

### 31. UPPER CRETACEOUS, K/T BOUNDARY, AND PALEOCENE AGGLUTINATED FORAMINIFERS FROM HOLE 959D (CÔTE D'IVOIRE-GHANA TRANSFORM MARGIN)<sup>1</sup>

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#### ABSTRACT

Upper Cretaceous agglutinated foraminifer assemblages from Hole 959D of Ocean Drilling Program (ODP) Leg 159, Côte d'Ivoire-Ghana Transform Margin, reflect the subsidence history and paleoceanography of the widening equatorial Atlantic gateway. Five benthic foraminifer assemblage types are recognized: (1) Santonian and the lowermost Campanian assemblages (Cores 159-959D-65R and 64R) are characterized by the occurrence of bathyal calcareous benthic foraminifers with an increasing proportion of agglutinated foraminifers. The disappearance of calcareous foraminifers and assemblages exclusively composed of organically cemented agglutinated forms in Section 159-959D-65R-3 reflects the subsidence of the seafloor below the calcite compensation depth (CCD); (2) lower Campanian "biofacies B" assemblages (Cores 159-959D-63R through 61R) are exclusively composed of low-diversity agglutinated foraminifers, accompanied by abundant and occasionally well-preserved radiolarian assemblages; (3) middle Campanian to upper Maastrichtian deposits (Cores 159-959D-59R through 49R) contain an exclusively agglutinated *Rzehakina epigona* biofacies, which is well-known from middle to deep bathyal sites along the North Atlantic margins; (4) a change in agglutinated foraminifer assemblage composition toward morphologies commonly observed in present infaunal habitats and the common occurrence of the presumably infaunal genus *Spiroplectamina* are observed in Core 159-959D-48R. This change in agglutinated foraminifer assemblages corresponds to the Tethyan early Paleocene "*Spiroplectamina* event;" (5) a diversified Paleocene "Lizard Springs type" assemblage is characterized by several diverse *Rzehakina*, *Saccamina*, and *Haplophragmoides* species. Assemblages from Cores 159-959D-48R through 44R display high species diversity and reflect the deepest (lower bathyal to upper abyssal) paleobathymetry.

Ranges of agglutinated foraminifer marker species and occurrences of paleoceanographic events within this biostratigraphic framework are almost identical to those observed in the North Atlantic, in the Western Tethys, and along the conjugate Brazilian margin. These observations lead us to confirm that a deep-water circulation system common to the North and South Atlantic has been active at least since the Santonian.

#### INTRODUCTION

Since the milestone paper of Geroch and Nowak (1984), deep-water agglutinated foraminifers (DWAF) have been used as biostratigraphic tools for Upper Cretaceous sub-calcite compensation depth (CCD) sediments in various oceanic basins. Initial DWAF zonation for the Atlantic Ocean were developed by Moullade et al. (1988) for the Cretaceous and by Kaminski (1988) for the Paleogene. More recent biostratigraphic work on DWAF includes material from the Cretaceous to Paleogene of various localities within the North Atlantic (Kuhnt et al., 1992; Kuhnt and Collins, 1996), the Western Tethys (Kuhnt and Kaminski, 1989; Bubik, 1995; Kaminski et al., 1996), the marginal basins of the South Atlantic (Volat et al., 1996), and the Western Pacific Ocean (Wightman and Kuhnt, 1992). A rough attempt to calibrate Upper Cretaceous DWAF zonation to magnetostratigraphy has been made using material from the Tethyan Cretaceous standard magnetic polarity section at Gubbio (Kuhnt, 1990).

During ODP Leg 159, the initial shipboard studies revealed that a continuous record of abundant and diverse DWAF ranging from the lowermost Campanian to the lower Eocene is present in Hole 959D (Fig. 1). The purpose of our study is to conduct an initial survey of the taxonomy and biostratigraphy of DWAF in Hole 959D and also to

provide new information on their paleobiogeographic significance. Thus, this study represents an additional opportunity to test the supra-regional validity of existing DWAF zonation and to monitor the paleogeographic extent of paleoceanographic events that characteristically influence assemblage composition and evolution of DWAF.

#### MATERIAL AND METHODS

Samples of varying sizes (see Table 1) were processed for the study of benthic foraminifers. The samples were dried, weighed, soaked in distilled water, and wet-sieved through a 63- $\mu$ m screen; the residue was then dried. Very consolidated samples were first treated with a buffered 5% hydrogen peroxide solution to help break them up before sieving. In rare cases, where this hydrogen peroxide treatment did not lead to complete disintegration of the clay, we soaked the dried sample in a concentrated anionic tenside solution (REWO-QUAT, of REWO Chemie, Steinau an der Straße, Federal Republic of Germany), which usually disintegrated even slightly silicified samples. Generally, the complete residue was picked for benthic foraminifers. In a few exceptional samples with very high faunal content we picked only splits of the samples. Splitting was done with a standard Otto-splitter. All recorded individuals were mounted into cardboard slides for reference. The abundance data are reported (Table 1) only in numbers of identified agglutinated individuals per sample. These data are somewhat biased because fragments and unidentifiable specimens were not taken into account. The abundance of such specimens differs significantly among samples because of large differences in preservation or differential dilution by terrigenous supply. In some cases, the numbers of unidentifiable forms exceed the recorded numbers of identified individuals. For selected species (mainly forms with high preservation potential) that occur with suf-

<sup>1</sup>Masle, J., Lohmann, G.P., and Moullade, M. (Eds.), 1998. *Proc. ODP, Sci. Results*, 159: College Station, TX (Ocean Drilling Program).

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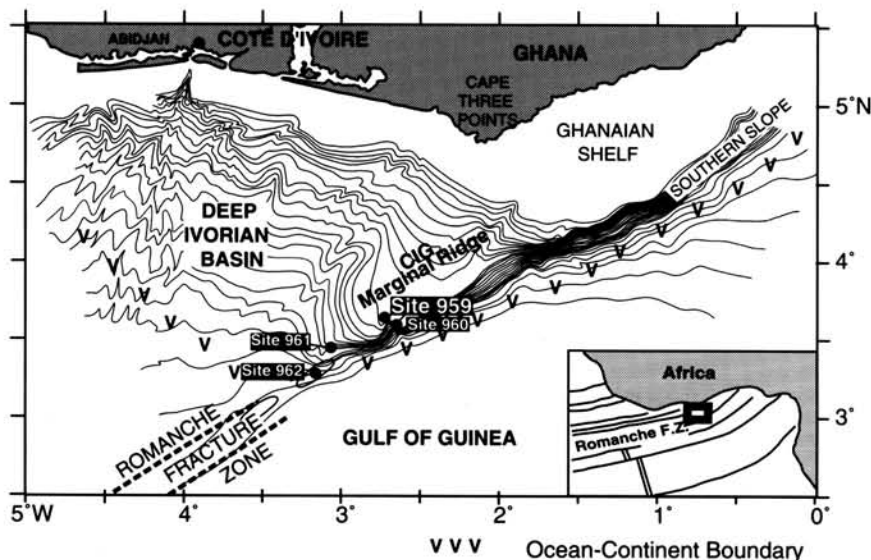


Figure 1. Sketch map showing the location of Hole 959D.

ficiently good preservation over the entire studied interval, numbers per gram of sediment were calculated and plotted.

## RESULTS

### Biostratigraphy

The last occurrences of planktonic and calcareous benthic marker species in Hole 959D and first occurrences, last occurrences, and acmes of at least 10 species of DWAF allow a biostratigraphic subdivision of Hole 959D Cores 159-959D-65R to 48R (Fig. 2), using the following index taxa:

1. The lowermost part of Core 159-959D-65R is characterized by a benthic foraminifer biofacies that is dominated by buliminids, including species characteristic of Turonian to Santonian sediments in West African coastal basins. Sample 159-959D-65R-6, 28–32 cm, contains the planktonic foraminifer *Dicarinella asymmetrica*, a zonal marker for the upper Santonian (Caron, 1985).
2. Within the calcareous deep-water benthic foraminifer assemblages of Core 65R, the lower Campanian marker *Neoflabellina rugosa* is observed in Sample 159-959D-65R-1, 49–52 cm. This correlates with the base of the Campanian (Koch, 1977).
3. A radiolarian-rich interval in Core 159-959D-61R may correspond to the early Campanian paleoceanographic event observed in various sections of the North Atlantic and western Tethys (Kuhnt, 1992). Within the Gubbio section (northern Italy), this biosiliceous event is observed in the upper part of the A34 magnetic reversed zone, which roughly corresponds to the lower Campanian.
4. The Turonian-mid-Campanian marker *Uvigerinamina jankoi* occurs in a single sample (Sample 159-959D-61R-2, 61–65 cm) at the top of the radiolarian-rich interval. This occurrence probably corresponds to the last appearance datum (LAD) of this species, since the higher samples do not contain *U. jankoi*, although the general assemblage composition indicates favorable oligotrophic deep-water environmental conditions for this species. Its absence within the radiolarian-rich interval and the underlying shallower deposits is not surprising, since these dysaerobic sediments constitute unfavorable environmental conditions for this taxon.

5. The first occurrences of typical *Rzehakina epigona* (Section 159-959D-60R-5) and *Hormosina velascoensis* (Section 159-959D-60R-2) indicate also the lowermost Campanian. The first occurrences of these species are correlative with the base of the lowermost Campanian *C. gigantea*-*U. jankoi* overlap zone in the North Atlantic and western Tethys (Kuhnt et al., 1992).
6. In Sample 159-959D-48R-6, 28–31 cm, the last occurrence of *Caudammina gigantea* is observed. This species is the zonal marker of the middle Campanian-Maastrichtian *Caudammina gigantea* zone, which is generally recognized in deep-water sequences of the North Atlantic and Western Tethys (Geroch and Nowak, 1984; Moullade et al., 1988). In Hole 959D, *Caudammina gigantea* first occurs in Sample 159-959D-49R-6, 27–30 cm (upper Maastrichtian). This late first occurrence of *C. gigantea* is unusually high and is probably controlled by the subsidence history of the site. *C. gigantea*, a typical abyssal species, has an upper depth limit of its distribution estimated as corresponding to lower bathyal depths (Kuhnt and Kaminski, 1990). The water depth at Site 959 was probably too shallow for *C. gigantea* before the late Maastrichtian.
7. The DWAF assemblage in Core 159-959D-48R is characterized by a distinct acme of *Spiroplectamina spectabilis*, a cosmopolitan Paleogene form (Kaminski, 1988). A single occurrence of *Conotrochammina whangaia*, a Paleocene marker in the North Atlantic and its marginal basins (Kuhnt and Kaminski, 1990), is observed in Sample 159-959D-48R-5, 28–31 cm.
8. A late Paleocene (Selandian/Thanetian) age assignment is based on the first occurrence (FO) of *Reticulophragmoides jarvisi* in Sample 159-959D-44R, CC. The FO of this species has been observed in the lower part of the upper Paleocene at several localities in the Atlantic and North Sea (Gradstein and Kaminski, 1989). The earliest forms of this species (from Zone P3 in Zumaya and Tunisia) are flat and resemble its assumed ancestor, *Haplophragmoides walteri*. Younger specimens, such as the types in the Cushman Collection (from Zone P5 in Trinidad), have a more lenticular shape. Such typical late Paleocene specimens were found in Sample 159-959D-43R-1, 28–32 cm. Other species that characterize the upper Paleocene at Lizard Springs include the large Paleogene form of *Haplophragmoides walteri* (FO in Sample 159-959D-47R-1, 19–22

Table 1. Distribution of agglutinated foraminifers in the Upper Cretaceous and lowermost Paleogene of Hole 959D.

Core, section, interval (cm)	<i>Ammobaculites</i> sp.	<i>Ammodiscus cretaceus</i>	<i>Ammodiscus</i> ex gr. <i>perryi</i>	<i>Ammodiscus glabratus</i>	<i>Ammodiscus peruvianus</i>	<i>Ammodiscus tenuissimus</i>	<i>Ammolagena clavata</i>	<i>Ammoscalaria</i> sp.	<i>Ammosphaeroidina</i> sp.	<i>Aschemocella</i> spp. (incl. fragments)	<i>Bathysiphon</i> spp.	<i>Budashvevella multicamerata</i>	<i>Bulbobaculites</i> ex gr. <i>problematicus</i>	<i>Bulbobaculites</i> sp.	<i>Buzasina</i> sp.	<i>Caudamina gigantea</i>	<i>Caudamina ovuloides</i>	<i>Caudamina ovula</i>	<i>Clavulinoides</i> sp.	<i>Conotrochammina whangaia</i>	<i>Cribrostomoides</i> sp.	<i>Dorothia bullata</i>	<i>Dorothia</i> ex gr. <i>filiformis</i>	<i>Dorothia</i> sp.	<i>Evolutinella</i> (?) sp.	<i>Gaudryina</i> sp.	<i>Glomospira charoides</i>	<i>Glomospira diffundens</i>	<i>Glomospira glomerata</i>	<i>Glomospira gordialis</i>					
159-959D-																																			
43R-1, 28-32					3	4			23	2	21																	6	5						
43R-3, 34-36					4	5			11	1	9																	6	2						
43R-5, 32-35					1	4					3																								
43R-CC					2	1			4		3																	2							
44R-2, 16-22					6				4	1	3																	5							
44R-3, 30-33						3			2	2	10											1						5							
44R-5, 30-33					2	3			36	15																		12	1						
44R-6, 30-33				4		7			8	13	13																4	1							
44R-CC					1	2			2	10	16																	1							
45R-1, 43-48	1				2	4			5	2	13																	2							
45R-CC					1	2			6		36				2													5							
46R-1, 80-85	1				2	7			9	6	37																6								
46R-CC					4	8			15		26																	13							
47R-1, 19-22	1	1			1	3			11	3	11																	4							
48R-1, 28-31		2				2			1	16	5																	4							
48R-1, 69-70		3								2	1																	6							
48R-2, 27-30		1				1				27	13																	3							
48R-3, 31-34	2					5			6	60	14																2								
48R-3, 137-139	3				5	14			12		16																7								
48R-4, 28-31						4			9	12	14																3								
48R-4, 48-50						1				1																	5								
48R-4, 66-68											5																7								
48R-4, 69-71			2							2	3																1								
48R-5, 28-31										5	9																1								
48R-5, 87-89										1	8																3								
48R-6, 28-31					2	10			23	50	40																9								
48R-CC						16			5	9	26																12								
49R-1, 28-31	6	8				10			9	9	33																18								
49R-1, 69-72		1							1	6																	5								
49R-1, 110-114		3							8																		6								
49R-2, 27-30	4(?)	6				7			1	1	29																10								
49R-3, 27-30	5	5				8			3	1																	6								
49R-4, 27-30	5										1																1								
49R-4, 69-72	1	3	1				1		2	44	2																1								
49R-5, 27-31		2						1	5	3	2(?)																2								
49R-6, 27-30	1	7	3			8		3(?)	25	10	30																1								
50R-1, 27-30									2	3																									
50R-1, 70-73										1																									
50R-2, 26-29	1	1						6	16	4	8																2								
50R-3, 28-31	1	3						3	3	3																	1								
50R-4, 26-29	2	1						1	2	5																									
50R-4, 68-71								10	10	11																									
50R-5, 30-34	1	1						2	10	4																		2							
51R-3, 28-31		5	1					1	2	2																									
52R-1, 23-27			4							2																									
52R-1, 29-33		2								1	12																								
52R-1, 67-71										1	11																								
52R-2, 25-27										1	4																								
52R-3, 27-31										1																									
52R-4, 30-33										1	5																								
52R-4, 45-48										1																									

