

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

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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 *Spiroplectammina* are observed in Core 159-959D-48R. This change in agglutinated foraminifer assemblages corresponds to the Tethyan early Paleocene "*Spiroplectammina* 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 (DWF) have been used as biostratigraphic tools for Upper Cretaceous sub-calcite compensation depth (CCD) sediments in various oceanic basins. Initial DWF zonations 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 DWF 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 DWF zonations 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 DWF 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 DWF 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 DWF zonations and to monitor the paleogeographic extent of paleoceanographic events that characteristically influence assemblage composition and evolution of DWF.

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- μ 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-

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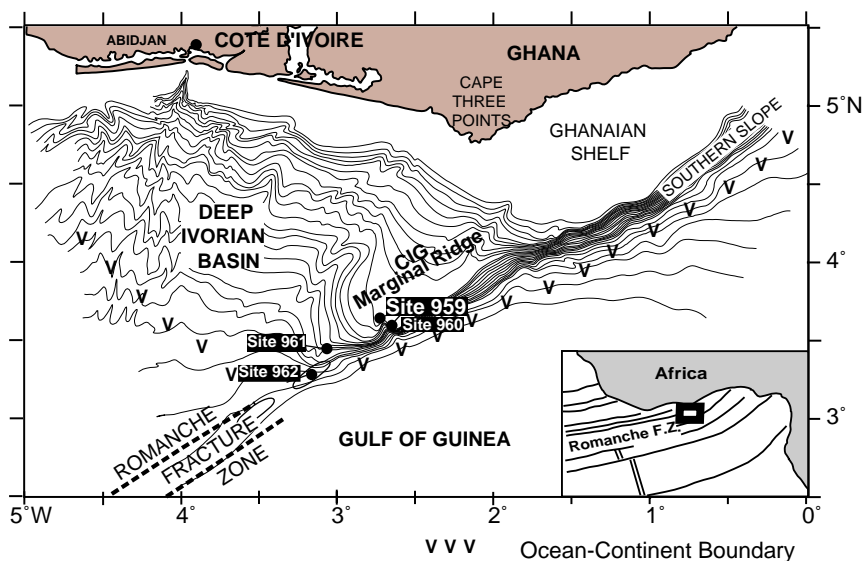


Figure 1. Sketch map showing the location of Hole 959D.

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 bulminids, 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 *Spiroplectammina 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 <i>gr. pennyi</i>	<i>Ammodiscus glabratus</i>	<i>Ammodiscus peruvianus</i>	<i>Ammodiscus tenuissimus</i>	<i>Ammolagena clavata</i>	<i>Ammoscalaria</i> sp.	<i>Ammosphæroides</i> sp.	<i>Aschemocella</i> spp. (incl. fragments)	<i>Bathysiphon</i> spp.	<i>Budasthevaella multicamerata</i>	<i>Bulbobaculites</i> ex <i>gr. problematicus</i>	<i>Bulbobaculites</i> sp.	<i>Buzasina</i> sp.	<i>Caudammina gigantea</i>	<i>Caudammina ovuloides</i>	<i>Caudammina ovula</i>	<i>Clavulinoides</i> sp.	<i>Conotrochammina whangaia</i>	<i>Cribrostomoides</i> sp.	<i>Dorothia bullella</i>	<i>Dorothia</i> ex <i>gr. filiformis</i>	<i>Dorothia</i> sp.	<i>Evolutinella</i> (?) sp.	<i>Gaudryna</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											1						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				1													2							
44R-2, 16-22					6			4	1	3									1	1							5							
44R-3, 30-33						3		2	2	10											1						5				1			
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											3						6							
46R-CC					4	8		15		26																	13							
47R-1, 19-22	1	1			1	3		11	3	11																	4		1					
48R-1, 28-31		2				2		1	16	5																	4							
48R-1, 69-70		3							2	1																	6					1		
48R-2, 27-30		1				1			27	13																	3							
48R-3, 31-34	2					5		6	60	14											3						2							
48R-3, 137-139	3				5	14		12		16				1							9						7							
48R-4, 28-31						4		9	12	14																	3							
48R-4, 48-50						1			1				1														5							
48R-4, 66-68				2						5																	7							
48R-4, 69-71								2	3	2			1														1							
48R-5, 28-31		1			1			5	5	9				1							1						1							
48R-5, 87-89		1						1	8	1																	3							
48R-6, 28-31					2	10		23	50	40											7						9							
48R-CC					1	16		5	9	26						1				1							12							
49R-1, 28-31	6	8				10		9	9	33					14	3					1						18							
49R-1, 69-72		1						1	6						5	1											5							
49R-1, 110-114		3						8							18	1	3				3						6							
49R-2, 27-30	4(?)	6				7		1	1	29			2		1	3			1								1	10						
49R-3, 27-30	5	5				8		3	1				1		3				1(?)		4						1	6						
49R-4, 27-30	5									1					1												1							
49R-4, 69-72	1	3	1			1		2	44	2					5		43	2(?)								3	2							
49R-5, 27-31		2						1	5	3	2(?)				1(?)		5	3	7	1(?)														
49R-6, 27-30	1	7	3			8	3(?)	25	10	30					5(?)	1											1							
50R-1, 27-30			1					2	3																									
50R-1, 70-73									1							1				1														
50R-2, 26-29	1	1						6	16	4			1														2							
50R-3, 28-31	1	3						3	3																		1							
50R-4, 26-29	2	1						1	2	5																								
50R-4, 68-71		1						10	10	11						1	2				1													
50R-5, 30-34	1	1						2	10	4																								
51R-3, 28-31		5	1					1	2	2						5	1(?)					1												
52R-1, 23-27			4							2																		1						
52R-1, 29-33		2							1	12																								
52R-1, 67-71									1	11	1																	2						
52R-2, 25-27									1	4																								
52R-3, 27-31									1				1(?)																					
52R-4, 30-33									1	5													2(?)											
52R-4, 45-48									1	1													2(?)											

