possibility that the low latitude areas acted as a source for warm saline bottom waters (WSBW) during the Early Eocene (Shackleton & Boersma, 1981; Brass et al., 1982; Kennett & Stott, 1990; Barron & Peterson, 1990; Oberhänsli, 1992; Pak & Miller, 1992; Zachos et al., 1992). The DWAF record from the Contessa Road indicates that paleoceanographic changes which led to a downward bathymetric migration of several taxa from outer neritic-bathyal to lower bathyal-abyssal settings began some 750 kyr and intensified some 250 kyr prior to the BEE. Recent studies of Recent benthic foraminiferal distribution indicates that the faunal composition is markedly controlled by organic matter flux rates and dissolved oxygen concentrations in the bottom and pore water (see a review in Van der Zwaan et al., 1999). Since in the open ocean both parameters exhibit a depth-dependent gradients they may control the bathymetric distribution of benthic



**Figure 7**. Faunal parametres record in DWAF assemblages across the P/E boundary in the Contessa Road section. Note the scale break in the faunal group graph.

foraminifera. On the other hand, modern benthic foraminiferal assemblages also show a temperaturedependant bathymetric distribution with shallower upper depth limits for particular species at higher latitudes, therefore in cooler waters (Milam & Anderson, 1981). The bathymetric migration of agglutinated foraminiferal species observed in the western Tethys may have, therefore, been caused by fluctuations of either temperature or food fluxes and oxygen content, or a combination of these factors. However, the record of deposit feeders from the Contessa Road section (Fig. 7), which would testify changes in food fluxes to the sea floor, shows large fluctuations across the P/E boundary which are neither restricted to nor coincide with the prelude. We suggest that temperature was likely the predominant factor controlling the observed downward migration of upper-middle bathyal taxa during the Late Paleocene. These trends suggest that a general re-organisation of deep-water masses occurred during the latest Paleocene in the Western Tethys. Based on a comparison of DWAF assemblages from the abyssal, Talaa Lakra Flysch in northern Morocco with coeval assemblages in the Carpathians, Kaminski et al. (1996) suggested that near the P/E boundary transition, bottom waters started to flow from the western Tethys into the Atlantic. At this locality, an observed size decrease of the DWAF and changes in morphogroups indicating oligotrophy are consistent with the idea of a nutrient-poor water mass of Tethyan origin. Although recording a typically Tethyan succession of DWAF events across the P/E boundary, the sub-CCD Talaa Lakraa locality does not show any signs of the invasion of shallower water taxa observed in the lower bathyal Contessa Road section. Accordingly, a general ocean circulation model suggests that the Tethys was likely a zone of high evaporation and sea-surface salinities during the Eocene, and therefore a prime site for the formation of WSBW (Barron & Peterson, 1990). Indeed, deep halothermal convection in the Tethys would have likely led to deepening of the intermediate water bioprovince within this domain, thereby explaining the bathymetric trend observed in the DWAF assemblages. In particular, a warm, young intermediate water mass of Tethyan origin spreading over lower bathyal settings would explain the presence of shallower water taxa in the uppermost Paleocene in the Contessa Road section. Bice et al. (1997, 2000) suggested that, due to high continental runoff in the Tethys region during the Early Eocene, surface waters could be mixed by low-latitude convection to intermediate depths only. This model could explain why the abyssal settings (e.g., Talaa Lakra in northern Morocco) were not affected by the bathymetric migration observed in DWAF assemblages.

Independent evidence for changes in the deep circulation is given by oxygen and carbon isotopic records (Corfield & Norris, 1998), which suggest the presence of an Atlantic or Western Tethyan deep water source during the early Paleocene. During the mid- to late Paleocene the Southern Ocean became the dominant deep-water source at the expense of the Tethys. However, the PETM seems to represent a brief change from thermohaline (high-latitude) to halothermal (low-latitude) deep-water formation (Corfield & Norris, 1998). However, Sloan & Thomas (1998) suggested that although background climates may have led to conditions conducive to tropical and subtropical deep water formation, surface salinity patterns that occurred within the subsequent PETM would have not sustained a large deep water



**Figure 8.** Summary scheme of bioevents recognised in the DWAF assemblages across the P/E boundary in the Gubbio area. Different biozonal schemes according to their authors are reported as: 1) Martini (1971); 2) Okada & Bukry (1980); 3) Berggren *et al.* (1995); 4) Berggren & Miller (1989).

contribution from the subtropics for a long time on a geological scale. In this context, the prelude interval evidenced by the DWAF record would represent a phase of intensification of deep water convection from the western Tethys.