cm), *Glomospira diffundens* (FO in Sample 159-959D-44R-6, 30–33 cm), *Trochammina ruthvenmurrayi* (in Sample 159-959D-43R, CC), the late Paleocene morphotype of *Conotrochammina whangaia* with more open coiling and a deep umbilicus, and *Spiroplectammina excolata* (in Sample 159-959D-43R-1, 28–32 cm). The presence of *Rzehakina fissistomata* (the index taxon of the Paleocene *R. fissistomata* zone of Geroch and Nowak, 1984) in Hole 959D suggests faunal similarities with the upper Paleocene of the western Tethys. However, equally important in this respect is the notable absence of *Glomospira grybowskii*, a form that is common in the Paleocene throughout the Carpathian region. Only a single occurrence of this species was observed in Hole 959D. The

recurrence of calcareous benthic foraminifers (a diverse "Velasco-type" assemblage dominated by *Gavelinella becariiiformis* and *Nuttallides truempyi*) was observed in Sample 159-959D-44R-3, 30–33 cm, signalling a drop in the CCD.

### Paleobathymetry

Within Core 159-959D-65R a major change is observed from calcareous deep-water benthic foraminifer assemblages (Samples 159-959D-65R-7, 31–35 cm, to 159-959D-65R-4, 30–34 cm) to assemblages exclusively composed of agglutinated forms with organic cement. This change in assemblage composition can only be explained by a subsidence of the depositional environment below the

Table 1 (continued).

Core, section, interval (cm)	<i>Glomospira irregularis</i>	<i>Glomospira serpens</i>	<i>Glomospirella grzybowskii</i>	<i>Haplophragmoides ex gr. excavatus</i>	<i>Haplophragmoides cf. walteri</i>	<i>Haplophragmoides horridus</i>	<i>Haplophragmoides porrectus</i>	<i>Haplophragmoides sp. (?kirki)</i>	<i>Haplophragmoides stomatus</i>	<i>Haplophragmoides walteri</i>	<i>Haplophragmoides suborbicularis</i>	<i>Hippocrepina sp.</i>	<i>Hormosina excelsa</i>	<i>Hormosina trinitatis</i>	<i>Hormosina velascoensis</i>	<i>Hormosina sp.</i>	<i>Hyperammima dilatata</i>	<i>Hyperammima sp. (incl. fragments)</i>	<i>Insculptarenula sp.</i>	<i>Kalamopsis grzybowskii</i>	<i>Karrerulina conversa</i>	<i>Karrerulina spp.</i>	<i>Lagenammima sp.</i>	<i>Lituotuba lituiformis</i>	<i>Nothia ex gr. excelsa</i>	<i>Paratrochamminoides irregularis</i>	<i>Paratrochamminoides mitratus</i>	<i>Paratrochamminoides olszewskii</i>	<i>Paratrochamminoides spp.</i>
159-959D-																													
43R-1, 28-32	3	2						2						1			1				6					4		10	
43R-3, 34-36	5							6	8	1			1		2						10								9
43R-5, 32-35									1																				
43R-CC	1	2									1				1						6							2	
44R-2, 16-22																	2				6								
44R-3, 30-33	1	1							3	2						4					7		1	1		1			
44R-5, 30-33	4								1	4											8		1	1					10
44R-6, 30-33		3						2					1				2				11					3		1	
44R-CC	2					1					1										13		1			1			1
45R-1, 43-48		1				2			5	3											9		2			1			
45R-CC							4	3		1	2				1		2		1		6					1			
46R-1, 80-85	2								5	10					1	4	2				12		3			4		4	
46R-CC					1				14	3							1				19								
47R-1, 19-22		1				1	1		4	1	5					1					39	1	9					2	
48R-1, 28-31															3														
48R-1, 69-70	5	1			1													3			17								
48R-2, 27-30	2	2					6		2						3						28								
48R-3, 31-34																					10		2			1	1	3	
48R-3, 137-139	2	2						2	5												24		1					12	8
48R-4, 28-31												1									19								
48R-4, 48-50	7					7															11		13					1	1
48R-4, 66-68											2										19								
48R-4, 69-71	2											4									15		1						
48R-5, 28-31	1				2			5		1		1		4							7		1						
48R-5, 87-89	2										1				2						17		18				2	6	1
48R-6, 28-31	2	1										1		1							38		4	1				1	4
48R-CC	10				6	3	4	3													50		5			1			4
49R-1, 28-31	10	2			1			2			13	14			1						116	4	2		14				21
49R-1, 69-72	2							11			2										25								8
49R-1, 110-114	4							4			13					3					56								6
49R-2, 27-30	15							4			8			3							155	2	3(?)					17	
49R-3, 27-30	5							14			4	1					6		3(?)		66	2						8	
49R-4, 27-30								2			3										12							1	
49R-4, 69-72	3							4			4										7							1	
49R-5, 27-31	6							3			1			1							16							1	
49R-6, 27-30	13							50			7	5									27							8	
50R-1, 27-30																	4	4		3	53	6(?)		1	12		4	19	
50R-1, 70-73											1										10								
50R-2, 26-29							2				5	1		2							8								2
50R-3, 28-31	2		1					7			1	2		1							12								4
50R-4, 26-29											1						1				27	4			83				
50R-4, 68-71		1			2			7			7			1		10					6		3		19				
50R-5, 30-34	2				1			9			2										20	5			37				4
51R-3, 28-31								2			5			1							10	9			122				6
52R-1, 23-27	1				1			2			2										3				19				2
52R-1, 29-33		1									1														6				
52R-1, 67-71												1									7				7				
52R-2, 25-27											1										2								
52R-3, 27-31											2										5								2
52R-4, 30-33																	1				4								
52R-4, 45-48																					1	1(?)							

CCD during the early Campanian. The position of the Central-Atlantic CCD was high at this time (at ~3000 m, Kuhnt and Moullade, 1991), and it may have been even shallower along the West African margins and the equatorial Atlantic gateway, affected by an oxygen deficiency (oxygen minimum zone) in its mid-water masses (see discussion in Holbourn and Kuhnt, Chap. 30, this volume). An increasing water depth since the early Campanian may be deduced from the increasing diversity of agglutinated assemblages (Fig. 3) and from a successive increase upsection in abundance of typical deep bathyal-abyssal species such as *Pseudobolivina* spp., *Karrerulina conversa*, and *Rhabdammina cylindrica*. The late first occurrence of the typical abyssal species *Caudammima gigantea* (see Kuhnt and Kaminski, 1990) at the base of Core 159-959D-49R is also probably

indicative of a water depth of at least 2500 to 3000 m in the late Maastrichtian.

The Paleocene assemblages are diverse, and display strong similarities to the classic "Lizard Springs Fauna" described by Cushman and Renz (1946) and Kaminski et al. (1988). This type of assemblage with abundant tubular forms and *Rzehakina* is interpreted as indicating lower bathyal to upper abyssal depths, probably in a lower slope or continental-rise setting (Kaminski et al., 1988). The presence of an array of cosmopolitan deep-water species in this assemblage at Site 959 suggests a deeper environmental setting than in the Campanian-Maastrichtian.

Our present observations in the Gulf of Guinea are consistent with those made along the conjugate South American margin in the Sergipe Basin (Brazil) by Koutsoukos and Hart (1990), Koutsoukos

Table 1 (continued).

Core, section, interval (cm)	<i>Popovia beckmanni</i>	<i>Psammospaera fusca</i>	<i>Pseudobolivina lagenaria</i>	<i>Pseudobolivina</i> spp.	<i>Recurvoidella lamella</i>	<i>Recurvoides deflexiformis</i>	<i>Recurvoides</i> sp.	<i>Remesella varians</i>	<i>Reophax duplex</i>	<i>Reophax</i> sp. 2.	<i>Reophax nodulosus</i>	<i>Reophax pilulifer</i>	<i>Reophax subfusiformis</i>	<i>Reophax</i> spp.	<i>Reticulophragmium</i>	<i>Reticulophragmoides jarvisi</i>	<i>Rhabdammina</i> sp.	<i>Rhizammina</i> (large)	<i>Rhizammina</i> spp.	<i>Rzehakina epigona</i>	<i>Rzehakina epigona lata</i>	<i>Rzehakina ex gr. epigona</i>	<i>Rzehakina fissistomata</i>	<i>Rzehakina inclusa</i>	<i>Rzehakina minima</i>	<i>Rzehakina</i> sp. (narrow)	<i>Saccamina grzybowskii</i>	<i>Saccamina placenta</i>	<i>Saccamina sphaerica</i>	<i>Saccorhiza ramosa</i>			
159-959D-																																	
43R-1, 28-32							11									5	14	174				3				1		15	3				
43R-3, 34-36							28										20	18	196				4				1	15	1				
43R-5, 32-35																	2	71				3											
43R-CC							14								1	1	3	78		1		4											
44R-2, 16-22	1						12								3	7	6	322		1					2		7						
44R-3, 30-33							13									35	5	347		2		1			4		3						
44R-5, 30-33				1			8				1				1	1	145		1							2	24						
44R-6, 30-33							15								3	3	205		6						15	7	21	2					
44R-CC							21								2		9	112		5						3							
45R-1, 43-48							35				1					4	18	295		4	1				3	14	1						
45R-CC							21									15	7	201		3		1			2	7	1						
46R-1, 80-85							20							1	1	39	6	242		6				3		13	4						
46R-CC				18			72		2			1				14		274		3					15	15							
47R-1, 19-22	1		4				17									5	3	387								25	1						
48R-1, 28-31			2													6		150							6	4	14	8					
48R-1, 69-70				3												6		253		8						2	8						
48R-2, 27-30							15									7	5	210					2		1	28	2						
48R-3, 31-34				1			7			2						3	7	133					3		2	16	7						
48R-3, 137-139							39			6		1				8	9	355		1						12	20						
48R-4, 28-31			1	3			20			4						5	2	210		7			3		1	11	6						
48R-4, 48-50							20									7		152		4							14						
48R-4, 66-68							26		2							1		131		4							8						
48R-4, 69-71				1			7							1		1	109		6					2		9					2(?)		
48R-5, 28-31							37			1						5	5	255		3					2	6	4						
48R-5, 87-89				7			22					4				1	1	85		5													
48R-6, 28-31			3			3	21			1						24	10	270		2	1						38	3					
48R-CC				1	1		65			8						30	4	346		7						22	13						
49R-1, 28-31			2				174							19		152	3	567		16							10						
49R-1, 69-72							30									13		46		1				1									
49R-1, 110-114				1			51		2							2	6	71		12	2				1(?)		8						
49R-2, 27-30				2			155									94		305		14													
49R-3, 27-30				1(?)			94		1(?)							29	1	175		16							3	4					
49R-4, 27-30							49	1(?)								10		51		11													
49R-4, 69-72	1(?)						49	4(?)	3							2	1	152		5													
49R-5, 27-31							31		6								25	360		1							2						
49R-6, 27-30				3			27		11							64	129		4					1			2	15	4				
50R-1, 27-30							3									11	195		6														
50R-1, 70-73																7	107		3														
50R-2, 26-29				1			18			5						50	289		16														
50R-3, 28-31							19		14							8	119		16														
50R-4, 26-29					1		14					6				5	14	151		19			1										
50R-4, 68-71							6	1				2		1	1		117		24					3			1						
50R-5, 30-34					1		27		3			6		10	1		7	222		17				1									
51R-3, 28-31							43		2			1				10		165		7							7	1(?)					
52R-1, 23-27																	7	24		25													
52R-1, 29-33			3				17										21	95		13		8		1									
52R-1, 67-71							6		1								4	69		19							2	2					
52R-2, 25-27							5										27	73		18							1						
52R-3, 27-31							6										47	95		47													
52R-4, 30-33	2(?)						9										242		21					8(?)									
52R-4, 45-48	12						4										193		21					6			3						

(1992), Koutsoukos and Bengtson (1993), and Koutsoukos et al. (1993). Along the northeastern and equatorial Brazilian margin, these authors have recognized an important deepening event that occurred by late Coniacian–early Santonian times, and was brought about by the final structural detachment of the South American and African plates. According to these authors, this late Coniacian–early Santonian event resulted in the establishment of a deep-oceanic circulation regime, which is reflected in a remarkable change in the sedimentary sequence from a carbonate-dominated (Cenomanian–middle Coniacian) to a siliciclastic cycle (Koutsoukos et al., 1993). Koutsoukos (1992) observed a sharp increase in species diversity of the benthic foraminifers in the upper Coniacian–Maastrichtian, with a maximum in the lower Campanian. The total diversity of benthic foraminifers progressively declined after the early Campanian maximum in a step-

wise pattern. In the Sergipe Basin, middle-lower bathyal late Coniacian–Santonian to Maastrichtian foraminifer assemblages are enriched in agglutinated specimens (Koutsoukos and Hart, 1990) the composition of which presents certain similarities with the Leg 159 material.