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 grzybowskii*, 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 beccariiformis* 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 gryzbowskii</i>	<i>Haplophragmoides</i> ex gr. <i>excavatus</i>	<i>Haplophragmoides</i> cf. <i>walteri</i>	<i>Haplophragmoides horridus</i>	<i>Haplophragmoides porrectus</i>	<i>Haplophragmoides</i> sp (?/kirki)	<i>Haplophragmoides stomatus</i>	<i>Haplophragmoides walteri</i>	<i>Haplophragmoides suborbicularis</i>	<i>Hippocrepina</i> sp.	<i>Hormosina excelsa</i>	<i>Hormosina trinitatensis</i>	<i>Hormosina velascoensis</i>	<i>Hormosina</i> sp.	<i>Hyperammima dilatata</i>	<i>Hyperammima</i> sp. (incl. fragments)	<i>Insculptarenula</i> sp.	<i>Kalamopsis gryzbowskii</i>	<i>Karrerulina conversa</i>	<i>Karrerulina</i> spp.	<i>Lagenammima</i> sp.	<i>Lituotuba lituiformis</i>	<i>Nothia</i> ex gr. <i>excelsa</i>	<i>Paratrochamminoides irregularis</i>	<i>Paratrochamminoides mitratus</i>	<i>Paratrochamminoides olszewskii</i>	<i>Paratrochamminoides</i> spp.		
159-959D-																															
43R-1, 28-32	3	2						2						1			1				6			2		4		10			
43R-3, 34-36	5							6	8	1		1		2			1				10									9	
43R-5, 32-35									1							3					6										
43R-CC	1	2									1					3					6								2		
44R-2, 16-22																2					6		1	1		1					
44R-3, 30-33	1	1						3	2							4		1	2	2	7									10	
44R-5, 30-33	4							1	4											8		1	1								
44R-6, 30-33		3						2				1								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			19		3			4		4				
46R-CC					1			14	3			1							1	42											
47R-1, 19-22		1			1	1		4	4	1	5			4			1			39	1	9						2			
48R-1, 28-31														3						10											
48R-1, 69-70	5	1			1															17		2			1						
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					1					24		1							12	8		
48R-4, 28-31												1					2			19		13			3		1	1			
48R-4, 48-50	7					7													10						2						
48R-4, 66-68										2									15		19										
48R-4, 69-71	2										4					1	3			1	7		1								
48R-5, 28-31	1				2		5		1		1		4						17		18						2	6			
48R-5, 87-89	2									1			4		2				8	13	2	1	1	5					1		
48R-6, 28-31	2	1									1		1						38		4	1					1	4			
48R-CC	10				6	3	4	3					2				1		50		5			1							
49R-1, 28-31	10	2			1			2			13	14		1					19	116	4	2		14				21			
49R-1, 69-72	2							11			2								3	25									8		
49R-1, 110-114	4							4			13					3			7	56								6			
49R-2, 27-30	15							4			8			3					155	2	3(?)							17			
49R-3, 27-30	5							14		4	1								66	2								8			
49R-4, 27-30								2			3								12	10				1				1			
49R-4, 69-72	3							4			4								16									1			
49R-5, 27-31	6							3			1		1						27										8		
49R-6, 27-30	13							50			7	5					4	4	3	53	6(?)		1	12			4	19			
50R-1, 27-30																			1	10			1								
50R-1, 70-73											1								8												
50R-2, 26-29								2			5	1		2					1	27									2		
50R-3, 28-31	2		1					7			1	2		1					10	12	4			83					4		
50R-4, 26-29											1						1				6	3		19							
50R-4, 68-71		1			2			7			7			1					11	20	5			37					4		
50R-5, 30-34	2				1			9			2								7	10	9			122							
51R-3, 28-31								2			5			1					5					98						6	
52R-1, 23-27	1				1						2													19					2		
52R-1, 29-33		1									1													6							
52R-1, 67-71												1												7							
52R-2, 25-27											1							2		2										2	
52R-3, 27-31											2										5										
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 Moulade, 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>Ammobaculites</i> sp.	<i>Ammodiscus cretaceus</i>	<i>Ammodiscus</i> ex gr. <i>penyi</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>Aschemoecella</i> spp. (incl. fragments)	<i>Bathysiphon</i> spp.	<i>Budasthevaella multicaemerata</i>	<i>Bulbobaculites</i> ex gr. <i>problematicus</i>	<i>Bulbobaculites</i> sp.	<i>Buzasina</i> sp.	<i>Caudammina gigantea</i>	<i>Caudammina ovaloides</i>	<i>Caudammina ovata</i>	<i>Clavulinoides</i> sp.	<i>Conotrochammina whangaia</i>	<i>Cribrostomoides</i> sp.	<i>Dorothia bullella</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-																															
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	2	2
55R-7, 36-38	2	.	.	.	1	1	.	2	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	1
56R-1, 127-132	3	.	.	.	.	1	.	2	.	.	3	1	.	.	.	.	.	.	.	.	.	1	.	.	.	.	1	.	.	.
57R-1, 28-32	.	.	.	.	.	1	.	.	.	17	.	3(?)	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.
57R-1, 134-137	.	.	.	.	.	.	.	.	.	4	2	1(?)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
57R-3, 30-34	.	.	.	.	.	.	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
57R-4, 14-17	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
57R-4, 29-33	1	.	2	.	.	.	.	1	.	1	1	.	.	.	.	.	.	.	.	.	.	10	1	.	.	.	.	.	.	.
57R-5, 27-31	.	.	1	.	.	.	.	.	1	1	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
58R-1, 58-61	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
58R-1, 70-72	.	.	.	.	.	.	.	2	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.
58R-1, 110-114	1	.	.	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	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
59R-1, 62-67	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.
59R-2, 27-32	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	3	.	.	.
59R-2, 32-36	.	.	3	.	.	.	.	.	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	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
63R-1, 69-72	2	.	.	.	.	.	.	.	.	.	.	1(?)	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
63R-4, 24-26	3	.	.	.	.	.	.	.	.	.	.	.	4	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
63R-4, 98-100	4	.	.	.	.	.	.	2	.	.	.	3(?)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
63R-5, 59-62	.	.	.	.	.	.	.	.	.	.	.	.	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
63R-6, 39-42	8	.	.	.	.	.	.	.	.	.	.	.	14	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
64R-1, 25-28	.	.	.	.	.	.	.	.	.	.	.	1(?)	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
64R-2, 3-6	.	.	.	.	.	.	.	.	.	.	.	.	1(?)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
64R-2, 30-34	2	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
64R-3, 32-35	3	.	.	.	.	.	.	2	.	.	.	.	41	6	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.
64R-4, 32-35	.	.	1	.	.	.	.	.	.	.	.	.	18	9	.	.	.	.	.	.	.	.	.	.	.	5	.	.	.	.
64R-5, 13-15	10	.	.	.	.	.	.	.	.	.	.	.	10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
64R-6, 9-12	.	.	.	.	.	.	.	.	.	.	.	.	5	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
65R-1, 28-32	6	.	5	.	1	.	.	.	.	.	.	9	9	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
65R-1, 49-52	4	.	.	.	.	.	.	.	.	.	.	.	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
65R-2, 28-32	.	.	.	.	.	.	.	.	.	.	.	3	3	.	.	.	.	.	.	.	.	.	9	.	.	.	.	.	.	.
65R-3, 32-36	1	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

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 *Caudammina 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 Sopelana 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., astrophorids 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>Glomospira irregularis</i>	<i>Glomospira serpens</i>	<i>Glomospirella gryzbowskii</i>	<i>Haplophragmoides</i> ex gr. <i>excavatus</i>	<i>Haplophragmoides</i> cf. <i>walteri</i>	<i>Haplophragmoides horridus</i>	<i>Haplophragmoides porrectus</i>	<i>Haplophragmoides</i> sp. (?kirki)	<i>Haplophragmoides stomatus</i>	<i>Haplophragmoides walteri</i>	<i>Haplophragmoides</i> sp.	<i>Hippocrepina</i> sp.	<i>Hormosina excelsa</i>	<i>Hormosina trinitatensis</i>	<i>Hormosina velascoensis</i>	<i>Hormosina</i> sp.	<i>Hyperammina dilatata</i>	<i>Hyperammina</i> sp. (incl. fragments)	<i>Insculptarenula</i> sp.	<i>Kalamopsis gryzbowskii</i>	<i>Karrerulina conversa</i>	<i>Karrerulina</i> spp.	<i>Lagenammina</i> sp.	<i>Lituotuba lituiformis</i>	<i>Nothia</i> ex gr. <i>excelsa</i>	<i>Paratrochamminoides irregularis</i>	<i>Paratrochamminoides mitratus</i>	<i>Paratrochamminoides olszewskii</i>	<i>Paratrochamminoides</i> spp.		
159-959D-																															
53R-5, 29-33	1										2				1						5		1		48						
54R-1, 30-34											4					2					6			1	40						
55R-5, 35-37											3										2				4						
55R-7, 36-38		1		1																	2										
56R-1, 127-132																	1					4			81						
57R-1, 28-32																	2				27				23						
57R-1, 134-137																					6				5						
57R-3, 30-34				1							1						3														
57R-4, 14-17	1										2						1			3											
57R-4, 29-33																					1				4						
57R-5, 27-31																				1											
58R-1, 58-61																					3				5						
58R-1, 70-72				1	2																12				3						
58R-1, 110-114																															
58R-3, 113-116				1																	3	1							1		
58R-4, 28-31																													2(?)		
58R-4, 67-71																					10										
59R-1, 25-30					1																1										
59R-1, 30-34				3																	4	1	6		5						
59R-1, 62-67	1										5										3				2						
59R-2, 27-32		1									1			3							30		2		12						
59R-2, 32-36											1			1							4										
59R-3, 22-27	1(?)			1							1			1							6(?)	3(?)		1	1						
59R-4, 30-35											1										2	2(?)									
59R-4, 75-80				1							1										2				5						
59R-5, 29-34											3										6				10						
60R-1, 22-24				2																	2				8						
60R-2, 26-28														4							18										
60R-3, 24-26				2																	20										
60R-4, 24-27																					4		1		15						
60R-4, 68-73				3																	14	2			4						
60R-4, 109-113																					9				5						
60R-5, 17-21				3																	1										
61R-2, 61-65								1													16				21						
63R-1, 38-40																					7	5(?)									
63R-1, 69-72																					3										
63R-4, 24-26				5							1										3	2									
63R-4, 98-100				2																											
63R-5, 59-62																					12				248						
63R-6, 39-42																						2(?)			38						
64R-1, 25-28																					14										
64R-2, 3-6																															
64R-2, 30-34	4																														
64R-3, 32-35				4	2																41			6	1						
64R-4, 32-35					4																87				10						
64R-5, 13-15					1																32	2		116							
64R-6, 9-12	1			1							2										7										
65R-1, 28-32											3										14										
65R-1, 49-52																		1			6										
65R-2, 28-32				13																											
65R-3, 32-36				2																											

and *Recurvoides*); and (3) a strong increase of infaunal calcareous agglutinating *Spiroplectammina* and *Dorothia* is observed in deep-water environments when the organic flux recovers.