#### CONCLUSIONS

A succession of events and changes in the taxonomic structure of DWAF has been well calibrated to the magnetostratigraphy and calcareous plankton biostratigraphy across the P/E Boundary of the Contessa Road section (Fig. 8). A distinct extinction in calcareous hyaline benthics occurring within Zones P5 and NP10 is correlative to a sharp change in DWAF assemblages which occurs within the same stratigraphic interval, indicating a major perturbation on the sea floor.

The record of DWAF, however, indicates a gradual initiation of such perturbation beginning some 750 kyr before the BEE with the entrance of shallower water taxa probably in response to warming of bottom waters. This prelude to the P/E boundary event led to the downward bathymetric migration of several (mostly calcareous-cemented) agglutinated taxa and is here ascribed to a re-organisation of intermediate and deep water masses following the onset of deep convection in the western Tethys.

The succession of events recognised in DWAF assemblages may be of use for supra-regional stratigraphic correlations across the P/E boundary interval. In particular, the bloom of small, finely-grained agglutinated DWAF dominated by ammodiscids (*Glomospira, Repmanina, Ammodiscus*) is characteristic of the lowermost Eocene at many Tethyan and Atlantic localities. This event is correlatable over a wide area and paleobathymetric range, and allows the identification of the P/E boundary in deep water settings at least in the western Tethys and North Atlantic. To what extent the so-called *"Glomospira* bloom" is related to the release of methane hydrates remains speculative, but the occurrence of opportunistic *Spiroplectammina* and *Subreophax* across the P/E boundary interval is regarded to be clear evidence of perturbation of the deep-sea ecosystem.

#### **TAXONOMIC NOTES**

Species concepts largely follow Kuhnt (1990), Kaminski & Geroch (1993), and Kaminski *et al.* (1996). Generic concepts follow the Agglut-2002 data base (Kaminski, 2002). Taxa are arranged alphabetically. For the sake of brevity, only primary references are cited.

#### Bulbobaculites sp.

#### Plate 3, Fig. 6

Test small, elongate, early stage with streptospiral arrangement of globose chambers. Later chambers become uncoiled and rectilinearly disposed. Sutures distinct, depressed and horizontal. Wall agglutinated, smoothly finished. aperture terminal, small and rounded.

#### Ammodiscus cretaceus (Reuss, 1845)

# Plate 2, Fig. 1

Operculina cretacea Reuss, 1845, p. 35, pl. 13, figs 64, 65.

Ammodiscus peruvianus Berry, 1928

Plate 2, Fig. 2

Ammodiscus peruvianus Berry, 1928, p. 342, pl. 27.

Ammodiscus tenuissimus Grzybowski, 1898

Plate 2, Fig. 3

Ammodiscus tenuissimus Grzybowski, 1898, p. 282, pl. 10, fig. 35.

*Ammosphaeroidina pseudopauciloculata* (Mjatliuk, 1966)

Plate 4, Fig. 1

*Cystamminella pseudopauciloculata* Mjatliuk, 1966, p. 264, pl. 1, figs 5 - 7; pl. 2, fig. 6; pl. 3, fig. 3.

Aschemocella carpathica Neagu, 1964

Plate 1, Fig. 9

Aschemocella carpathica Neagu, 1964, text-figs. 2.2-4, 3.1-3, 4.1-6.

Aschemocella grandis (Grzybowski, 1898)

Plate 1, Fig. 8

Reophax grandis Grzybowski, 1898, p. 277, pl. 10, figs 13-15.

# Aschemocella?

Plate 1, Fig. 5

We tentatively place in the genus *Aschemocella* specimens with a a coarsely grained agglutinated wall with elongate regularly-sized chambers.

Cribrostomoides trinitatensis Cushman & Jarvis, 1928

Plate 3, Fig. 16

Cushman & Jarvis, 1928, p. 91, pl. 12, figs 12a-b.

Dorothia retusa (Cushman, 1926)

Plate 4, Fig. 13

*Gaudryina retusa* Cushman, 1926, p. 588, pl. 16; figs 10 a,b.

Glomospira glomerata (Grzybowski, 1898)

Plate 2, Fig. 7

Ammodiscus glomeratus Grzybowski, 1898, p. 285, pl. 11, fig. 4.

Glomospira gordialis (Jones & Parker, 1860)

#### Plate 2, Fig. 5

*Trochammina squamata* Jones & Parker var. *gordialis* Jones & Parker, 1860, p. 304.