## Paleoceanographic Events

### Lower Campanian Event (LCE)

A very prominent interval of biosiliceous sedimentation is observed within Cores 159-959D-61R to 63R. Microfossil assemblages within this interval are characterized by poorly preserved agglutinated foraminifers, mainly composed of unidentifiable, flattened and silicified tests and abundant but poorly preserved radiolarians. The

Table 1 (continued).

Core, section, interval (cm)	<i>Sculptobaculites barri</i>	<i>Silicosigmolina cf. californica</i>	<i>Silicosigmolina</i> sp.	<i>Sphaerammina gerochi</i>	<i>Spiroplectammina dentata</i>	<i>Spiroplectammina excolata</i>	<i>Spiroplectammina navarroana</i>	<i>Spiroplectammina</i> sp.	<i>Spiroplectammina spectabilis</i>	<i>Spiroplectammina</i> sp. (elongate)	<i>Subreophax cf. gutifer</i>	<i>Subreophax pseudoscalaris</i>	<i>Subreophax scalaris</i>	<i>Subreophax</i> sp.	<i>Subreophax splendidus</i>	<i>Thurammina papillata</i>	<i>Tolypammina</i> sp.	<i>Tritaxia</i> sp.	<i>Trochammina</i> spp.	<i>Trochammina gyroidinaeformis</i>	<i>Trochammina ruhvenmurrayi</i>	<i>Trochamminoides grzybowskii</i>	<i>Trochamminoides proteus</i>	<i>Trochamminoides subcoronatus</i>	<i>Trochamminoides</i> spp.	<i>Uvigerinammina jankoi</i>	<i>Vermetulinoides</i> sp.	AGE	
159-959D-																													
43R-1, 28-32						1	5		22			1	25		2				4										
43R-3, 34-36									8			16	16		7				3										
43R-5, 32-35									41			4	4		1				1										
43R-CC									6			2	17		1														
44R-2, 16-22									14			2	2		1					1									
44R-3, 30-33				4					19			14	2		2														
44R-5, 30-33							7		4			10	2		2				2										
44R-6, 30-33				1			1					1	20		5														
44R-CC												4	4																
45R-1, 43-48									24			6	6																
45R-CC									1			8	8						5										
46R-1, 80-85				1			1		19			1	19						2		1								
46R-CC							9		93			12	12						9										
47R-1, 19-22							4		18			16	16						9										
48R-1, 28-31				1			1		88			3	3		2														
48R-1, 69-70									68		1	8	8						4										
48R-2, 27-30				3			1		50			11	11	1	2														
48R-3, 31-34	1			1			7		35			11	2						1										
48R-3, 137-139				1			10		39			25	25		1				7										
48R-4, 28-31				2			4		95			11	11						2										
48R-4, 48-50							7		26			8	8						1										
48R-4, 66-68							5		32			8	8						6										
48R-4, 69-71							6		28			1	1						17										
48R-5, 28-31				1			5	1	5			7	7						5					1					
48R-5, 87-89													1						2										
48R-6, 28-31				5			9				2								9										
48R-CC							17	1				22	22		2				13										
49R-1, 28-31							34				7	1	39		1				80										
49R-1, 69-72							13												3										
49R-1, 110-114							31					7	3						9										
49R-2, 27-30							28					19	4						35					2					
49R-3, 27-30							21				1		5						25										
49R-4, 27-30							13				1		3	4					15	3(?)									
49R-4, 69-72							15					1	1	4					15										
49R-5, 27-31												2(?)	21	4					19										
49R-6, 27-30							23					4	61	21					12	1									
50R-1, 27-30											1		4																
50R-1, 70-73												4	4						3										
50R-2, 26-29							3	3			1		5						5										
50R-3, 28-31													4						3										
50R-4, 26-29							1												3										
50R-4, 68-71					1								6						29	2									
50R-5, 30-34									1			5	2						7										
51R-3, 28-31							2					6							2										
52R-1, 23-27												2																	
52R-1, 29-33							3				2		3																
52R-1, 67-71							2						4																
52R-2, 25-27							1						4	1															
52R-3, 27-31																													
52R-4, 30-33								1											3										
52R-4, 45-48																													

last occurrence of *Uvigerinammina jankoi* is at the top of this interval, dating this biosiliceous event between the lowermost Campanian and the base of the middle Campanian.

A similar lower Campanian radiolarian-rich interval with comparable changes in assemblage composition of benthic foraminifers has been observed in Deep Sea Drilling Project (DSDP) Holes 368, 385, 386, 398D, 543, 543A, 603B, ODP Hole 641A, and outcrop sections in northern Morocco, southern Spain, Zumaya (northern Spain), Gubbio (Italy), Bad Reichenhall (the Bavarian Alps), and the Romanian Eastern Carpathians (Herm, 1962; Neagu, 1968; Butt, 1981; Hemleben and Troester, 1984; Kuhnt et al., 1989; Kuhnt, 1992). Characteristic features in this interval include (1) increased importance of pelagic carbonate ooze and biosiliceous, radiolarian-rich sedimentation; (2) geochemical and micropaleontological evidence for deep-water oxygen deficiency; (3) low diversity assemblages of

opportunistic deep-water benthic foraminifers, followed by an important radiation; and (4) extinction of several major groups of planktonic foraminifers. Available geochemical and stable isotope data are indicative of changes in the composition of surface and deep-water masses during a short time interval in the early Campanian (*Globotruncanites elevata* planktonic foraminifer zone, *Goesella rugosa/Caudammina gigantea* benthic foraminifer zone, reversed part of Chron 34 of the paleomagnetic time scale). During this period, a short-term warming that may have occurred and flooded the Tethyan shelf areas during the corresponding transgressive cycle may also have been a source for increased formation of warm saline bottom waters, resulting in changes of the western Tethyan and Central Atlantic deep-water circulation. The micropaleontological record of Hole 959D provides first indications of the occurrence of this early Campanian paleoceanographic event in the South Atlantic. This led

Table 1 (continued).

Core, section, interval (cm)	<i>Ammobaculites</i> sp.	<i>Ammodiscus cretaceus</i>	<i>Ammodiscus</i> ex gr. <i>pennyi</i>	<i>Ammodiscus glabratus</i>	<i>Ammodiscus peruvianus</i>	<i>Ammodiscus tenuissimus</i>	<i>Ammolagena clavata</i>	<i>Ammoscolaria</i> sp.	<i>Ammosphaeroidina</i> sp.	<i>Aschemocella</i> spp. (incl. fragments)	<i>Bathysiphon</i> spp.	<i>Budashevella multicaemata</i>	<i>Bulbobaculites</i> ex gr. <i>problematicus</i>	<i>Bulbobaculites</i> sp.	<i>Buzasina</i> sp.	<i>Caudamina gigantea</i>	<i>Caudamina ovuloides</i>	<i>Caudamina ovula</i>	<i>Clavulinoides</i> sp.	<i>Conotrochammina whangaia</i>	<i>Cribrostomoides</i> sp.	<i>Dorothia bullata</i>	<i>Dorothia</i> ex gr. <i>fitiformis</i>	<i>Dorothia</i> sp.	<i>Evolutinella</i> (?) sp.	<i>Gaudryina</i> sp.	<i>Glomospira charoides</i>	<i>Glomospira diffusans</i>	<i>Glomospira glomerata</i>	<i>Glomospira gordialis</i>					
159-959D-																																			
53R-5, 29-33	1							1	2	2							1					1					1								
54R-1, 30-34		1						1	2	2	5	2																							
55R-5, 35-37									2	1																									
55R-7, 36-38	2				1	1		2	1					1													1								
56R-1, 127-132	3					1			2		3	1											1												
57R-1, 28-32						1				17		3(?)															1								
57R-1, 134-137											2																								
57R-3, 30-34										4		1(?)																							
57R-4, 14-17						2																													
57R-4, 29-33	1		2						1	1	1	1											1	1											
57R-5, 27-31			1							1		1																							
58R-1, 58-61									1																										
58R-1, 70-72									2					6										3											
58R-1, 110-114					1																				12			1							
58R-3, 113-116	1										1																								
58R-4, 28-31						1								1									3	3											
58R-4, 67-71									1	7		6(?)																							
59R-1, 25-30	4	1								6				1									5					2							
59R-1, 30-34	3	1			1				1	7																									
59R-1, 62-67												2												1	1										
59R-2, 27-32	4																						1					3							
59R-2, 32-36			3						1	16													13				2								
59R-3, 22-27	3								1					2									1	2		1									
59R-4, 30-35	1	1							2														2(?)				1								
59R-4, 75-80	1								2														7												
59R-5, 29-34									4														1												
60R-1, 22-24																																			
60R-2, 26-28						1																					1								
60R-3, 24-26									8	4		1(?)															2								
60R-4, 24-27										3		3(?)																							
60R-4, 68-73									5			1(?)											13				2								
60R-4, 109-113									2			1(?)											2												
60R-5, 17-21												2(?)																							
61R-2, 61-65									1				8	3																					
63R-1, 38-40									1														1(?)	1(?)	1										
63R-1, 69-72	2											1(?)	6																						
63R-4, 24-26	3												4	2																					
63R-4, 98-100	4								2			3(?)											6				4								
63R-5, 59-62												5																							
63R-6, 39-42	8											14											38	3			2								
64R-1, 25-28												1(?)	4																						
64R-2, 3-6													1(?)														2(?)								
64R-2, 30-34	2											4																							
64R-3, 32-35	3								2			41	6										3				3								
64R-4, 32-35			1									18	9										2												
64R-5, 13-15	10											10											3	8											
64R-6, 9-12												5	1																						
65R-1, 28-32	6		5		1							9	9	1									3												
65R-1, 49-52	4												2	1																					
65R-2, 28-32												3	3										9				14								
65R-3, 32-36	1												2													249									

us to suggest that a deep-water circulation system was already well-established between the North and South Atlantic at this time.

#### K/T Boundary Event

Quantitative changes in benthic foraminifer composition were observed across the K/T boundary within Cores 159-959D-48R and 159-959D-49R (Fig. 4). The main changes are (1) a decrease in abundance and finally the LO of *Caudamina gigantea* in Sample 159-959D-48R-6, 28-31 cm; (2) a general decrease in epifaunal detritus feeders (e.g., rzehakinids and some ammodiscids), which indicates moderate to high organic carbon fluxes (as a typical representative of this group, the abundance values of *Rzehakina epigona* are plotted in Fig. 4); and (3) a drastic increase in abundance of the genus *Spiroplectammina* within Section 159-959D-48R-4, corresponding

to the earliest Paleocene *Spiroplectammina* event (Kuhnt and Kaminski, 1996).

Changes in Hole 959D Cores 159-959D-48R through 49R are comparable to the observations made in deep-water sections in northern Spain (Zumaya and Sopolana sections, Kuhnt and Kaminski, 1993), southern Spain (Caravaca section, Coccioni and Galeotti, 1994), and central Italy (Contessa, Bottaccione, and Petriccio sections, Kuhnt, 1990; Kuhnt and Kaminski, 1996). In these areas, the following characteristic succession of agglutinated foraminifer assemblages is observed within the K/T boundary interval: (1) late Maastrichtian deep-water agglutinated foraminifer (DWF) assemblages are dominated by epifaunal suspension- and detritus-feeders (e.g., astrorhizids and some ammodiscids); (2) foraminifer assemblages within and directly above the boundary clay are dominated by infaunal agglutinated species (*Reophax*, *Subreophax*, *Ammobaculites*







Table 1 (continued).

Core, section, interval (cm)	<i>Sculptobaculites barri</i>	<i>Silicosigmoilina cf. californica</i>	<i>Silicosigmoilina</i> sp.	<i>Sphaerammina gerochi</i>	<i>Spiroplectammmina dentata</i>	<i>Spiroplectammmina excolata</i>	<i>Spiroplectammmina navarroana</i>	<i>Spiroplectammmina</i> sp.	<i>Spiroplectammmina spectabilis</i>	<i>Spiroplectammmina</i> sp. (elongate)	<i>Subreophax cf. guttifer</i>	<i>Subreophax pseudoscalaris</i>	<i>Subreophax scalaris</i>	<i>Subreophax</i> sp.	<i>Subreophax splendidus</i>	<i>Thurammmina papillata</i>	<i>Tolypammmina</i> sp.	<i>Tritaxia</i> sp.	<i>Trochammmina</i> spp.	<i>Trochammmina gyrodiinaeformis</i>	<i>Trochammmina ruthvenmurrayi</i>	<i>Trochammminoides grybowskii</i>	<i>Trochammminoides proteus</i>	<i>Trochammminoides subcoronatus</i>	<i>Trochammminoides</i> spp.	<i>Uvigerinammmina jankoi</i>	<i>Vermetulinoides</i> sp.	AGE		
159-595D-																														
53R-5, 29-33									8(?)			1							9											
54R-1, 30-34											5	1																		
55R-5, 35-37								1																						
55R-7, 36-38	10									16																				
56R-1, 127-132												3							1											
57R-1, 28-32																			1											
57R-1, 134-137																														
57R-2, 30-34								4				2							2											
57R-3, 30-34												1																		
57R-4, 14-17										2		2							2											
57R-4, 29-33												1			1				1											
57R-5, 27-31													1																	
58R-1, 58-61	1																		1											
58R-1, 70-72	3							3				3							11											
58R-1, 110-114	1						2	1											3						2					
58R-3, 113-116												1							4											
58R-4, 28-31	1						1												1											
58R-4, 67-71	14																													
59R-1, 25-30	18											1							1											
59R-1, 30-35	17											1	3(?)																	
59R-1, 62-67	12																		4											
59R-2, 27-32	22											2							16											
59R-2, 32-36	10						1																							
59R-3, 22-27	8							1											4											
59R-4, 30-35	4								1																					
59R-4, 75-80	2																		2											
59R-5, 29-34	9																		3											
60R-1, 22-24	1											1																		
60R-2, 26-28	14										3																			
60R-3, 24-26	13																													
60R-4, 24-27	10										2																			
60R-4, 68-73	8										1								1											
60R-4, 109-113	5											1																		
60R-5, 17-21	4																													
61R-2, 61-65											3		2						5						1		1			
63R-1, 38-40																														
63R-1, 69-72																														
63R-4, 24-26																														
63R-4, 98-100																														
63R-5, 59-62																														
63R-6, 39-42																														
64R-1, 25-28																														
64R-2, 3-6																														
64R-2, 30-34																														
64R-3, 32-35															1															
64R-4, 32-35																														
64R-5, 13-15																				1										
64R-6, 9-12																														
65R-1, 28-32		1																		2										
65R-1, 49-52																				1										
65R-2, 28-32																														
65R-3, 32-36																														3

CAMPANIAN

Using all these DWAF occurrences and zones provides further evidence of the utility of these organisms for stratigraphic correlation on an ocean-wide scale.