These quantitative faunal changes in deep-water agglutinated foraminifers across the K/T boundary are consistent with a model of decreased surface productivity, and a collapse of the food web for deep-water benthic communities at the K/T boundary. Benthic foraminifer populations slowly recover to background levels over a time span of at least 300 k.y. following the K/T boundary event. Most Maastrichtian species of deep-water benthic foraminifers recur after this recovery phase and, as a result, the overall faunal turnover of benthic foraminifers across the K/T boundary does not remarkably exceed normal turnover rates in the Late Cretaceous or early Paleogene (Kuhnt et al., 1996). *Spiroplectammina*-dominated bathyal benthic foraminifer assemblages characterize the recovery phase of the marine eco-

system and are potentially useful correlation tools for the interval from the top of the P0 Zone to the lower part of the *P. eugubina* zone.

CONCLUSIONS

The deep-water agglutinated foraminifer zonation of Geroch and Nowak (1984) for the Polish Carpathians, Moullade et al. (1988) for the North Atlantic, and Kuhnt et al. (1989, 1992) for the western Tethys can be applied to the Campanian-Paleogene interval of Hole 959D. Three zones are identified: (1) the *Uvigerinammina jankoi/Caudammina ovulum gigantea* concurrent zone (lower Campanian), (2) the *Caudammina ovulum gigantea* zone (middle Campanian to upper Maastrichtian), (3) the *Rzehakina epigona/Spiroplectammina spectabilis* zone (lower Paleocene).

Table 1 (continued).

Core, section, interval (cm)	<i>Popovia beckhami</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 pitulifer</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</i> ex gr. <i>epigona</i>	<i>Rzehakina fissistomata</i>	<i>Rzehakina inclusa</i>	<i>Rzehakina minima</i>	<i>Rzehakina</i> sp. (narrow)	<i>Saccammina grzybowskii</i>	<i>Saccammina placenta</i>	<i>Saccammina sphaerica</i>	<i>Saccohiza ramosa</i>		
159-595D-																																
53R-5, 29-33							4		2					17				141	18													
54R-1, 30-34						3	26							8				142	72								7		2	1(?)		
55R-5, 35-37							7											210	13													
55R-7, 36-38																		194	11					5								
56R-1, 127-132							3		6			1		10				86			1							1				
57R-1, 28-32							19							5		1		92	24													
57R-1, 134-137							18		2					6				5	12			3									1	
57R-2, 30-34				3			17							16			8	57	12		3											
57R-3, 30-34							2							3			5	>60	14		6											
57R-4, 14-17							15		2					2		24	3	66	28		47						2					
57R-4, 29-33							6										21	5	2		9											
57R-5, 27-31							6							7			4	7	9					1				5				
58R-1, 58-61		1					16		1								19	9														
58R-1, 70-72							17										11	134	12		20											
58R-1, 110-114							6							3			22	67	25		13								5(?)			
58R-3, 113-116							6							7			12	39	25							2						
58R-4, 28-31							8		4					1					11		1		3					1(?)				
58R-4, 67-71							9		1					14			19	22	5									2(?)				
59R-1, 25-30							33							10			10	130	15		4					1						
59R-1, 30-35							52							27				88	16		4							1				
59R-1, 62-67							17							9			11	83	14		8						1					
59R-2, 27-32							17							13		1		71			20		1					22				
59R-2, 32-36				1			14							10				66	10		11											
59R-3, 22-27							19							17				81	11		12					1	1					
59R-4, 30-35							23							3				130	17		9											
59R-4, 75-80						1	10							14			23	36	9													
59R-5, 29-34							20		1					4				48	23		6		3				5	5(?)				
60R-1, 22-24							7							3				2														
60R-2, 26-28							44							12				240	9		16								17			
60R-3, 24-26							57							6				106	8										3			
60R-4, 24-27							30							11				26	10													
60R-4, 68-73							61		1					7			10	154			28		8				3	3				
60R-4, 109-113							3							3			5	32	6		6		1					1				
60R-5, 17-21							1							4			16	22	2		7		2									
61R-2, 61-65							1							6		6	9	134			1											
63R-1, 38-40							6											70									3					
63R-1, 69-72							8							7				174			6											
63R-4, 24-26		38					20							3				75														
63R-4, 98-100							19							4			2	27			1											
63R-5, 59-62							14							2																		
63R-6, 39-42							19							12				87			4		1									
64R-1, 25-28							17							1				229														
64R-2, 3-6																		16														
64R-2, 30-34							16							5				174			2											
64R-3, 32-35							20							4				459														
64R-4, 32-35							2	60										189			1(?)											
64R-5, 13-15							10							9				67														
64R-6, 9-12		1					6							2			15	114					1									
65R-1, 28-32							33							11			21	172			1					1						
65R-1, 49-52							28							8			4	277			14		1									
65R-2, 28-32							40							2			5	88														
65R-3, 32-36				1										3				18			1											

The disappearance of calcareous foraminifers and the occurrence of assemblages exclusively composed of organically cemented agglutinated forms in Section 159-959D-65R-3 are attributed to the subsidence of the seafloor below the CCD.

The North Atlantic early Campanian paleoceanographic event is reflected in a biosiliceous radiolarian facies and associated changes in the benthic biofacies within Core 159-959D-61R.

The drastic decrease in surface productivity and a collapse of the food web for deep-water benthic communities across the K/T boundary probably led to the extinction of large-sized hormosinids (i.e., *Caudammina gigantea*). A significant increase in individuals of the genus *Spiroplectammina* and the first common occurrence of the Paleogene species *Spiroplectammina spectabilis* are observed within Core 159-959D-48R. This “*Spiroplectammina* event” characterizes

the recovery phase of the marine ecosystem after the K/T boundary in several classic boundary sections and is used as an indicator of the interval from the top of the P0 to the lower part of the *G. eugubina* zones in several classic boundary sections. Although precise calibrations to the planktonic foraminifer zonation are lacking, the thickness of the *S. spectabilis* acme in Hole 959D suggests that it may have had a longer duration at this site.

Within the Paleocene, first occurrences of cosmopolitan DWAF can be used to refine the chronostratigraphic calibration of Hole 959D. The occurrence of the index species *Reticulophragmoides jarvisi* in Cores 159-959D-43R and 44R indicates a late Paleocene age. Additional taxa such as *Trochammina ruthvenmurrayi* and *Glomospira diffundens* are characteristic of the upper Paleocene in both Trinidad and the Carpathians.

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>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. gutifer</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 gyroideiformis</i>	<i>Trochammmina ruthvenmurrayi</i>	<i>Trochamminoides gryzbowskii</i>	<i>Trochamminoides proteus</i>	<i>Trochamminoides subcoronatus</i>	<i>Trochamminoides</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																	
55R-5, 35-37								1				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.

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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 pseudopauiculolata* (Mjatluk)
Aschemocella spp. (incl. fragments)
Bathysiphon spp.
Budashevaella multicamerata (Veloshinova)
Bulbobaculites ex gr. *problematicus* (Neagu)
Bulbobaculites sp.
Buzasina sp.
Caudamina gigantea (Geroch)
Caudamina ovuloides (Grzybowski)
Caudamina 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 Binoumba-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 Kuhnt 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