Glomospira irregularis (Grzybowski, 1898)

#### Plate 2, Fig. 4

Ammodiscus irregularis Grzybowski, 1898, p. 285, pl. 2, figs 2-3.

Glomospira serpens (Grzybowski, 1898)

Plate 2, Fig. 10

Ammodiscus serpens Grzybowski, 1898, p. 285, pl. 10, figs 31-33.

#### Glomospira ? sp.

Plate 2, Fig. 6

Finely grained agglutinated, irregularly coiled. The later portion of the second tubular chambers, apparently shows slight annular constriction, similarly to *Lituotuba*.

*Glomospirella gaultina* (Berthelin, 1880)

Ammodiscus gaultinus Berthelin, 1880, p. 19, pl. 1, figs 3a-b.

Haplophragmoides horridus (Grzybowski, 1901)

Plate 3, Fig. 7

Haplophragamium horridum Grzybowski, 1901, pl.7, fig. 12.

Haplophragmoides kirki Wickenden, 1932

Plate 3, Fig. 12

Haplophragmoides kirki Wickenden, 1932, p. 85, pl. 1, fig. 1.

Haplophragmoides porrectus Maslakova, 1955

Plate 3, Fig. 8

Haplophragmoides porrectus Maslakova, 1955, p. 47, pl. 3, figs 5-6.

Haplophragmoides stomatus (Grzybowski, 1989)

Plate 3, Fig. 9

Trochammina stomata Grzybowski, 1898, p. 290, pl. 11, figs 26-27.

Haplophragmoides suborbicularis (Grzybowski, 1896)

Plate 3, Fig. 14

*Cyclammina suborbicularis* Grzybowski, 1896, p. 24, pl. 9, figs 5-6.

Haplophragmoides walteri (Grzybowski, 1898)

Plate 3, Fig. 10

Trochammina walteri Grzybowski, 1898, p. 290, pl. 11, fig. 31.

Hormosinella distans (Brady, 1881)

Plate 3, Fig. 1

Reophax distans Brady, 1881, p. 50.

Kalamopsis cf. grzybowskii (Dylà"anka, 1923)

Plate 1, Fig. 4

Hyperammina grzybowskii Dylà"anka, 1923, p. 65.

Karrerulina coniformis (Grzybowski, 1898)

Plate 4, Fig. 18

Gaudryina coniformis Grzybowski, 1898, p. 284, pl. 12, fig. 7.

Karrerulina conversa (Grzybowski, 1901)

#### Plate 4, Fig. 16

Gaudryina conversa Grzybowski, 1901, p. 285, pl. 12, fig. 7.

#### Karrerulina horrida (Mjatliuk 1970)

# Plate 4, Fig. 17

*Karrerulina horrida* Mjatliuk, 1970, p. 114, pl. 5, fig. 9; pl. 33, figs 15-16c.

#### Internal mould

#### Plate 1, Figs 6, 12-13.

We observed numerous specimens of a tubular agglutinanted foraminifera, probably a species of *Rhizammina*, that has invaded the interior of empty planktic foraminiferal tests. Some specimens faithfully reproduce the internal morphology of *Subbotina* and *Morozovella*, and even display elevated "bumps" that correspond to the internal pores of the planktic foraminifera (e.g., Plate 1, Fig. 13).

#### Lagenammina sp.

Plate 1, Fig. 1

This species possesses an elongate neck typical of the genus. Wall is coarsely agglutinated. The aperture is terminal, produced on the elongate neck.

*Lituotuba lituiformis* (Brady, 1879)

Plate 2, Fig. 13

Trochammina lituiformis Brady, 1879, p. 59, pl. 5, fig. 16.

#### Lituotuba sp.

#### Plate 2, Fig. 12

Test comprised of an irregularly coiled part followed by a more regular (trochospiral) portion. Wall thin, medium-grained agglutinated.

#### Lituotuba vermetiformis (Grzybowski, 1898)

*Trochammina vermetiformis* Grzybowski, 1898, p. 286, pl. 11, fig. 19.

Paratrochamminoides heteromorphus (Grzybowski, 1898)

#### Plate 4, Fig. 5

*Trochammina heteromorpha* Grzybowski, 1898, p. 286, pl. 11, fig. 16.

#### Paratrochamminoides olszewskii (Grzybowski, 1898)

#### Plate 4, Fig. 6

*Trochammina olszewskii* Grzybowski, 1898, p. 286, pl. 11, fig. 6.

Praecystammina globigerinaeformis Krasheninnikov, 1973

Krasheninnikov, 1973, p. 210, pl. 2, figs 1a-c, 2.