## ACKNOWLEDGMENTS

We thank Thomas Pletsch for sharing his first-hand shipboard experience and information with us, for organizing the sample processing in the "alternative clay mineralogy lab" at Kiel, and for numerous discussions over the last two years on the stratigraphy and paleoecology of Site 959. Ivan and Sandrine de Klasz made comparative material from the Danian of Senegal available to WK. MAK thanks Richard Norris (WHOI) for kindly providing access to his core-catcher samples from Hole 959D. We also thank Christoph Hemleben and Eduardo A.M. Koutsoukos for their constructive reviews

of an initial version of the manuscript. Specimens were photographed using a Camscan 44 SEM at Kiel and a Zeiss 940 SEM at UCL; U. Schuldt (Kiel) and J. Davey (UCL) are thanked for photographic work, and Bruno Jeanguyot (Nice) is thanked for technical assistance. This study was supported by the Deutsche Forschungsgemeinschaft grant Ku 649/2 ("Atlantic Gateways") and grants from the British Council and DAAD (BC-Alliance Programme grant to MAK and MM; BC-DAAD Academic Exchange Programme grant no. 797 to MAK and WK). This is contribution no. 55 of the Deep Water Agglutinated Foraminiferal Project, and no. 132 of the UMR-CNRS "Geosciences Azur," Nice.

## REFERENCES

Bubik, M., 1995. Cretaceous to Paleogene agglutinated foraminifera of the Bile Karpaty Unit (West Carpathians, Czech Republic). *In* Kaminski,

- M.A., Geroch, S., and Gasinski, M.A. (Ed.), *Proceedings of the Fourth International Workshop on Agglutinated Foraminifera*. Grzybowski Found. Spec. Publ., 3:71–116.
- Butt, A., 1981. Depositional environments of the Upper Cretaceous rocks in the northern part of the Eastern Alps. *Spec. Publ. Cushman Found. Foraminiferal Res.*, 20:1–121.
- Caron, M., 1985. Cretaceous planktic foraminifera. In Bolli, H.M., Saunders, J.B., and Perch-Nielsen, K. (Eds.), *Plankton Stratigraphy*: Cambridge (Cambridge Univ. Press), 17–86.
- Coccioni, R., and Galeotti, S., 1994. K-T boundary extinction: geologically instantaneous or gradual event? Evidence from deep-sea benthic foraminifera. *Geology*, 22:779–782.
- Cushman, J.A., and Renz, H.H., 1946. The foraminiferal fauna of the Lizard Springs Formation of Trinidad, British West Indies. *Spec. Publ. Cushman Lab. Foraminiferal Res.*, 18:1–48.
- Geroch, S., and Nowak, W., 1984. Proposal of zonation for the late Tithonian-Eocene, based upon the arenaceous foraminifera from the outer Carpathians, Poland. In Oertli, H.J. (Ed.), *BENTHOS '83: 2nd Int. Symp. Benthic Foraminifera*. Bull. Cent. Rech. Explor.-Prod. Elf-Aquitaine, 6:225–239.
- Gradstein, F.M., and Kaminski, M.A., 1989. Taxonomy and biostratigraphy of new and emended species of Cenozoic deep-water agglutinated foraminifera from the Labrador and North Seas. *Micropaleontology*, 35:72–92.
- Hemleben, C., and Troester, J., 1984. Campanian-Maastrichtian deep-water foraminifera from Hole 534A, Deep Sea Drilling Project. In Biju-Duval, B., Moore, J.C., et al., *Init. Repts. DSDP, 78A*: Washington (U.S. Govt. Printing Office), 509–532.
- Herm, D., 1962. Stratigraphische und mikropaläontologische Untersuchungen der Oberkreide im Lattengebirge und Nierental (Gosaubecken von Reichenhall und Salzburg). *Bayerische Akad. Wiss. Abh., Math.-Naturw. Kl.*, 104:1–119.
- Kaminski, M.A., 1984. Shape Variation in *Spiroplectammina spectabilis* (Grzybowski). *Acta Palaeontol. Polonica*, 29:29–49.
- , 1988. Cenozoic deep-water agglutinated foraminifera in the North Atlantic [Ph.D. thesis]. Woods Hole Oceanogr. Inst./Mass. Inst. Technol., Joint Program in Oceanography.
- Kaminski, M.A., and Geroch, S., 1993. A revision of foraminiferal species in the Grzybowski Collection. In Kaminski, M.A., Geroch, S., and Kaminski, D.G. (Eds.), *The Origins of Applied Micropaleontology: The School of Józef Grzybowski*. Grzybowski Found. Spec. Publ., 1:239–323.
- Kaminski, M.A., Gradstein, F.M., Berggren, W.A., Geroch, S., and Beckmann, J.P., 1988. Flysch-type agglutinated foraminiferal assemblages from Trinidad: taxonomy, stratigraphy and paleobathymetry. *Abh. Geol. Bundesanst.*, 41:155–227.
- Kaminski, M.A., Kuhnt, W., and Radley, J., 1996. Palaeocene-Eocene deep water agglutinated foraminifera from the Numidian Flysch (Rif, Northern Morocco): their significance for the palaeoceanography of the Gibraltar gateway. *J. Micropaleontol.*, 15:1–19.
- Koch, W., 1977. Biostratigraphie in der Oberkreide und Taxonomie von Foraminiferen. *Geol. Jahrb., Reihe A*, 38:11–123.
- Koutsoukos, E.A.M., 1992. Late Aptian to Maastrichtian foraminiferal biogeography and paleoceanography of the Sergipe Basin, Brazil. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 92:295–324.
- Koutsoukos, E.A.M., and Bengtson, P., 1993. Towards an integrated biostratigraphy of the upper Aptian-Maastrichtian of the Sergipe Basin, Brazil. *Doc. Lab. Geol. Lyon*, 125:241–262.
- Koutsoukos, E.A.M., Destro, N., Azambuja Filho, N.C., and Spadini, A.R., 1993. Upper Aptian-lower Coniacian carbonate sequences in the Sergipe Basin, northeastern Brazil. In Simo, T., Scott, R.W., and Masse, J.-P. (Eds.), *Cretaceous Carbonate Platforms*. AAPG Mem., 56:127–144.
- Koutsoukos, E.A.M., and Hart, M.B., 1990. Cretaceous foraminiferal morphogroup distribution patterns, palaeocommunities and trophic structures: a case study from the Sergipe Basin, Brazil. *Trans. R. Soc. Edinburgh: Earth Sci.*, 81:221–246.
- Kuhnt, W., 1990. Agglutinated foraminifera of western Mediterranean Upper Cretaceous pelagic limestones (Umbrian Apennines, Italy, and betic Cordillera, Southern Spain). *Micropaleontology*, 36:297–330.
- , 1992. An early Campanian paleoceanographic event in the North Atlantic and Western Tethys? *Fourth Int. Conf. Paleocyanogr., ICP IV. Geomar Rep. 15/Rep.*, *Geol. Palaeontol. Inst. Univ. Kiel*, 57:171.
- Kuhnt, W., and Collins, E.S., 1996. Cretaceous to Paleogene benthic foraminifera from the Iberia Abyssal Plain. In Whitmarsh, R.B., Sawyer, D.S., Klaus, A., and Masson, D.G. (Eds.), *Proc. ODP, Sci. Results*, 149: College Station, TX (Ocean Drilling Program), 203–216.
- Kuhnt, W., Geroch, S., Kaminski, M.A., Moullade, M., and Neagu, T., 1992. Upper Cretaceous abyssal claystones in the North Atlantic and Western Tethys: current status of biostratigraphical correlation using agglutinated foraminifera and palaeoceanographic events. *Cretaceous Res.*, 13:467–478.
- Kuhnt, W., and Kaminski, M.A., 1989. Upper Cretaceous deep-water agglutinated benthic foraminiferal assemblages from the Western Mediterranean and adjacent areas. In Wiedmann, J. (Ed.), *Cretaceous of the Western Tethys*: Stuttgart (Schweizerbart), 91–120.
- , 1990. Paleocology of Late Cretaceous to Paleocene deep-water agglutinated foraminifera from the North Atlantic and western Tethys. In Hemleben, C., Kaminski, M.A., Kuhnt, W., and Scott, D.B. (Eds.), *Paleoecology, Biostratigraphy, Paleoceanography and Taxonomy of Agglutinated Foraminifera*: Dordrecht (Kluwer), 433–505.
- , 1993. Changes in the community structure of deep-water agglutinated foraminifera across the K/T boundary in the Basque Basin (Northern Spain). *Rev. Esp. Micropaleontol.*, 25:57–92.
- , 1996. The response of benthic foraminifera to the K/T boundary event: a review. In *Géologie de l'Afrique et de l'Atlantique Sud: Actes Colloques Angers 1994*. Elf Aquitaine Édition (Memoire 16: 433–442).
- Kuhnt, W., Kaminski, M.A., and Moullade, M., 1989. Late Cretaceous deep-water agglutinated foraminiferal assemblages from the North Atlantic and its marginal seas. *Geol. Rundsch.*, 78:1121–1140.
- Kuhnt, W., and Moullade, M., 1991. Quantitative analysis of upper Cretaceous abyssal agglutinated foraminiferal distribution in the North Atlantic—paleoceanographic implications. *Rev. Micropaleontol.*, 34:313–349.
- Kuhnt, W., Moullade, M., and Kaminski, M.A., 1996. Ecological structuring and evolution of deep sea agglutinated foraminifera: a review. *Rev. Micropaleontol.*, 34:271–281.
- Moullade, M., Kuhnt, W., and Thurow, J., 1988. Agglutinated benthic foraminifera from Upper Cretaceous variegated clays of the North Atlantic Ocean (DSDP Leg 93 and ODP Leg 103). In Boillot, G., Winterer, E.L., et al., *Proc. ODP, Sci. Results*, 103: College Station, TX (Ocean Drilling Program), 349–377.
- Neagu, T., 1968. Biostratigraphy of Upper Cretaceous deposits in the southern Eastern Carpathians near Brasov. *Micropaleontology*, 14:225–241.
- Volat, J.-L., Hugo, B., and Bignoumba-Ilogue, J., 1996. Foraminifères arénacés du Crétacé supérieur du Gabon—Arenaceous foraminifera from the late Cretaceous of Gabon. *Bull. Centres Rech. Explor.—Prod. Elf Aquitaine*, 20:229–275.
- Wightman, W.G., and Kuhnt, W., 1992. Biostratigraphy and paleoecology of Late Cretaceous abyssal agglutinated foraminifera from the western Pacific Ocean (Deep Sea Drilling Project Holes 196A and 198A and Ocean Drilling Program Holes 800A and 801A). In Larson, R.L., Lancelot, Y., et al., *Proc. ODP, Sci. Results*, 129: College Station, TX (Ocean Drilling Program), 247–264.

## SPECIES LIST

Most of the species mentioned are described and illustrated in Geroch and Nowak (1984), Moullade et al. (1988), Kaminski et al. (1988), Kuhnt (1990), Kuhnt and Kaminski (1990, 1993), Kaminski and Geroch (1993), and Kaminski et al. (1996).