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Ms 159SR-039

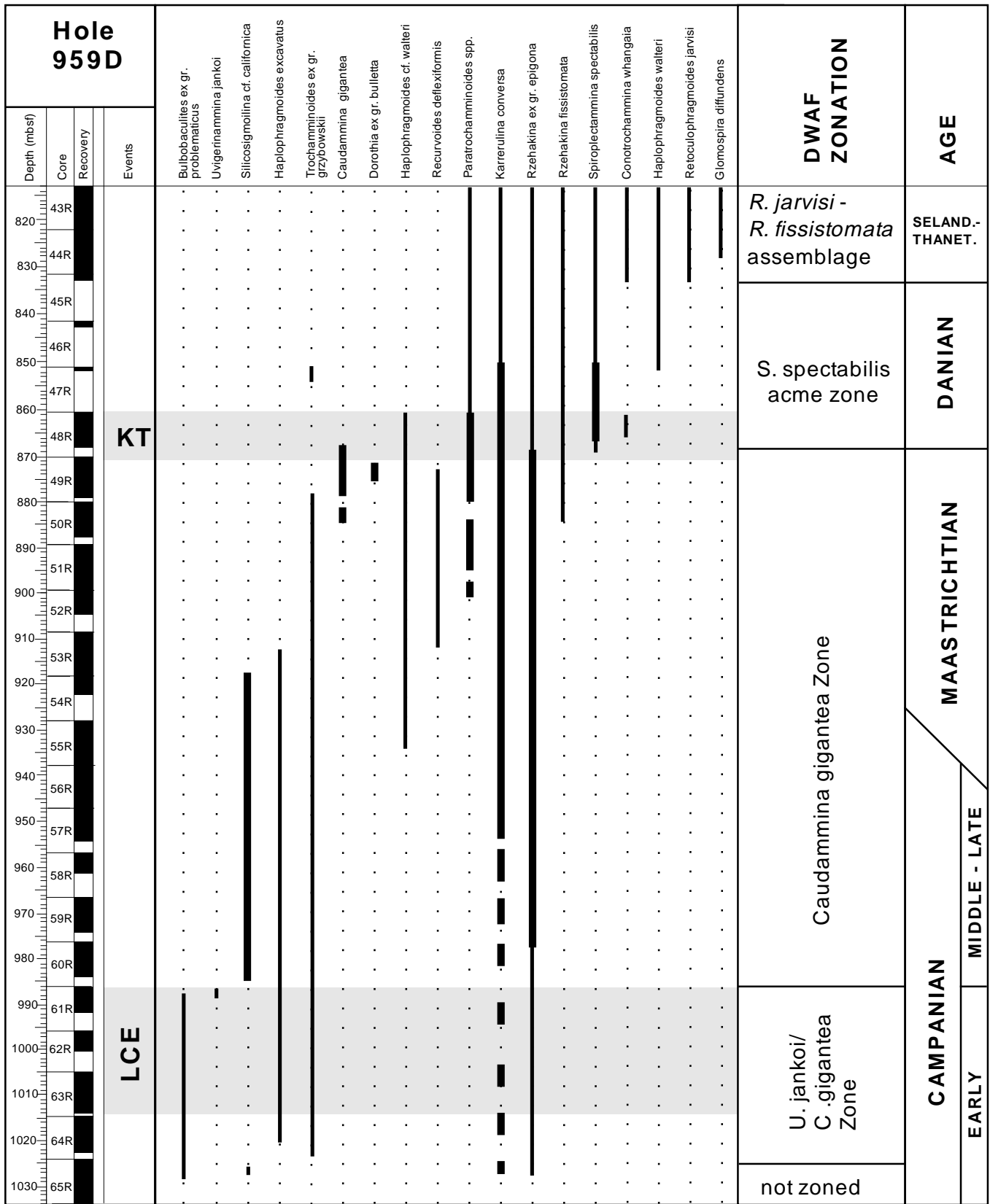


Figure 2. Stratigraphic ranges of marker species of agglutinated foraminifers within Hole 959D, Cores 159-959D-43R through 65R. Paleocanographic events: KT = Cretaceous/Tertiary Boundary Event; LCE = Lower Campanian Event.

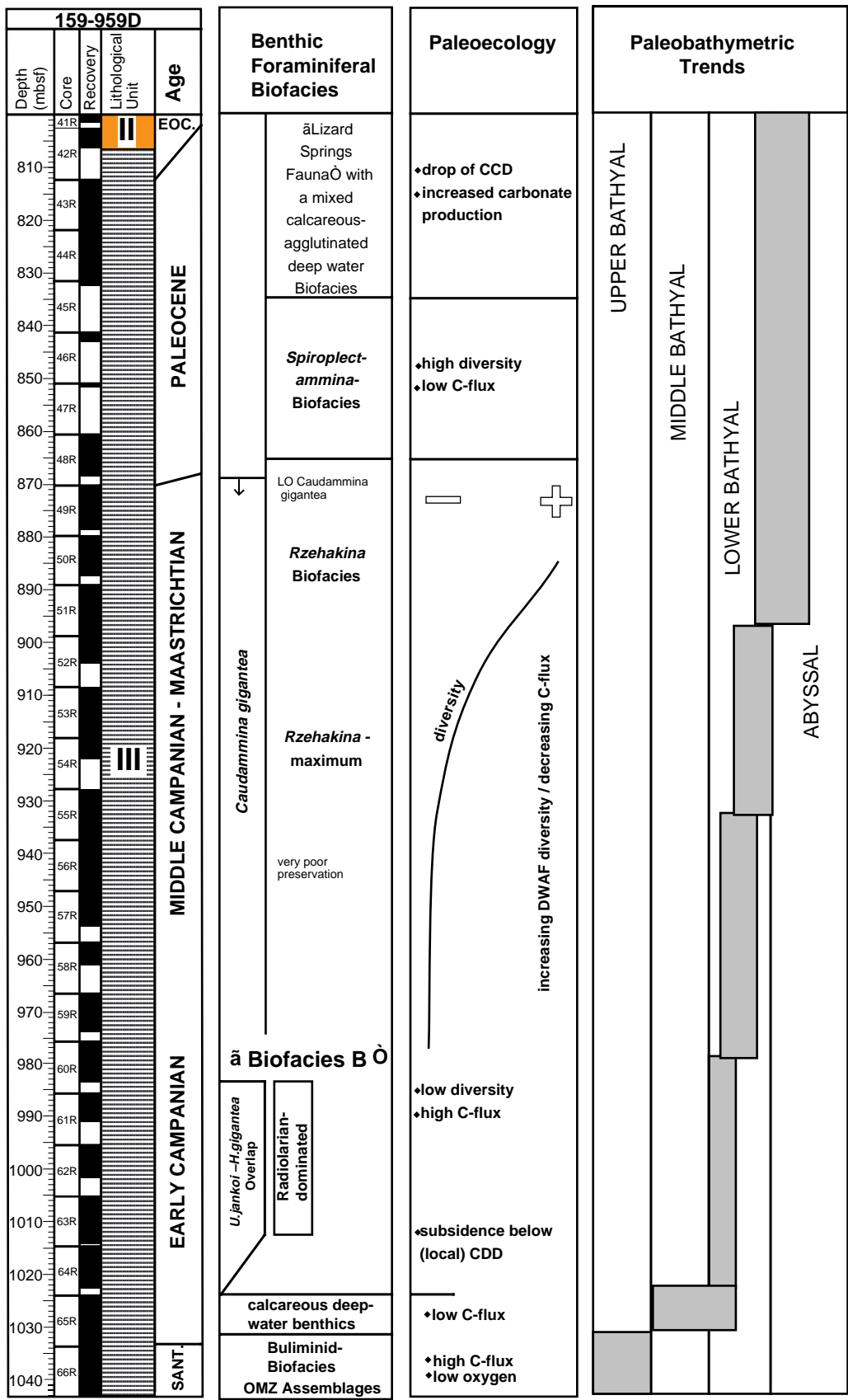


Figure 3. Benthic foraminifer biofacies and inferred paleoecologic-paleobathymetric trends in Hole 959D.

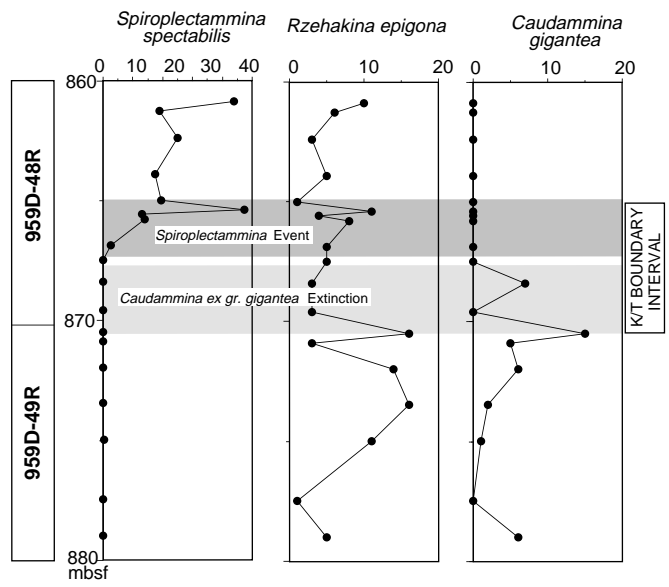


Figure 4. Quantitative changes of selected benthic foraminifer abundances across the K/T boundary interval in Hole 959D.