#### *Psammosphaera scruposa* (Berthelin, 1880)

#### Plate 1, Fig. 7

Haplophragmium scruposum Berthelin, 1880, p. 21, pl. 1, fig. 1.

#### Pseudobolivina lagenaria Krasheninnikov, 1974

Plate 4. Fig. 8

*Pseudobolivina lagenaria* Krasheninnikov, 1974, p. 639, pl. 5, figs. 1a-b, 2a.

Pseudobolivina munda Krasheninnikov, 1973

#### Plate 4, Fig. 7

Pseudobolivina munda Krasheninnikov, 1973, p. 210, pl. 2, figs 10-11.

#### *Pseudobolivina* sp. 1

#### Plate 4, Fig. 10

Test elongate small, finely agglutinated. Differs from *P. munda* in its smaller size, more elongated chambers and aperture clearly produced on a neck.

#### Pseudobolivina sp. 2

#### Plate 4, Fig. 9

Test elongate and bent, tapered at the base. Chambers are slightly twisted. Sutures horizontal. The wall is finely agglutinated.

#### Pseudonodosinella parvula (Huss, 1966)

Plate 3, Fig. 2

Reophax parvulus Huss, 1966, p. 21, pl. 1, figs 26-30.

Pseudonodosinella cf. troyeri (Tappan, 1960)

Plate 3, Fig. 3

*Reophax troyeri* Tappan, 1960, p. 291, pl. 1 figs 10-12.

#### Recurvoides nucleolus (Grzybowski, 1898)

#### Plate 3, Fig. 11

Trochammina nucleolus Grzybowski, 1898, p. 291, pl. 11, figs 28-29.

#### Recurvoides sp.

#### Plate 3, Fig. 13

A medium-sized species of *Recurvoides* characterised by a quasi-trochospiral chamber arrangement. The 5-6 visible chambers are characterised by a finely agglutinated wall.

*Remesella varians* (Glaessner, 1937)

#### Plate 4, Fig. 14

Textulariella? varians Glaessner, 1937, p. 366, pl. 2, fig. 15a-c.

#### Reophax elongatus Grzybowski, 1898

Reophax elongata Grzybowski, 1898, p. 279, pl. 10, figs 19-20.

#### Repmanina charoides (Jones & Parker, 1860)

#### Plate 2, Figs 8-9

Trochammina squamata Jones & Parker var. charoides Jones & Parker, 1860, 304.

# Reticulophragmoides jarvisi (Thalmann, 1932) emended Gradstein & Kaminski, 1989

#### Plate 3, Fig. 17

Nonion cretacea Cushman & Jarvis, 1932, pl. 12, figs 12a, b. Nonion jarvisi Thalmann, 1932, p. 312.

*Reticulophragmoides jarvisi* (Thalmann). – Gradstein & Kaminski, 1989, p. 81, pl. 7, figs 1-8; textfig. 4.

#### Rhabdammina spp.

#### Plate 1, Fig. 10

We place in this group tubular fragments of constant diameter characterised by a thick, coarsely agglutinated wall with a smooth cavity interior

#### Rhizammina indivisa Brady 1884

Rhizammina indivisa Brady, 1884, p. 277, pl. 29, figs 5-7.

#### Rhizammina sp.

### Plate 1, Fig. 11

Curved tubular fragments characterised by a rather rough surface.

Rzehakina epigona (Rzehak, 1895)

# Plate 2, Fig. 11

Silicina epigona Rzehak, 1895, p. 214, pl. 6, fig. 1.

#### Saccammina grzybowskii (Schubert, 1902)

# Plate 1, Fig. 2

Reophax grzybowskii Schubert, 1902, p. 20, pl. 1, fig. 13.

#### Saccammina placenta (Grzybowski, 1898)

# Plate 1, Fig. 3

Reophax placenta Grzybowski, 1898, p. 276, pl. 10, figs 9-10.

#### Saccammina sphaerica Sars, 1872

Saccammina sphaerica Sars, 1872, p. 250

#### Spiroplectammina spectablis (Grzybowski, 1898)

#### Plate 4, Fig. 12

Spiroplecta spectablis Grzybowski, 1898, p. 293, pl. 12, fig. 12.

#### Subreophax cf. splendidus (Grzybowski, 1898)

#### Plate 3, Fig. 5

*Reophax splendida* Grzybowski, 1898, p. 278, pl. 10, fig. 16. *Subreophax pseudoscalaris* (Samuel, 1977)

Reophax pseudoscalaria Samuel, 1977, p. 36, pl. 3, figs 4a-b.