- Ammobaculites* sp.  
*Ammodiscus cretaceus* (Reuss)  
*Ammodiscus* ex gr. *pennyi* (Cushman and Jarvis)  
*Ammodiscus glabratus* (Cushman and Jarvis)  
*Ammodiscus peruvianus* (Berry)  
*Ammodiscus tenuissimus* Grzybowski  
*Ammolagena clavata* (Jones and Parker)  
*Ammoscalaria* sp.  
*Ammosphaeroidina* sp., mostly *Ammosphaeroidina pseudopauciloculata* (Mjatluk)  
*Aschemocella* spp. (incl. fragments)  
*Bathysiphon* spp.  
*Budashevaella multicamerata* (Veloshinova)  
*Bulbobaculites* ex gr. *problematicus* (Neagu)  
*Bulbobaculites* sp.  
*Buzasina* sp.  
*Caudammia gigantea* (Geroch)  
*Caudammia ovuloides* (Grzybowski)  
*Caudammia ovula* (Grzybowski)

- Clavulinoides* spp.  
*Conotrochammina whangaia* Finlay  
*Cribrostomoides* sp.  
*Dorothia* ex gr. *filiformis* (Berthelin)  
*Dorothia* sp.  
*Evolutinella* (?) sp., similar to *Evolutinella ewongueensis* Volat, Hugo and Bi-gnoumba-Ilogue, 1996  
*Gaudryina* sp.  
*Glomospira charoides* (Jones and Parker)  
*Glomospira diffundens* (Cushman and Renz)  
*Glomospira glomerata* (Grzybowski)  
*Glomospira gordialis* (Jones and Parker)  
*Glomospira irregularis* (Grzybowski)  
*Glomospira serpens* (Grzybowski)  
*Glomospirella grzybowskii* (Jurkiewicz)  
*Haplophragmoides* ex gr. *excavatus* (Cushman and Waters)  
*Haplophragmoides* cf. *walteri* (Grzybowski) of Kuhn and Kaminski (1990)  
*Haplophragmoides horridus* (Grzybowski)  
*Haplophragmoides porrectus* (Maslakova)  
*Haplophragmoides* sp. ?kirki Wickenden  
*Haplophragmoides suborbicularis* (Grzybowski)  
*Haplophragmoides stomatus* (Grzybowski)  
*Haplophragmoides walteri* (Grzybowski)  
*Haplophragmoides* sp.  
*Hippocrepina* sp.  
*Hormosina trinitatensis* (Cushman and Renz)  
*Hormosina velascoensis* (Cushman)  
*Hyperammina dilatata* (Grzybowski)  
*Hyperammina* sp. (incl. fragments)  
*Insculptarenula* sp.  
*Kalamopsis grzybowskii* (Dylazanka)  
*Karrerulina conversa* (Grzybowski)  
*Karrerulina* spp.  
*Lagenammina* sp.  
*Lituotuba lituiformis* (Brady)  
*Nothia excelsa* (Grzybowski)  
*Paratrochamminoides irregularis* (White)  
*Paratrochamminoides mitratus* (Grzybowski)  
*Paratrochamminoides olszewskii* (Grzybowski)  
*Paratrochamminoides* spp.  
*Popovia beckmanni* (Kaminski and Geroch)  
*Psammosphaera fusca* Schultze  
*Pseudobolivina lagenaria* Krashenninikov  
*Pseudobolivina* spp.  
*Recurvoidella lamella* (Grzybowski)  
*Recurvoides deflexiformis* (Noth) sensu Geroch  
*Recurvoides* sp.  
*Reophax duplex* Grzybowski  
*Reophax pilulifer* Brady
- Reophax* sp. 2  
*Reophax subfusiformis* Hoeglund  
*Reophax* spp.  
*Reticulophragmoides jarvisi* (Thalman)  
*Rhabdammina* sp.  
*Rhizammina* (large)  
*Rhizammina* spp.  
*Rzehakina epigona* (Rzehak)  
*Rzehakina epigona lata* (Cushman and Jarvis)  
*Rzehakina* ex gr. *epigona* (Rzehak)  
*Rzehakina fissistomata* (Grzybowski)  
*Rzehakina inclusa* (Grzybowski)  
*Rzehakina minima* (Cushman and Renz)  
*Rzehakina* sp. (narrow)  
*Saccammina grzybowskii* (Schubert)  
*Saccammina placenta* (Grzybowski)  
*Saccorhiza ramosa* Brady  
*Sculptobaculites barri* Beckmann  
*Silicosigmoilina* cf. *californica* Cushman and Church  
*Sphaerammina gerochi* Hanzlikova  
*Spiroplectammina dentata* (Alth)  
*Spiroplectammina excolata* (Cushman)  
*Spiroplectammina navarroana* (Cushman)  
*Spiroplectammina* sp.  
*Spiroplectammina spectabilis* (Grzybowski)  
*Spiroplectammina* sp. (elongate)  
*Subreophax* cf. *guttifer* (Brady)  
*Subreophax pseudoscalaris* (Samuel)  
*Subreophax scalaris* (Grzybowski)  
*Subreophax* sp.  
*Subreophax splendidus* (Grzybowski)  
*Textularia* sp.  
*Thurammina papillata* Brady  
*Trochammina ruthvenmurrayi* Cushman and Renz  
*Trochammina* spp.  
*Trochamminoides grzybowskii* Kaminski and Geroch  
*Trochamminoides proteus* (Karrer)  
*Trochamminoides subcoronatus* (Grzybowski)  
*Trochamminoides* spp.  
*Uvigerinammina jankoi* Majzon  
*Verneulinoides* sp.

Date of initial receipt: 23 September 1996

Date of acceptance: 4 June 1997

Ms 159SR-039

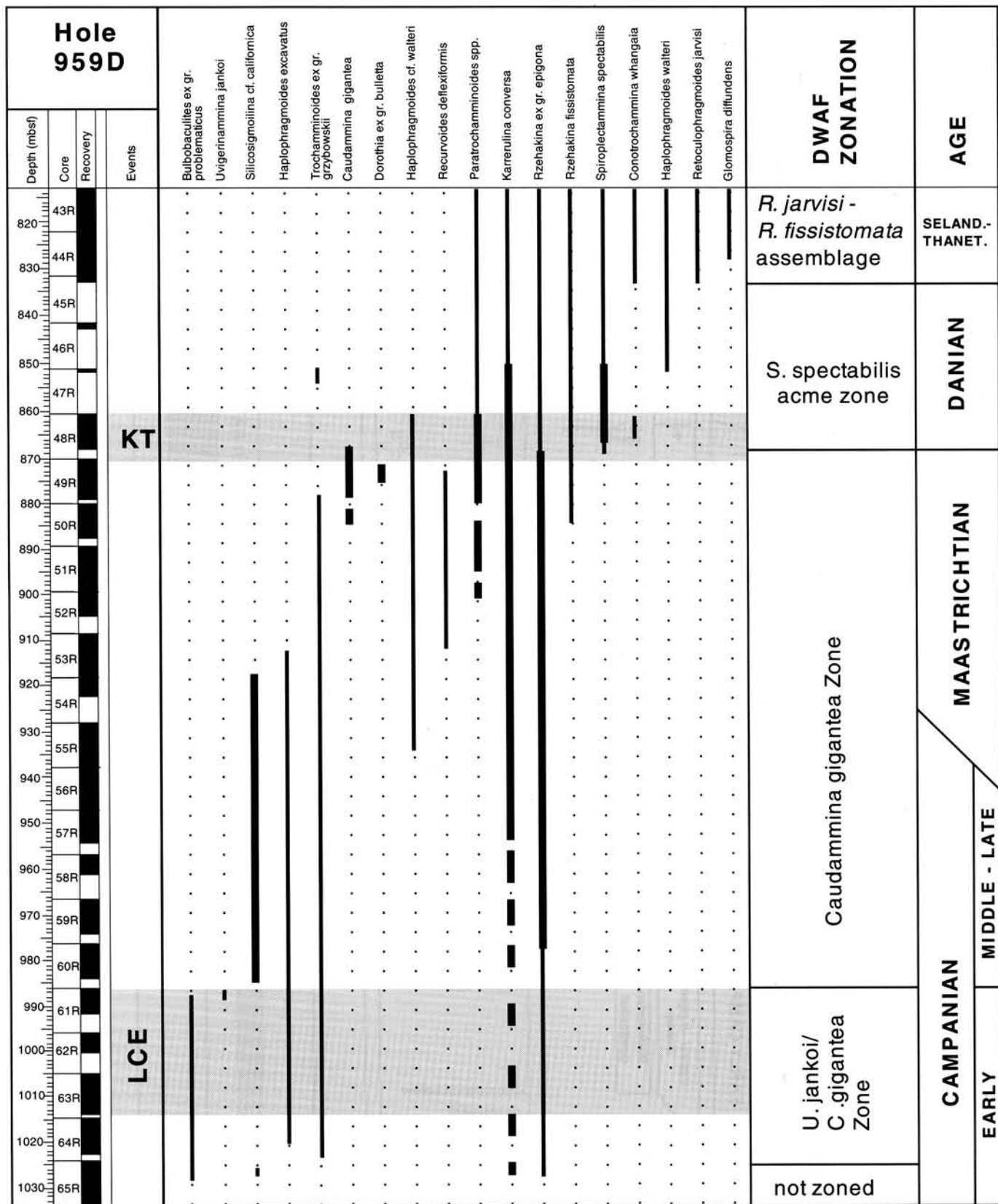


Figure 2. Stratigraphic ranges of marker species of agglutinated foraminifers within Hole 959D, Cores 159-959D-43R through 65R. Paleoceanographic events: KT = Cretaceous/Tertiary Boundary Event; LCE = Lower Campanian Event.

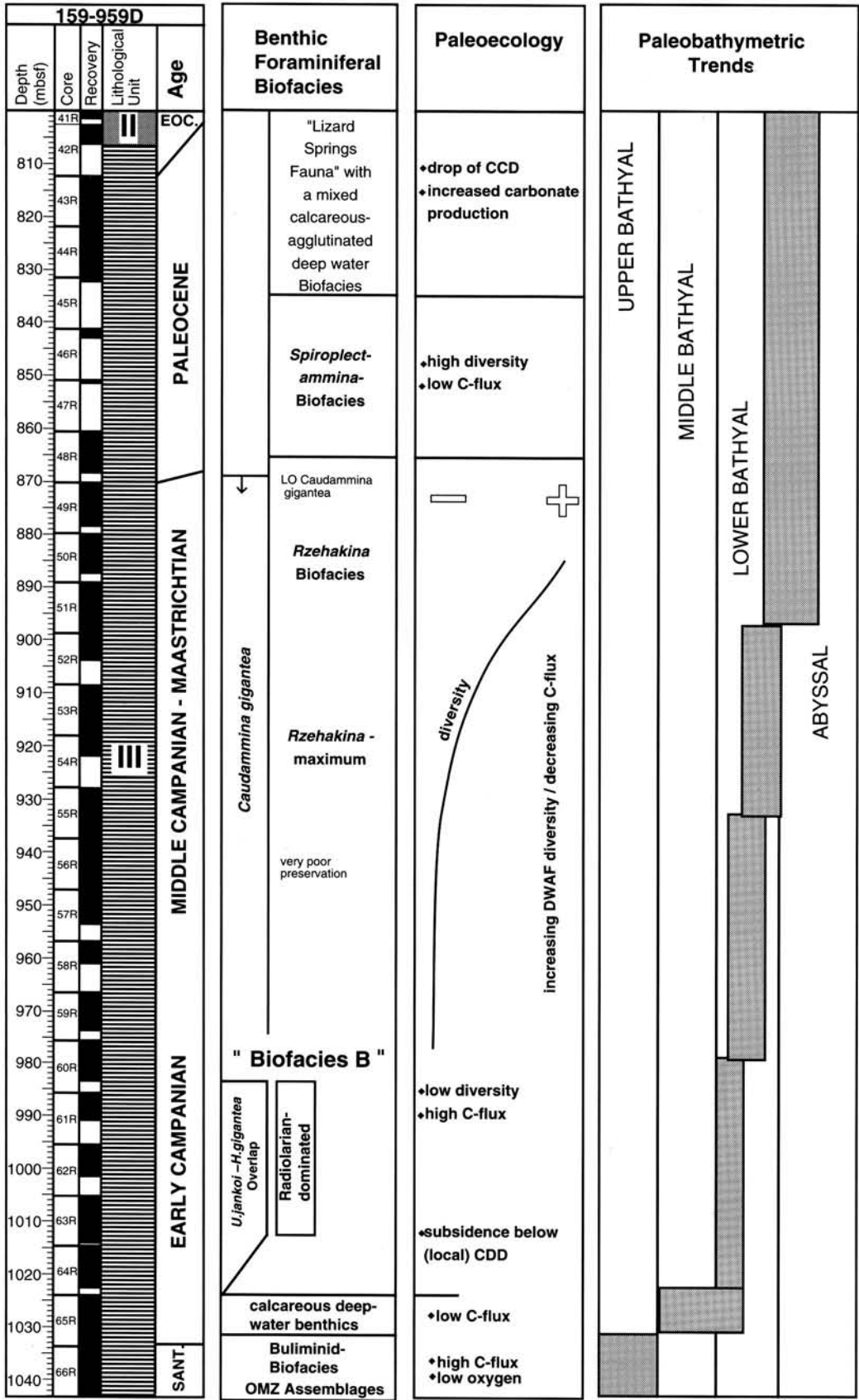


Figure 3. Benthic foraminifer biofacies and inferred paleoecologic-paleobathymetric trends in Hole 959D.

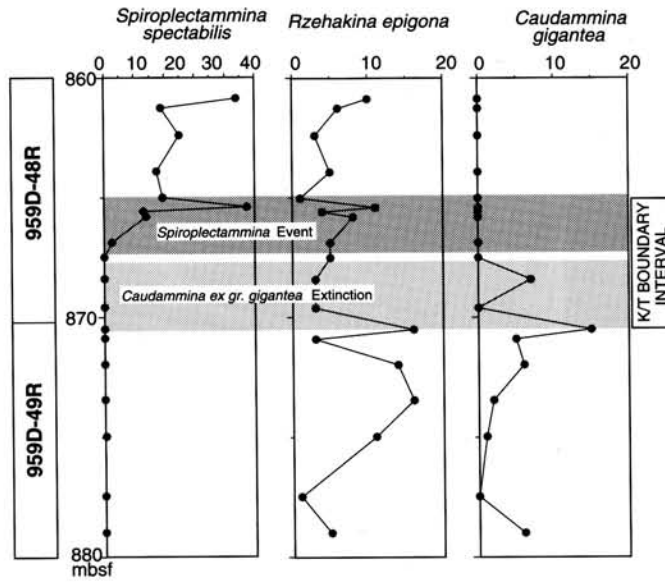


Figure 4. Quantitative changes of selected benthic foraminifer abundances across the K/T boundary interval in Hole 959D.