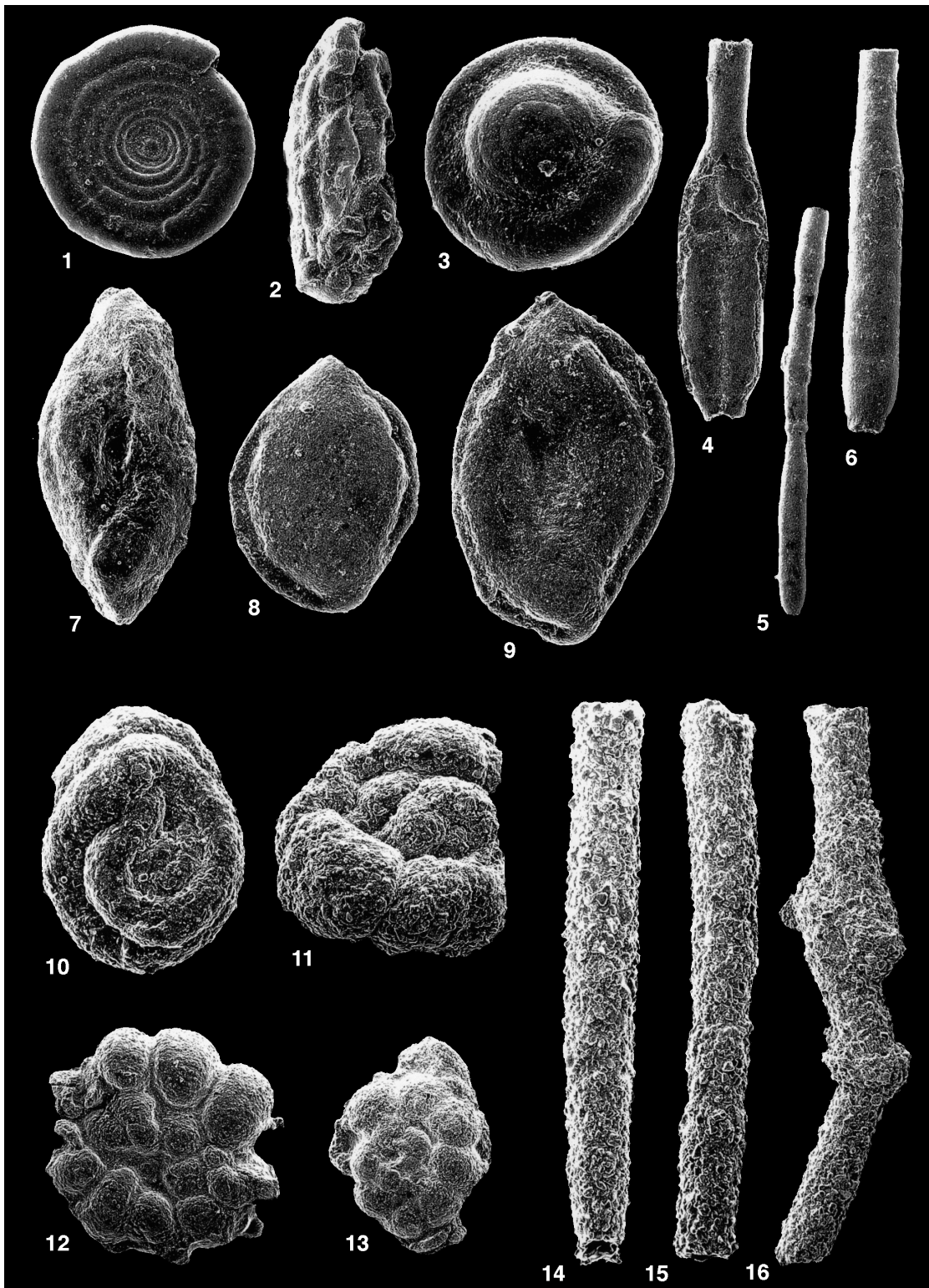


Plate 1. **1.** *Ammodiscus cretaceus*, (35×), Sample 159-959D-49R-1, 28–31 cm. **2.** *Glomospira serpens*, (65×), Sample 159-959D-49R-1, 28–31 cm. **3.** *Glomospira charoides*, (130×), Sample 159-959D-49R-1, 28–31 cm. **4.** *Kalamopsis grzybowskii*, (85×), Sample 159-959D-49R-1, 28–31 cm. **5.**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

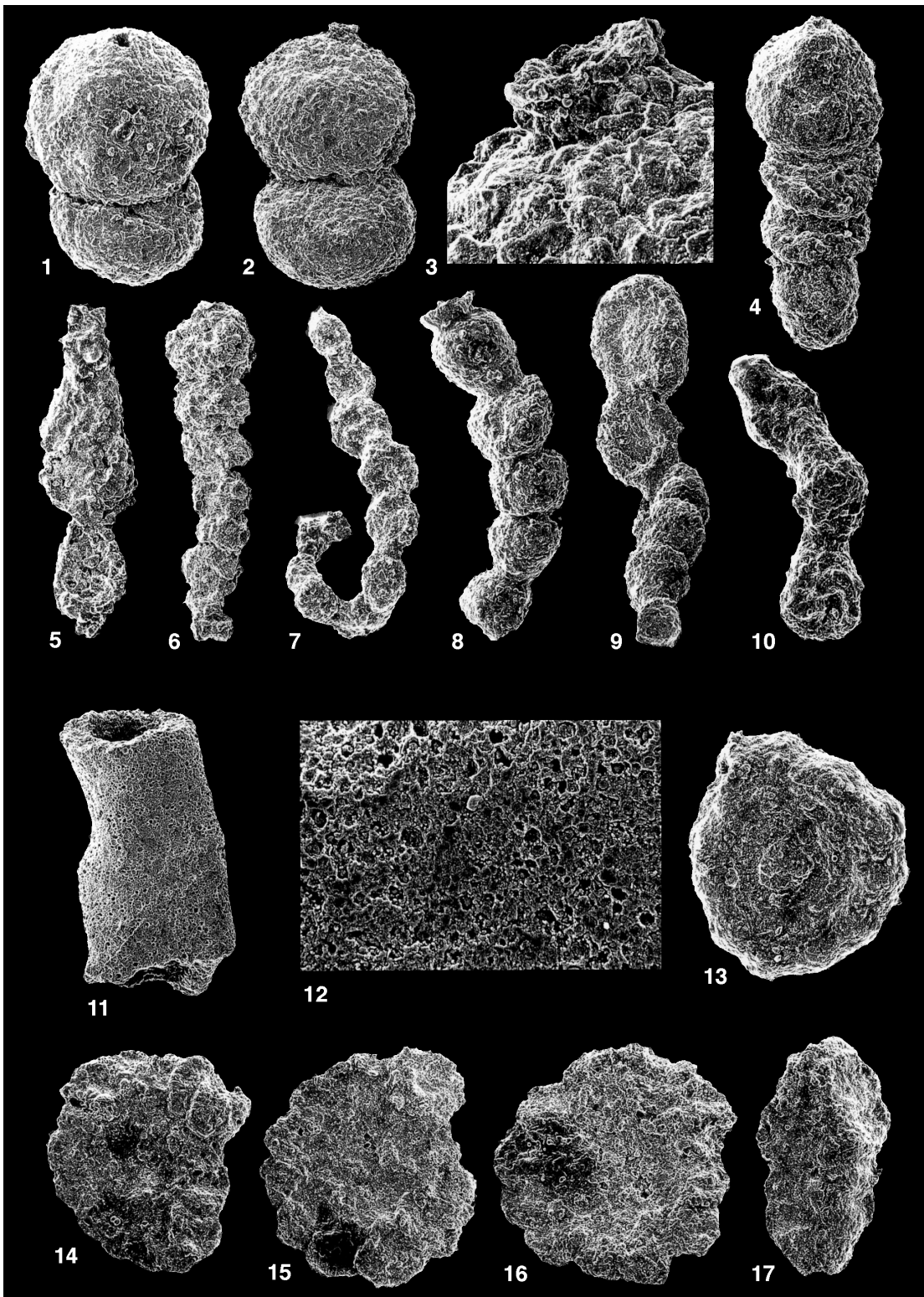


Plate 2. **1.** *Reophax duplex*, (50 \times), Sample 159-959D-50R-3, 28–31 cm. **2.** *Reophax duplex*, (40 \times), Sample 159-959D-50R-3, 28–31 cm. **3.** Detail of Fig. 2, aperture protruding on a short neck, (205 \times). **4.** *Reophax* sp., (100 \times), Sample 159-959D-49R-1, 28–31 cm. **5.** *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).