#### Subreophax scalaris (Grzybowski, 1896)

#### Plate 3, Fig. 4

*Reophax guttifera* var. *scalaria* Grzybowski, 1896, p. 277, pl. 8, fig. 26.

#### Thalmannammina? sp.

### Plate 3, Fig. 15

Test globular, small. The last whorl, formed by 4 chambers, shows a sharp change in the coiling direction. Wall coarsely agglutinated.

# Tritaxia aspera (Cushman, 1926)

#### Plate 4, Fig. 15

Clavulina trilatera var. aspera Cushman, 1926, p. 589, pl. 17,

fig. 3.

*Trochammina deformis* Grzybowski, 1898 *Trochammina deformis* Grzybowski, 1898, pl. 11, figs 20-22.

#### Trochammina quadriloba Höglund, 1948

Plate 4, Fig. 3

Trochammina pusilla Höglund, 1947, pl. 17, figs 4a-c.

Trochamminoides cf. dubius (Grzybowski, 1901)

#### Plate 2, Figs 15-16

Ammodiscus dubius Grzybowski, 1901, p. 274, pl. 8, figs. 12-14.

Tochamminoides proteus (Karrer, 1866)

### Plate 2, Fig. 17

Trochammina proteus Karrer, 1866, p. 494, pl. 1, fig. 8.

#### Trochamminoides septatus (Grzybowski, 1898)

Ammodiscus septatus Grzybowski, 1898, p. 283, pl. 11, fig. 1.

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**Plate 1. 1.** Lagenammina? x 350; **2.** Saccammina grzybowskii x 200; **3.** Saccammina placenta x 100; **4.** Kalamospis cf. grzybowskii x150; **5.** Aschemocella ? x 75; **6.** Internal mould (*Rhizammina indivisa*?) x 200; **7.** Psammosphaera scruposa x 350; **8.** Aschemocella grandis x 75; **9.** Aschemocella carpathica x 100; **10.** Rhabdammina sp. x 75; **11.** Rhizammina sp. x200; **12.** Internal mould (*R. indivisa*?) x 200; **13.** Internal mould (*R. indivisa*?) x 200.



**Plate 2. 1.** Ammodiscus cretaceus x 100; **2.** Ammodiscus peruvianus x 75; **3.** Ammodiscus tenuissimus x 200; **4.** Glomospira irregularis x 100; **5.** Glomospira gordialis x 200; **6.** Glomospira sp. x 200; **7.** Glomospira glomerata x 75; **8.** Repmanina charoides x 150; **9.** Repmanina charoides x 200; **10.** Glomospira serpens x 100; **11.** Rzehakina epigona x 150; **12.** Lituotuba sp. x 100; **13.** Lituotuba lituiformis x 100; **14.** Litutotuba ? x 150; **15.** Trochamminoides cf. dubius x 100; **17.** Trochamminoides proteus x 75.



**Plate 3. 1.** Hormosinella distans x 200; **2.** Pseudonodosinella parvula x 200; **3.** Pseudonodosinella cf. troyeri x 200; **4.** Subreophax scalaris x 75; **5.** Subreophax cf. splendidus x 75; **6.** Bulbobaculites sp. x 200; **7.** Haplophragmoides horridus x 200; **8.** Haplophragmoides porrectus x 350; **9.** Haplophragmoides stomatus x 200; **10.** Haplophragmoides walteri x 200; **11.** Recurvoides nucleolus x 100; **12.** Haplophragmoides kirki x 350; **13.** Recurvoides sp. x 200; **14.** Haplophragmoides suborbicularis x 150; **15.** Thalmannammina? sp. x 200; **16.** Cribrostomoides trinitatensis x 20; **17.** Reticulophragmoides jarvisi x 200.



**Plate 4. 1.** Ammosphaeroidina pseudopaciloculata x 200; **2.** Trochammina sp. x 200; **3.** Trochammina quadriloba x 200; **4.** Trochammina sp. x 350; **5.** Paratrochamminoides heteromorphus x 100; **6.** Paratrochamminoides olszewskii x 100; **7.** Pseudobolivina munda x 200; **8.** Pseudobolivina lagenaria x 200; **9.** Pseudobolivina sp. 2 x 350; **10.** Pseudobolivina sp. 1 x 350; **11.** Pseudobolivina ? x 350; **12.** Spiroplectammina spectabilis x 100; **13.** Dorothia retusa x 100; **14.** Remesella varians x 100; **15.** Tritaxia aspera x 150; **16.** Karrerulina conversa x 200; **17.** Karrerulina horrida x 200; **18.** Karrerulina coniformis x 150.