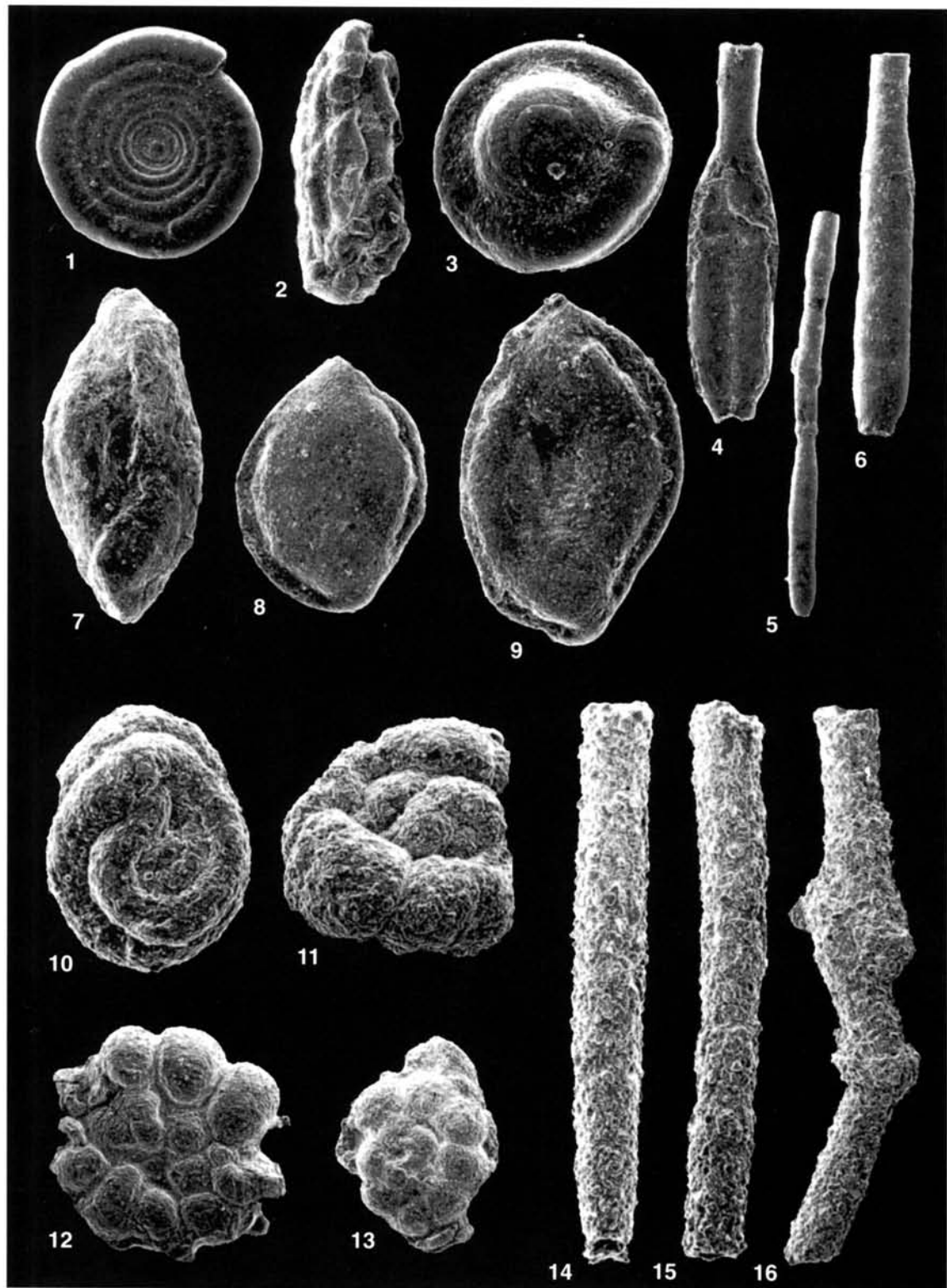


Plate 1. 1. *Ammodiscus cretaceus*, (35 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. 2. *Glomospira serpens*, (65 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. 3. *Glomospira charoides*, (130 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. 4. *Kalamopsis grzybowskii*, (85 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. 5. *Kalamopsis grzybowskii*, (35 $\times$ ), Sample 159-959D-48R-4, 48–50 cm. 6. *Kalamopsis grzybowskii*, (55 $\times$ ), Sample 159-959D-48R-4, 48–50 cm. 7. (85 $\times$ ), *Rzehakina inclusa*, Sample 159-959D-65R-1, 49–52 cm. 8. *Rzehakina epigona*, (85 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. 9. *Rzehakina epigona*, (90 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. 10. *Glomospira irregularis*, (105 $\times$ ), Sample 159-959D-49R-1, 110–114 cm. 11. *Paratrochamminoides* sp., (70 $\times$ ), Sample 159-959D-49R-1, 110–114 cm. 12. *Paratrochamminoides* sp., (30 $\times$ ), Sample 159-959D-50R-4, 68–71 cm. 13. *Paratrochamminoides acervulatus*, (30 $\times$ ), Sample 159-959D-50R-4, 68–71 cm. 14.–16. *Rhabdammina cylindrica*, (14: 40 $\times$ , 15: 30 $\times$ , 16: 25 $\times$ ), Sample 159-959D-49R-2, 27–30 cm.



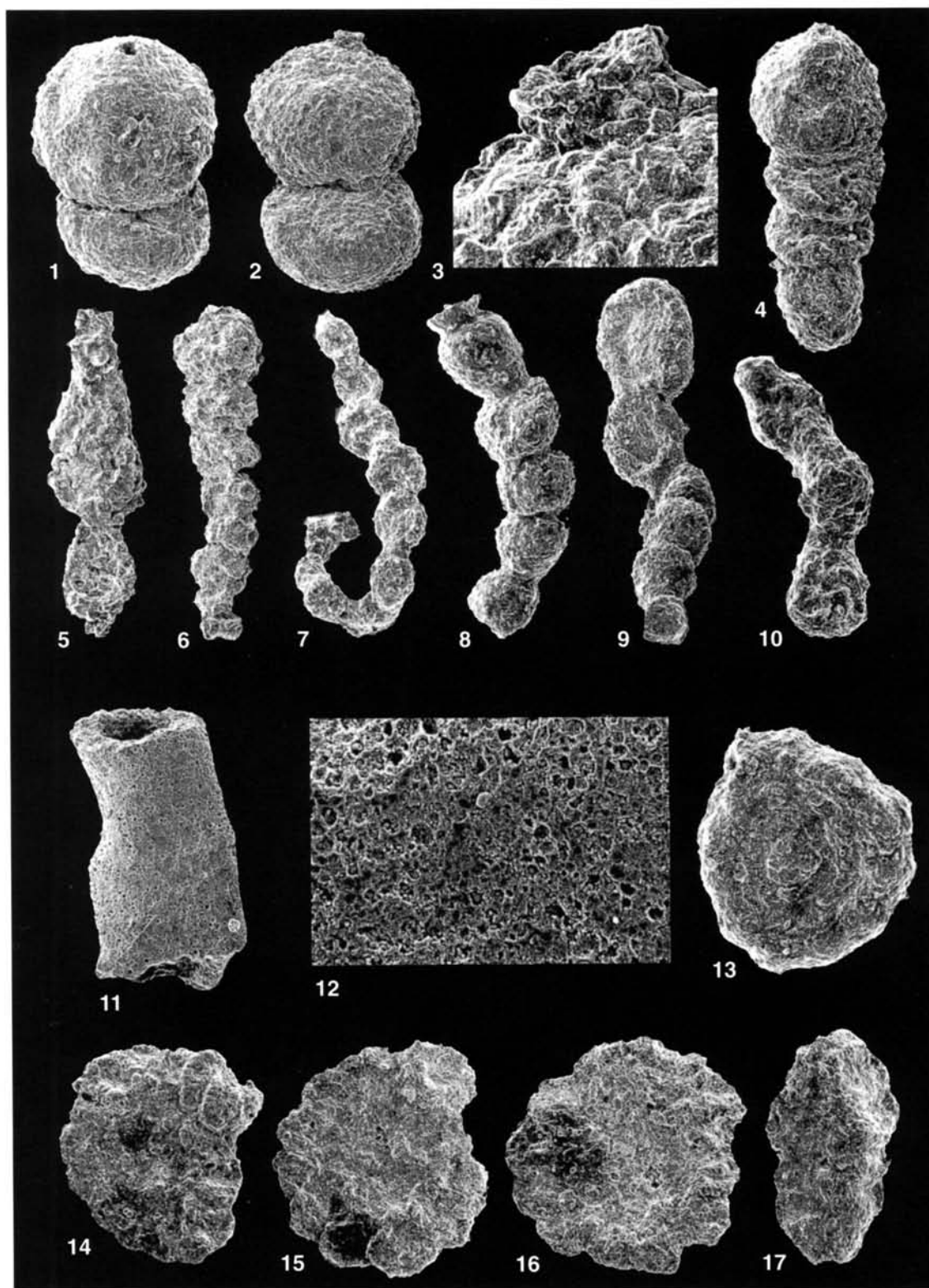


Plate 2. 1. *Reophax duplex*, (50 $\times$ ), Sample 159-959D-50R-3, 28–31 cm. 2. *Reophax duplex*, (40 $\times$ ), Sample 159-959D-50R-3, 28–31 cm. 3. Detail of Fig. 2, aperture protruding on a short neck, (205 $\times$ ). 4. *Reophax* sp., (100 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. 5. *Reophax* sp., (60 $\times$ ), Sample 159-959D-50R-2, 26–29 cm. 6. *Subreophax* sp., (45 $\times$ ), Sample 159-959D-50R-2, 26–29 cm. 7. *Subreophax scalaris*, (75 $\times$ ), Sample 159-959D-50R-2, 26–29 cm. 8. *Subreophax scalaris*, (60 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. 9. *Subreophax* sp., (65 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. 10. *Subreophax* ex gr. *guttifer*, (130 $\times$ ), Sample 159-959D-61R-2, 61–65 cm. 11. *Nothia* ex gr. *excelsa*, (60 $\times$ ), Sample 159-959D-65R-4, 95–98 cm. 12. Detail of Fig. 1 showing dissolution of agglutinated carbonate grains, (245 $\times$ ). 13. *Trochamminoides* sp., (90 $\times$ ), Sample 159-959D-50R-2, 26–29 cm. 14.–17. *Evolutinella* sp., Sample 159-959D-65R-2, 28–32 cm (14, 16: 85 $\times$ ; 15, 17: 80 $\times$ ).

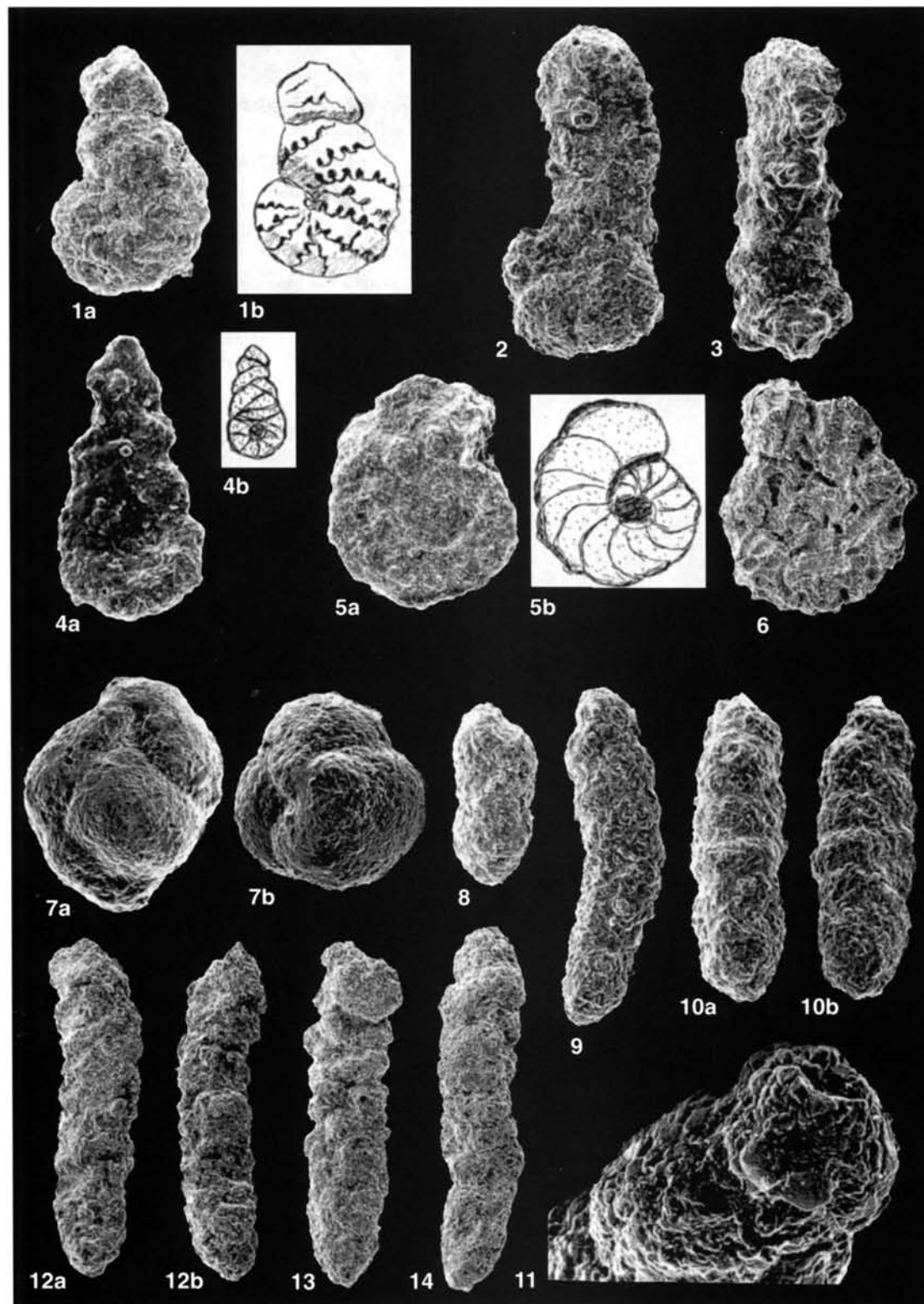


Plate 3. **1a, b.** *Reticulophragmium* sp. (early form), (60×), Sample 159-959D-50R-3, 28–31 cm. **2.** *Bulbobaculites problematicus*, (115×), Sample 159-959D-65R-2, 28–32 cm. **3.** *Bulbobaculites problematicus*, (100×), Sample 159-959D-65R-2, 28–32 cm. **4a, b.** *Ammoscalaria* sp., (a: 150×; b: 65×), Sample 159-959D-50R-2, 26–29 cm. **5a, b.** *Ammoscalaria* sp., (75×), Sample 159-959D-50R-2, 26–29 cm. **6.** *Ammobaculites* sp., (50×), Sample 159-959D-50R-3, 28–31 cm. **7a, b.** *Uvigerinamina jankoi*, (100×), Sample 159-959D-61R-2, 61–65 cm. **8.** *Karrerulina conversa* (juvenile form, 90×), Sample 159-959D-49R-1, 28–31 cm. **9.** *Karrerulina conversa*, (75×), Sample 159-959D-49R-1, 28–31 cm. **10a, b.** *Karrerulina conversa*, (75×), Sample 159-959D-49R-1, 28–31 cm. **11.** Detail of Fig. 10 with terminal aperture, (240×). **12a, b.** *Dorothis* ex gr. *filiformis*, (70×), Sample 159-959D-65R-2, 28–32 cm. **13.** *Dorothis* ex gr. *filiformis*, (70×), Sample 159-959D-65R-2, 28–32 cm. **14.** *Dorothis* ex gr. *filiformis*, (70×), Sample 159-959D-65R-4, 95–98 cm.