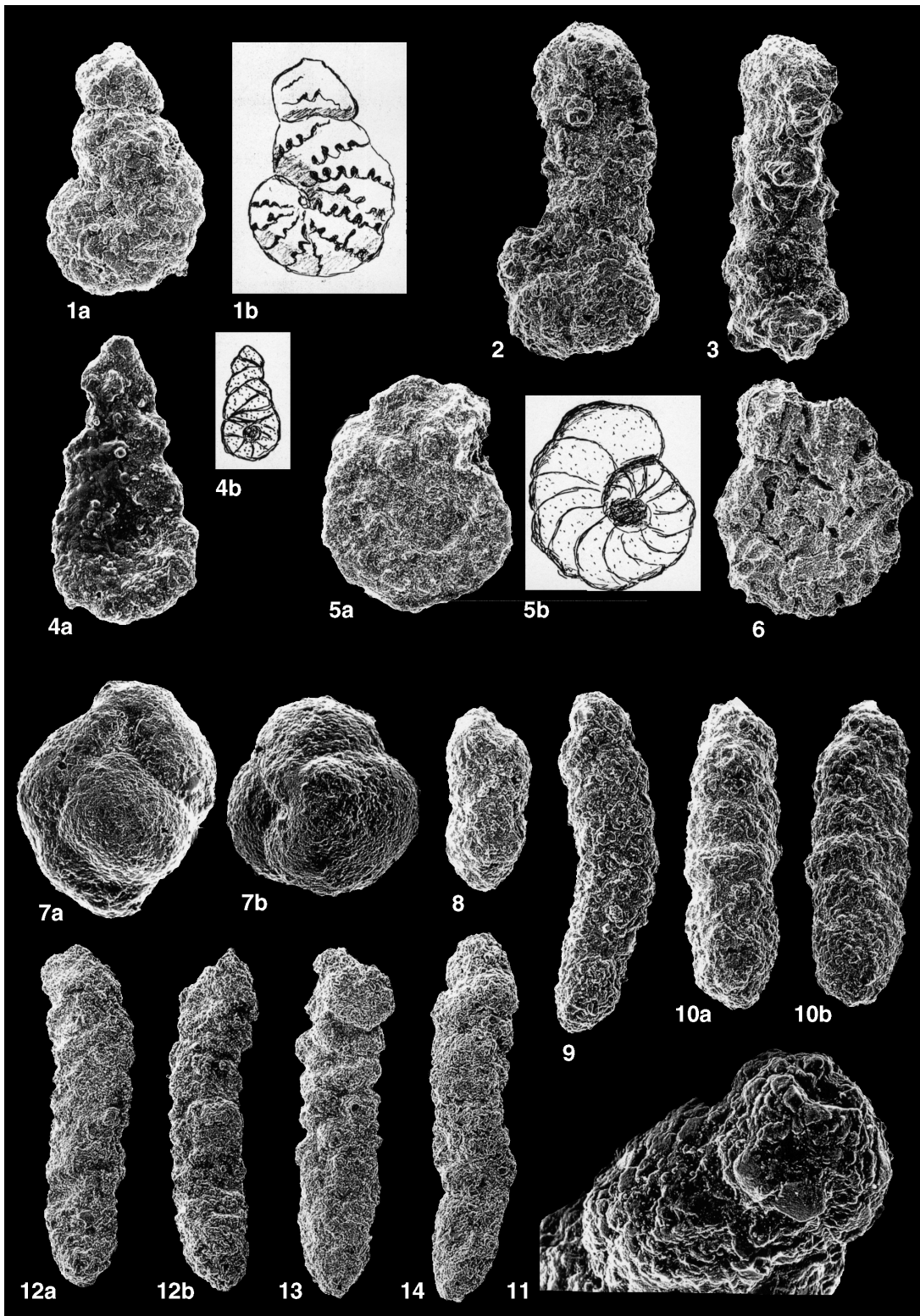


Plate 3. **1a, b.** *Reticulophragmium* sp. (early form), (60 \times), Sample 159-959D-50R-3, 28–31 cm. **2.** *Bulbobaculites problematicus*, (115 \times), Sample 159-959D-65R-2, 28–32 cm. **3.** *Bulbobaculites problematicus*, (100 \times), Sample 159-959D-65R-2, 28–32 cm. **4a, b.** *Ammoscalaria*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

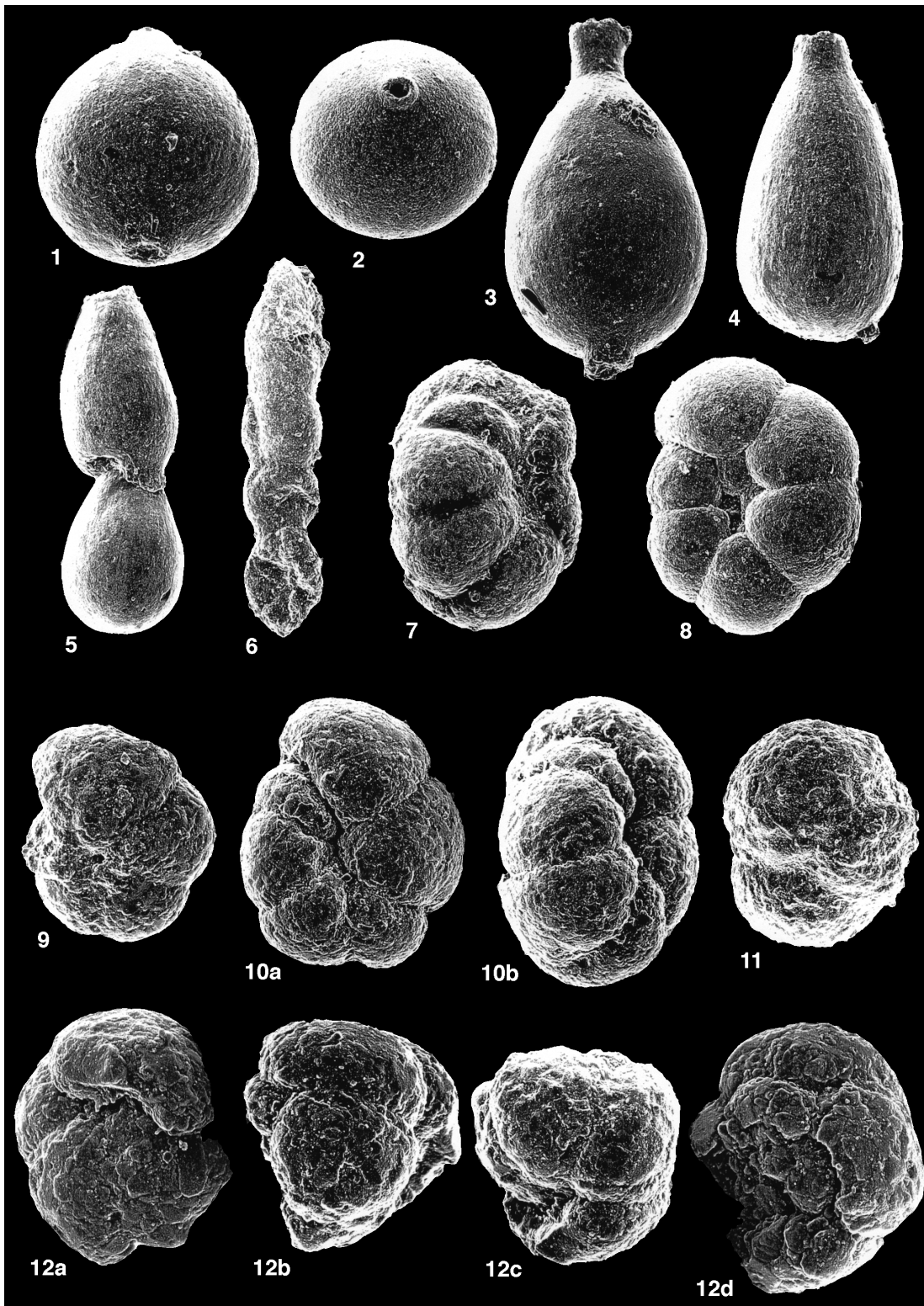


Plate 4. **1.** *Caudammina ovula*, (115 \times), Sample 159-959D-49R-1, 28–31 cm. **2.** *Caudammina ovula*, (115 \times), Sample 159-959D-49R-1, 28–31 cm. **3.** *Caudammina ovuloides*, (75 \times), Sample 159-959D-49R-1, 28–31 cm. **4.** *Caudammina ovuloides*, (75 \times), Sample 159-959D-49R-1, 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.** *Ammosphaeroidina 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.

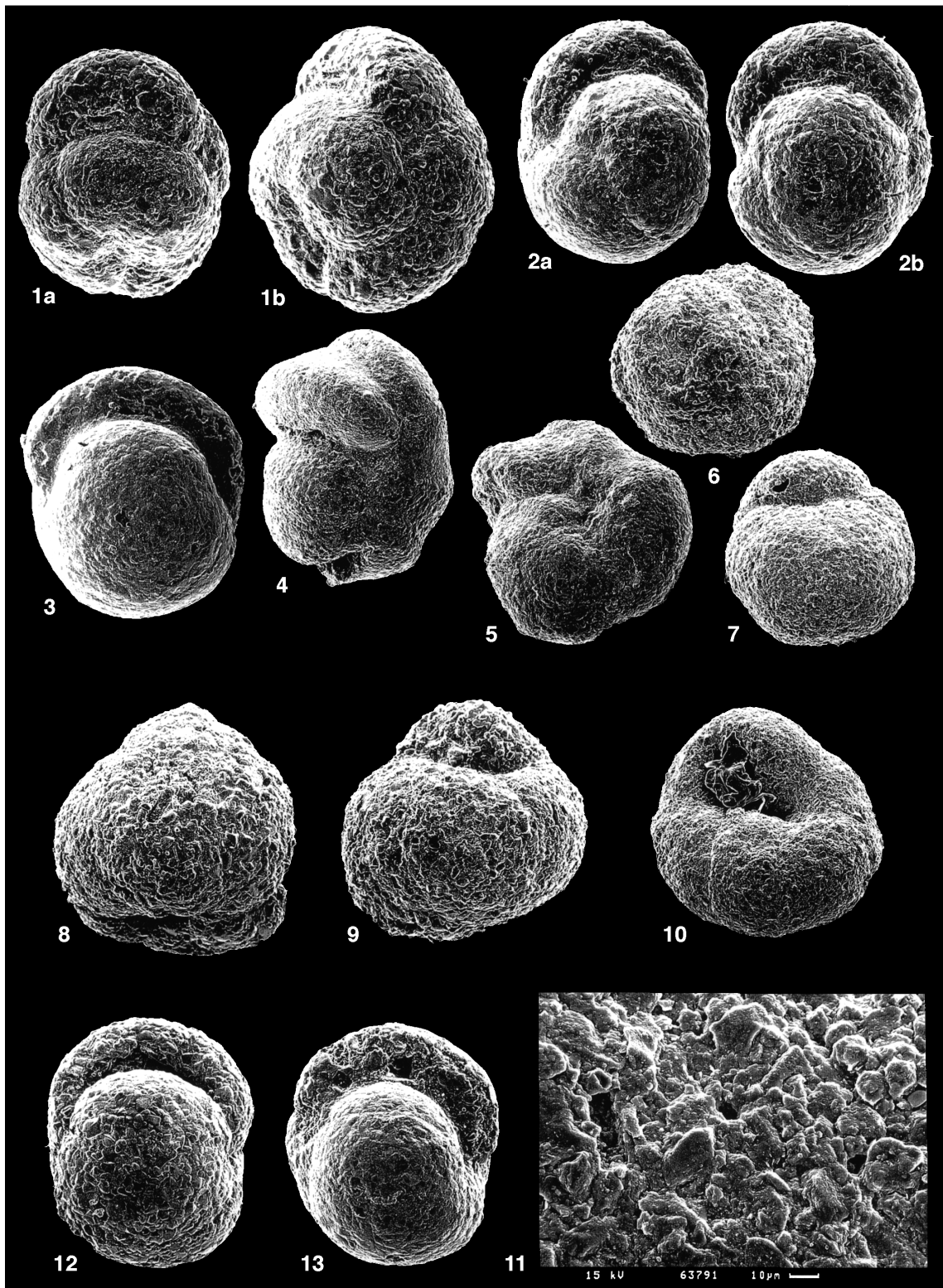


Plate 5. **1a, b.** *Recurvoides* sp., (a: 70×; b: 75×), Sample 159-959D-49R-1, 110–114 cm. **2a, b.** *Recurvoides* sp., (65×), Sample 159-959D-49R-1, 110–114 cm. **3.** *Recurvoides* sp., (65×), Sample 159-959D-49R-1, 28–31 cm. **4.** *Recurvoides* sp., (45×), Sample 159-959D-49R-1, 110–114 cm. **5.** *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.

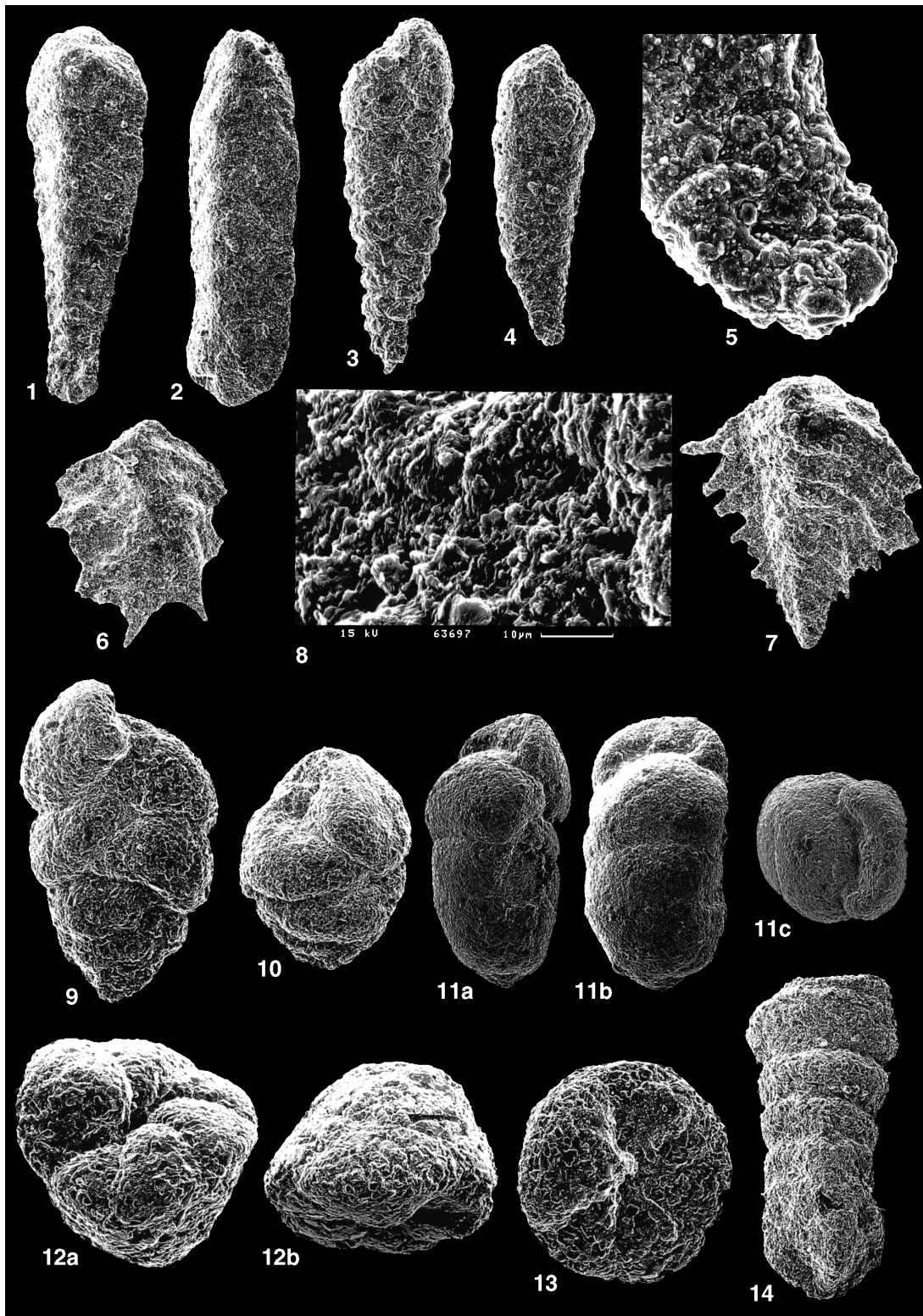


Plate 6. **1.** *Spiroplectammina spectabilis* (microsphere), (110 \times), Sample 159-959D-48R-4, 48–50 cm. **2.** *Spiroplectammina spectabilis* (megalosphere), (95 \times), Sample 159-959D-48R-4, 48–50 cm. **3.** *Spiroplectammina navarroana* (microsphere), (80 \times), Sample 159-959D-49R-1, 28–31 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.