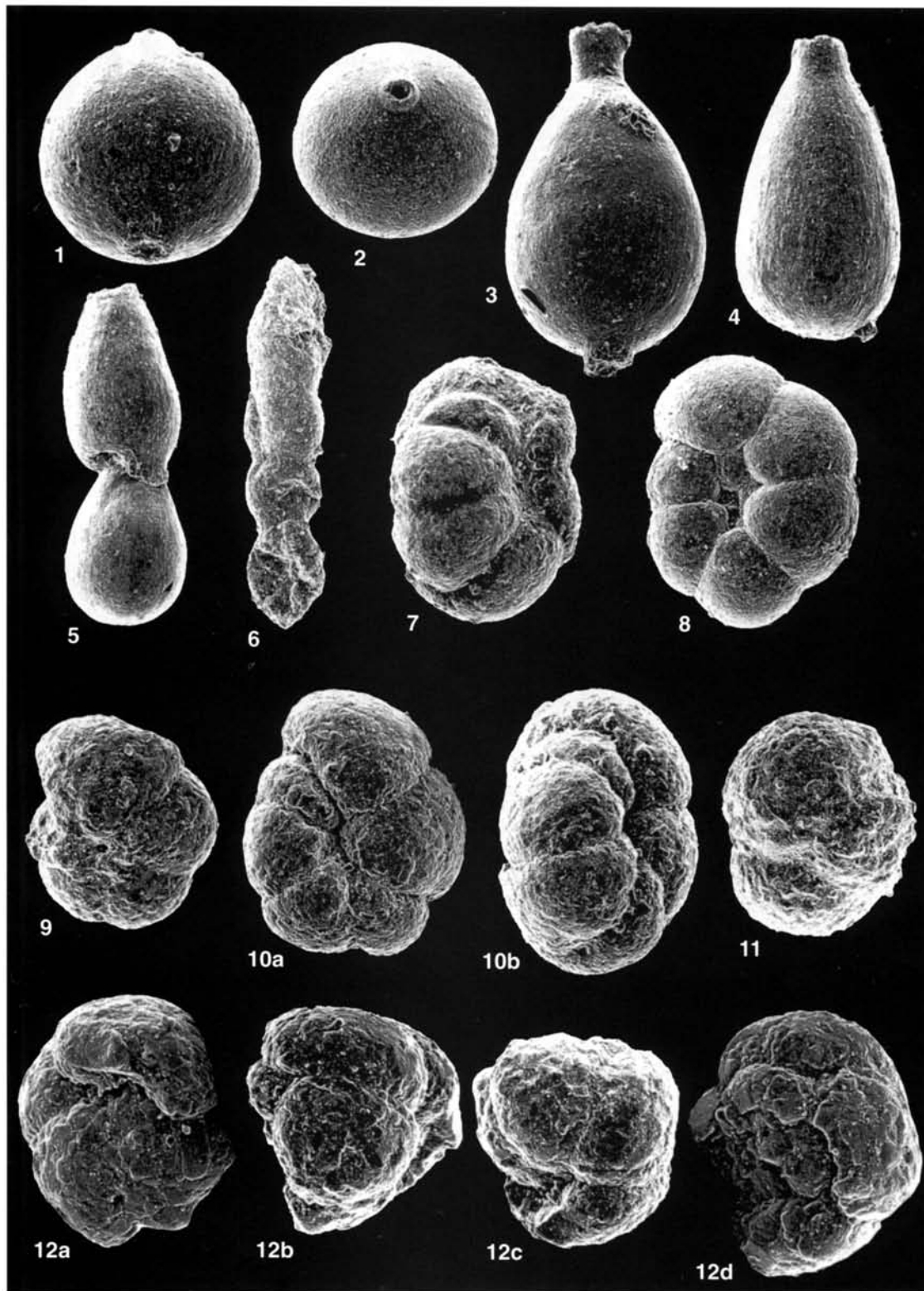


Plate 4. **1.** *Caudammina ovula*, (115 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. **2.** *Caudammina ovula*, (115 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. **3.** *Caudammina ovuloides*, (75 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. **4.** *Caudammina ovuloides*, (75 $\times$ ), Sample 159-959D-49R-1, 110–114 cm. **5.** *Caudammina ovuloides*, (75 $\times$ ), Sample 159-959D-49R-1, 110–114 cm. **6.** *Hormosina velascoensis*, (90 $\times$ ), Sample 159-959D-50R-3, 28–31 cm. **7.** *Haplophragmoides* sp., (100 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. **8.** *Haplophragmoides* ex gr. *perexplicatus*, (115 $\times$ ), Sample 159-959D-49R-4, 27–30 cm. **9.** *Haplophragmoides* cf. *decussatus*, (150 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. **10a, b.** *Haplophragmoides* sp., (a: 125 $\times$ ; b: 135 $\times$ ), Sample 159-959D-49R-4, 27–30 cm. **11.** *Ammonia pseudopauciloculata*, (165 $\times$ ), Sample 159-959D-50R-2, 26–29 cm. **12a–d.** *Trochammina gyroidinaeformis* (a,b: 220 $\times$ ; c: 200 $\times$ ; d: 245 $\times$ ), Sample 159-959D-49R-4, 27–30 cm.

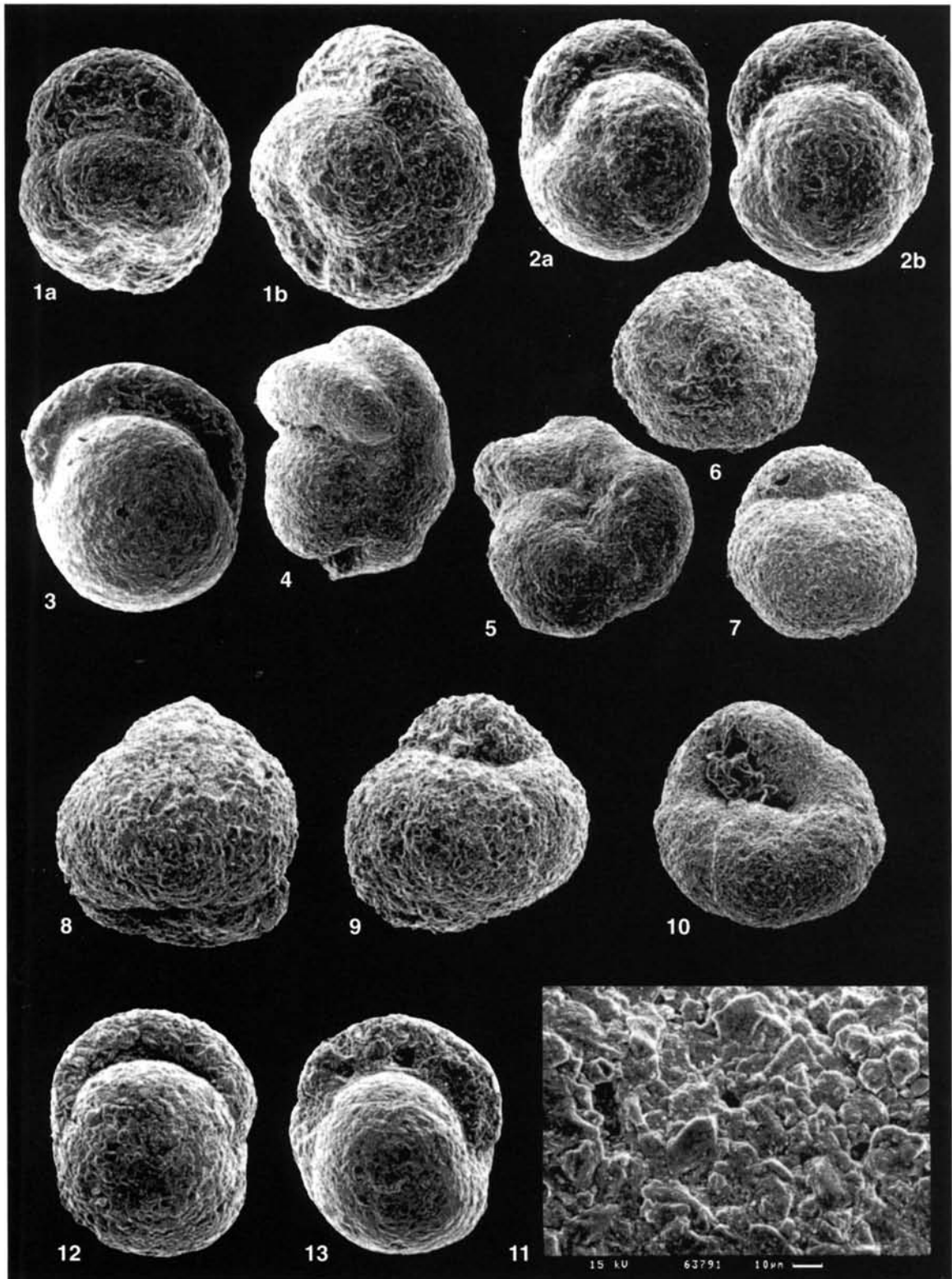


Plate 5. **1a, b.** *Recurvoides* sp., (a: 70×; b: 75×), Sample 159-959D-49R-1, 110–114 cm. **2a, b.** *Recurvoides* sp., (65×), Sample 159-959D-49R-1, 110–114 cm. **3.** *Recurvoides* sp., (65×), Sample 159-959D-49R-1, 28–31 cm. **4.** *Recurvoides* sp., (45×), Sample 159-959D-49R-1, 110–114 cm. **5.** *Recurvoides* sp., (45×), Sample 159-959D-49R-1, 28–31 cm. **6.** *Conotrochammina* cf. *whangaia* (dorsal view), (50×), Sample 159-959D-50R-3, 28–31 cm. **7.** *Conotrochammina* cf. *whangaia* (ventral view), (50×), Sample 159-959D-50R-3, 28–31 cm. **8.** *Conotrochammina* cf. *whangaia* (side view), (65×), Sample 159-959D-49R-4, 27–30 cm. **9.** *Conotrochammina* cf. *whangaia* (ventral view), (70×), Sample 159-959D-49R-4, 27–30 cm. **10.** *Conotrochammina* cf. *whangaia* (ventral view), (45×), Sample 159-959D-49R-4, 27–30 cm. **11.** Detail of Fig. 10: perforate wall structure, (465×). **12.** *Cribrostomoides* sp., (55×), Sample 159-959D-49R-3, 27–30 cm. **13.** *Cribrostomoides* p., (80×), Sample 159-959D-49R-3, 27–30 cm.