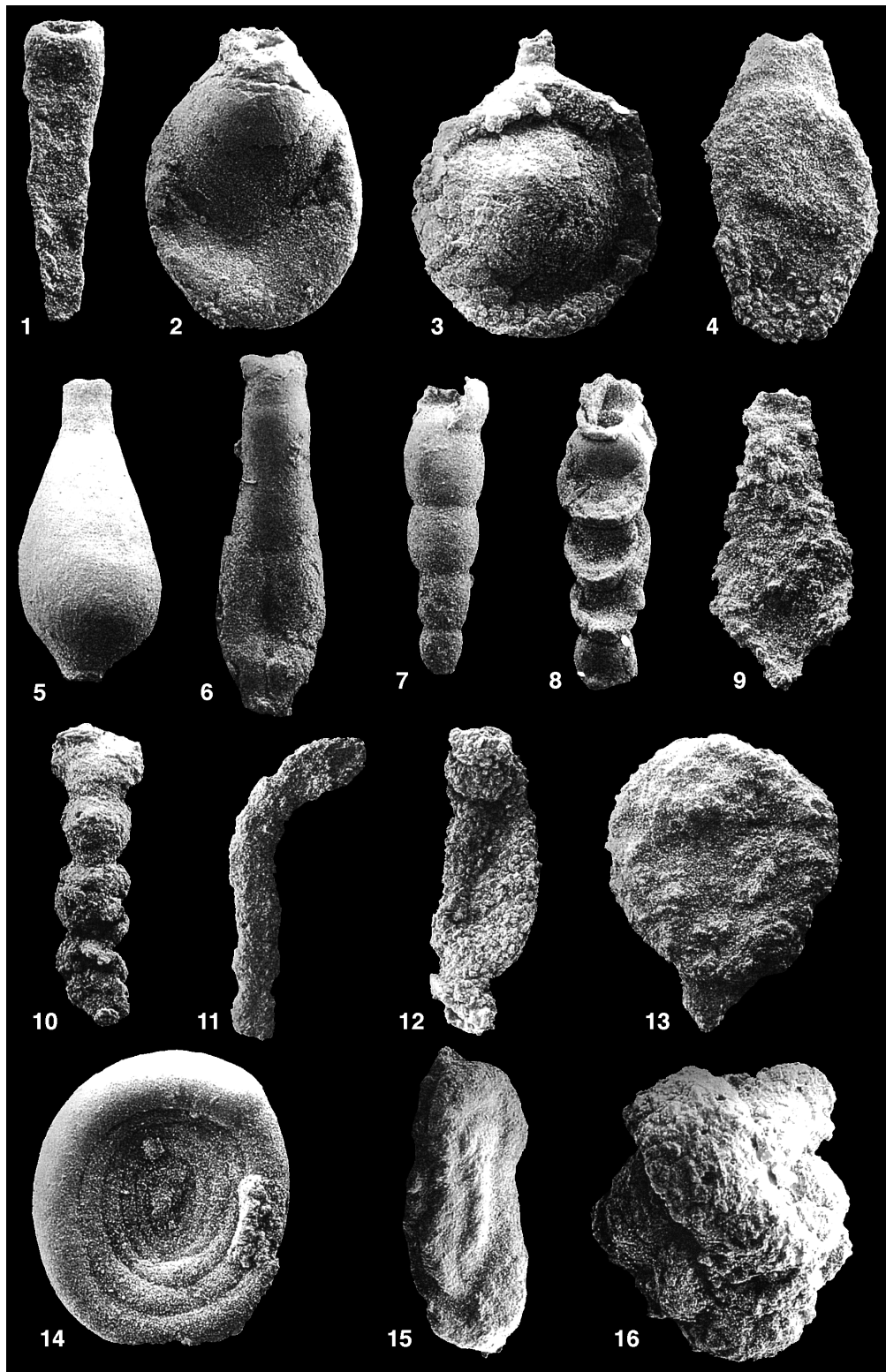


Plate 7. **1.** *Hippocrepina* sp., (115×), Sample 159-959D-44R-6, 30–33 cm. **2.** *Hyperammina dilatata*, (60×), Sample 159-959D-46R-1, 80–85 cm. **3.** *Saccamina grzybowskii*, (165×), Sample 159-959D-48R, CC. **4.** *Aschemocella* sp., (50×), Sample 159-959D-47R-1, 19–22 cm. **5.** *Caudammina ovuloides*,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

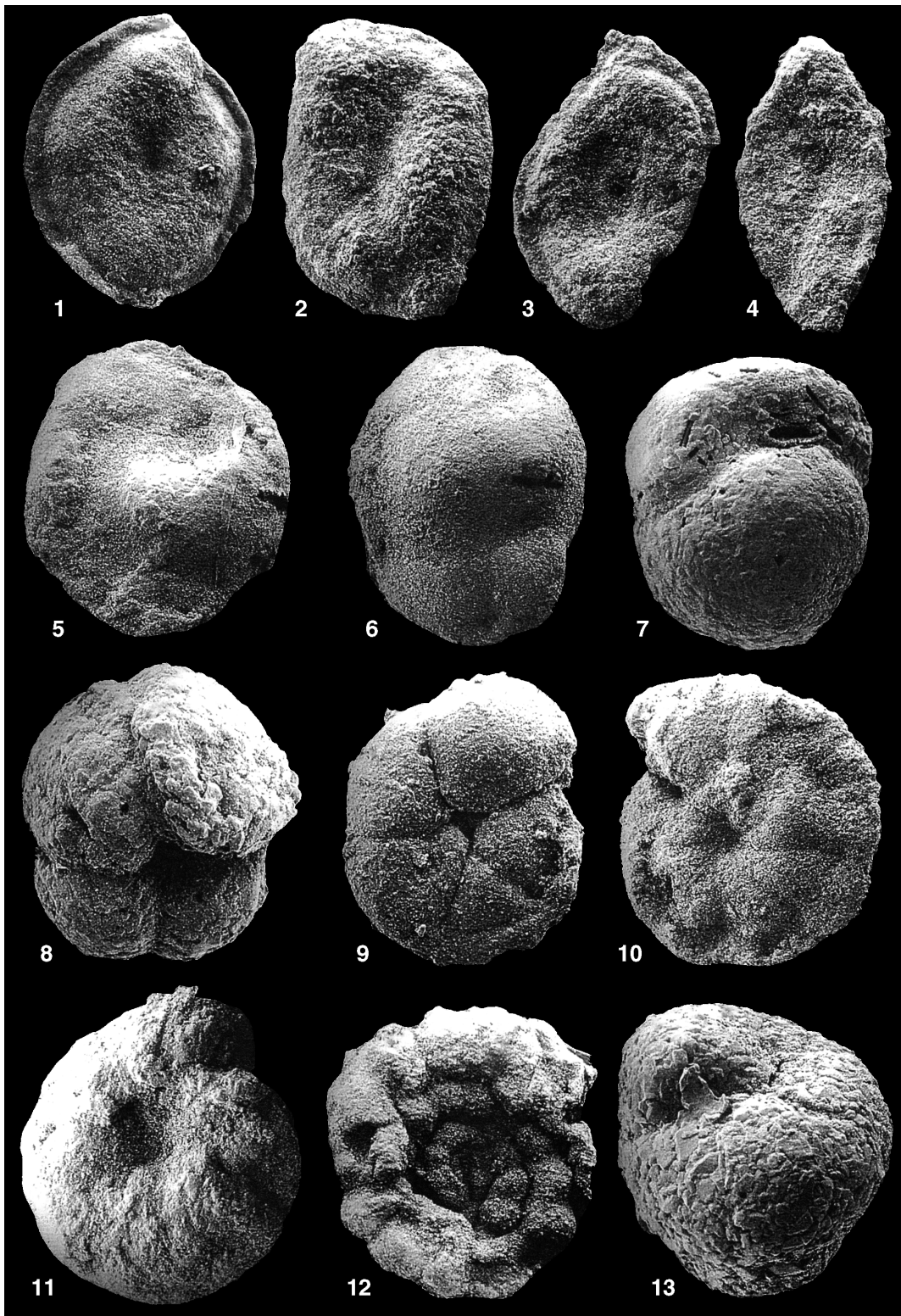


Plate 8. **1.** *Rzehakina epigona lata*, a large specimen showing a well-developed keel, (35 \times), Sample 159-959D-45R-1, 43–48 cm. **2.** *Rzehakina epigona*, (85 \times), Sample 159-959D-44R-6, 30–33 cm. **3.** *Rzehakina fissistomata*, (60 \times), Sample 159-959D-44R-6, 30–33 cm. **4.** *Rzehakina 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.