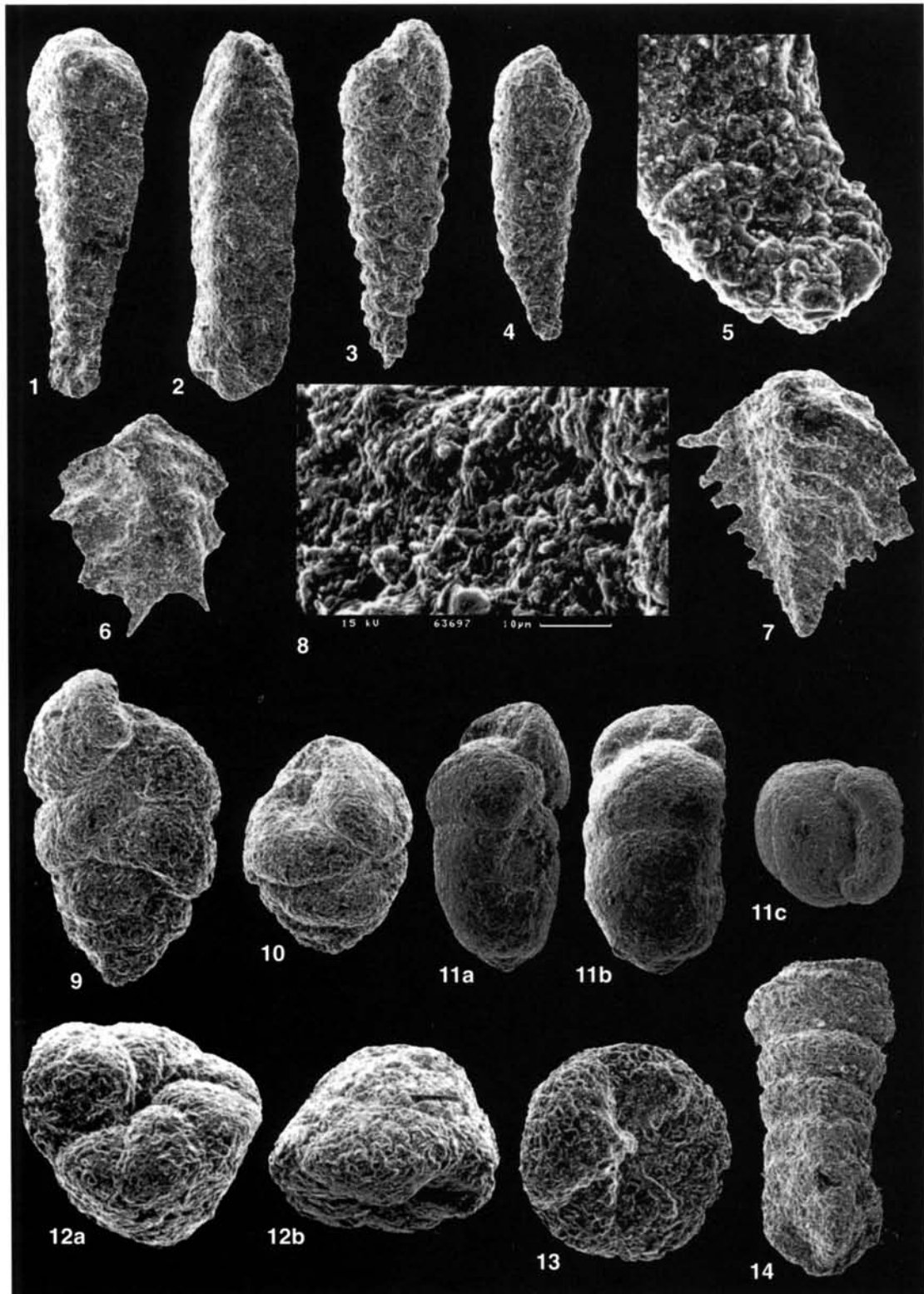


Plate 6. **1.** *Spiroplectammina spectabilis* (microsphere), (110 $\times$ ), Sample 159-959D-48R-4, 48–50 cm. **2.** *Spiroplectammina spectabilis* (megalosphere), (95 $\times$ ), Sample 159-959D-48R-4, 48–50 cm. **3.** *Spiroplectammina navarroana* (microsphere), (80 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. **4.** *Spiroplectammina navarroana* (megalosphere), (80 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. **5.** Detail of 4 with spiral initial portion, (440 $\times$ ), Sample 159-959D-49R-1, 28–31 cm. **6.** *Spiroplectammina ex gr. dentata* (megalosphere), (70 $\times$ ), Sample 159-959D-50R-2, 26–29 cm. **7.** *Spiroplectammina ex gr. dentata* (microsphere), (70 $\times$ ), Sample 159-959D-50R-2, 26–29 cm. **8.** Detail of 7 showing microperforate wall, (1080 $\times$ ), Sample 159-959D-50R-2, 26–29 cm. **9.** *Remesella varians* (?), (45 $\times$ ), Sample 159-959D-49R-4, 69–72 cm. **10.** *Remesella varians* (?), (50 $\times$ ), Sample 159-959D-49R-4, 69–72 cm. **11a–c.** *Dorothis bulletta*, (35 $\times$ ), Sample 159-959D-50R-4, 68–71 cm. **12a–b.** *Trochammina ruthvenmurrayi*, (90 $\times$ ), Sample 159-959D-49R-3, 27–30 cm. **13.** *Trochammina ruthvenmurrayi*, (90 $\times$ ), Sample 159-959D-49R-3, 27–30 cm. **14.** *Clavulinoides* sp., (40 $\times$ ), Sample 159-959D-49R-4, 69–72 cm.

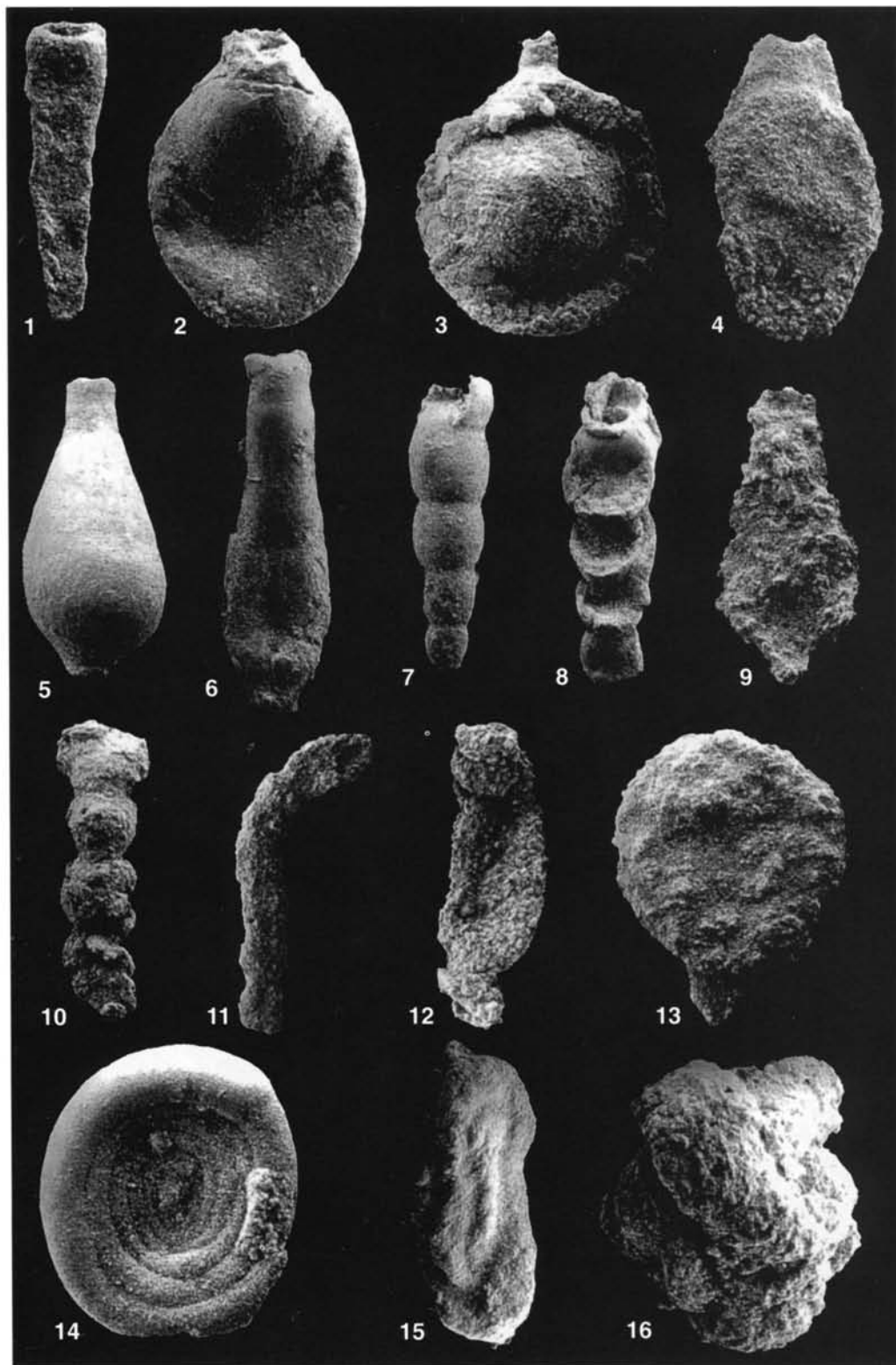


Plate 7. **1.** *Hippocrepina* sp., (115 $\times$ ), Sample 159-959D-44R-6, 30–33 cm. **2.** *Hyperammina dilatata*, (60 $\times$ ), Sample 159-959D-46R-1, 80–85 cm. **3.** *Saccamina grzybowskii*, (165 $\times$ ), Sample 159-959D-48R, CC. **4.** *Aschemocella* sp., (50 $\times$ ), Sample 159-959D-47R-1, 19–22 cm. **5.** *Caudamina ovuloides*, (55 $\times$ ), Sample 159-959D-48R, CC. **6.** *Kalamopsis grzybowskii*, (35 $\times$ ), Sample 159-959D-46R-1, 80–85 cm. **7.** *Reophax nodulosus*, (35 $\times$ ), Sample 159-959D-45R-1, 43–48 cm. **8.** *Hormosina velascoensis*, (20 $\times$ ), Sample 159-959D-45R, CC. **9.** *Lagenammina* sp., (60 $\times$ ), Sample 159-959D-47R-1, 19–22 cm. **10.** *Subreophax scalaris*, (70 $\times$ ), Sample 159-959D-46R-1, 80–85 cm. **11.** *Subreophax scalaris*, (55 $\times$ ), Sample 159-959D-47R-1, 19–22 cm. **12.** *Subreophax splendidus*, (65 $\times$ ), Sample 159-959D-48R, CC. **13.** *Aschemocella grandis*, (50 $\times$ ), Sample 159-959D-47R-1, 19–22 cm. **14.** *Ammodiscus glabratus*, (115 $\times$ ), Sample 159-959D-48R, CC. **15.** *Glomospira serpens*, (65 $\times$ ), Sample 159-959D-45R-1, 43–48 cm. **16.** *Glomospira irregularis*, (140 $\times$ ), Sample 159-959D-48R, CC.

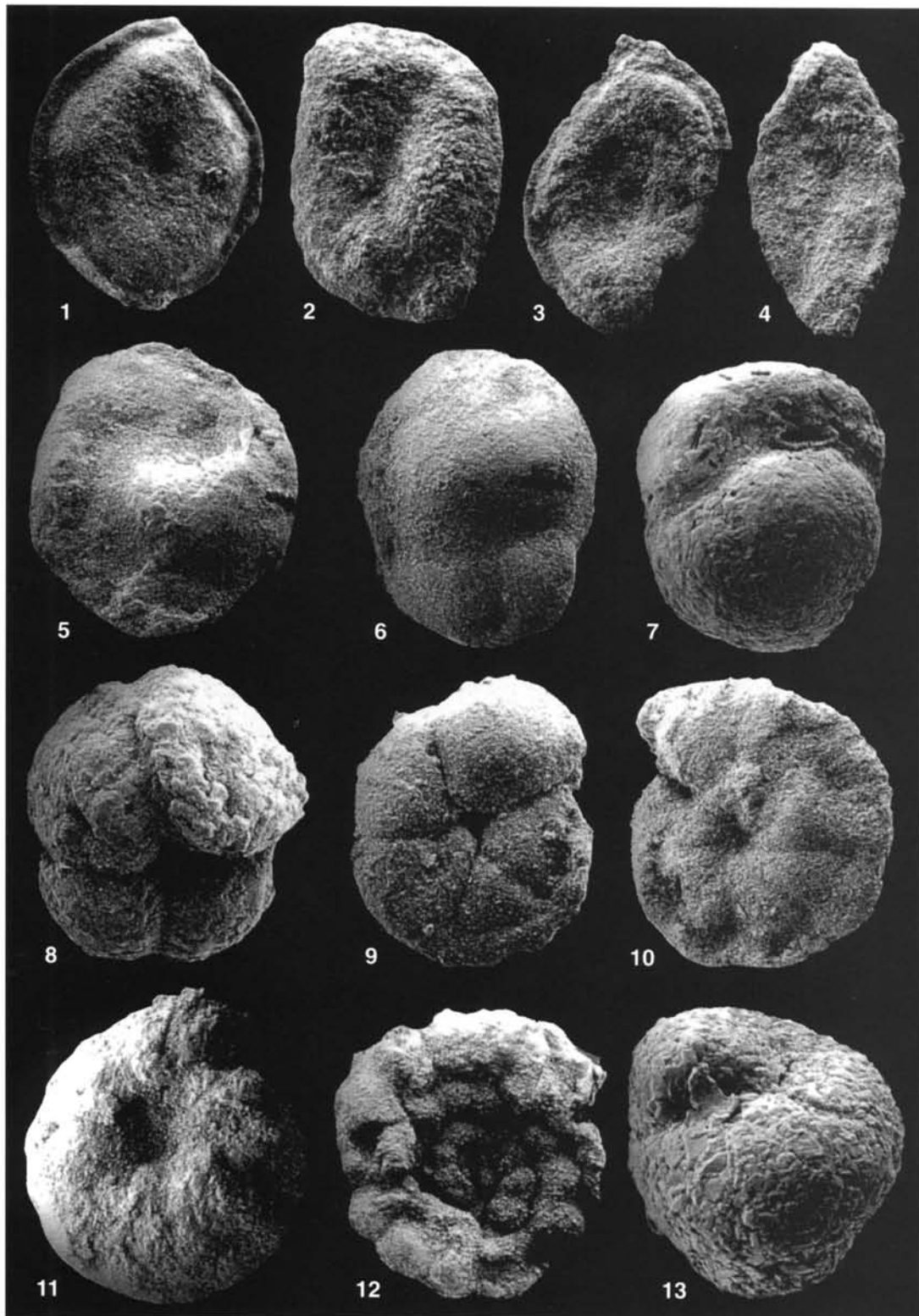


Plate 8. **1.** *Rzehakina epigona lata*, a large specimen showing a well-developed keel, (35 $\times$ ), Sample 159-959D-45R-1, 43–48 cm. **2.** *Rzehakina epigona*, (85 $\times$ ), Sample 159-959D-44R-6, 30–33 cm. **3.** *Rzehakina fissistomata*, (60 $\times$ ), Sample 159-959D-44R-6, 30–33 cm. **4.** *Rzehakina minima*, (85 $\times$ ), Sample 159-959D-44R-6, 30–33 cm. **5.** *Buzasina* sp., (60 $\times$ ), Sample 159-959D-45R, CC. **6.** *Buzasina* sp., (65 $\times$ ), Sample 159-959D-45R, CC. **7.** *Cribrostomoides* sp., (65 $\times$ ), Sample 159-959D-48R, CC. **8.** *Haplophragmoides kirki*, (165 $\times$ ), Sample 159-959D-48R, CC. **9.** *Haplophragmoides* cf. *walteri* of Kuhnt and Kaminski (1990), (165 $\times$ ), Sample 159-959D-48R, CC. **10.** *Reticulophragmoides jarvisi*, an early form transitional to *Haplophragmoides walteri*, (75 $\times$ ), Sample 159-959D-46R-1, 80–85 cm. **11.** *Haplophragmoides* sp., a distinctive form with a depressed umbilicus, (75 $\times$ ), Sample 159-959D-45R, CC. **12.** *Trochamminoides grzybowskii*, (30 $\times$ ), Sample 159-959D-45R, CC. **13.** *Conotrochammina whangaia*, (115 $\times$ ), Sample 159-959D-48R, CC.