Raymo, M.E., Jansen, E., Blum, P., and Herbert, T.D. (Eds.), 1999
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 162

3. *BOLBOFORMA* BIOSTRATIGRAPHY FROM THE HATTON-ROCKALL BASIN (NORTH ATLANTIC)[1]

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ABSTRACT

Although they are fossils of uncertain origin, bolboforms are the best calcareous microfossil group for Neogene biostratigraphy in the North Atlantic.

Fifty-two *Bolboforma* species were observed at the Hatton-Rockall Basin in Ocean Drilling Program Holes 982A (26 samples) and 982B (301 samples) and in Deep Sea Drilling Project Hole 116 (71 samples). The sequence investigated spans the interval from lower Miocene to upper Pliocene. Fourteen zones/subzones were identified and correlated with the calcareous nannoplankton zones, the planktonic foraminifer biostratigraphy, and the time (Ma). The last occurrence of the genus *Bolboforma* can be dated to 2.84 Ma.

Different *Bolboforma* specimens of middle Miocene age, observed in upper Miocene and upper middle Miocene sediments at Site 982, document redeposition of sediment from the Rockall Bank into the Hatton-Rockall Basin during the latest middle Miocene and late Miocene.

INTRODUCTION

During Ocean Drilling Program (ODP) Leg 162, a continuous sequence of carbonate-rich sediments was drilled at Site 982 in a bathymetric depression on the Rockall Plateau (Fig. 1), a platform lying at ~1000 m water depth (WD) situated in the North Atlantic roughly between Iceland and Ireland. At Site 982, four holes were cored: in Holes 982A and 982C, the drilling stopped in upper Miocene sediments, Hole 982B extended to the lower Miocene, and Hole 982D only penetrated Holocene sediments. Of these, Holes 982A (57°30.992′N, 15°52.001′W, 1135.30 m WD) and 982B (57°31.002′N, 15°51.993′W, 1134 m WD) were investigated for *Bolboforma* studies. Preliminary biostratigraphic data on *Bolboforma* assemblages identified at Site 982 are included in the Leg 162 *Initial Reports* volume of the *Proceedings of the Ocean Drilling Program* (Jansen, Raymo, Blum, et al., 1996). The main characteristics of *Bolboforma* assemblages and the stratigraphic distribution of the taxa are described here in more detail.

Site 982 is located close to Deep Sea Drilling Project (DSDP) Hole 116 (57°29.76′N, 15°55.46′W, 1115 m WD), rotary drilled in 1970 and only spot cored. Nevertheless, Spiegler and Müller (1992) investigated the calcareous nannoplankton and the *Bolboforma* assemblages of this hole and presented a correlation of *Bolboforma* zonation and nannoplankton stratigraphy in the Neogene at that site. The redrilled continuous-cored sedimentary sequence at Site 982 gives the opportunity to review and complete the biostratigraphic results at Site 116.

Bolboforma are useful index fossils that supplement the standard microfossil zones based on planktonic foraminifers and calcareous nannofossils. They are marine calcareous microfossils of uncertain origin. Nearly 100 different species are known, ranging from the early Eocene to late Pliocene in age. They have not been recorded in Holocene material. *Bolboforma* taxa are characteristic of predominantly temperate to cool regions in both the Northern and Southern Hemispheres. Qvale and Spiegler (1989) and Spiegler and von Daniels (1991) defined *Bolboforma* zones. Spiegler and Müller (1992) correlated Neogene *Bolboforma* zones with nannoplankton stratigraphy.

Bolboforma specimens are *Lagena*-shaped and measure 50–250 µm in diameter. Most of the specimens are 150 µm in size or smaller. However, in contrast to *Lagena* (benthic foraminifer), several *Bolboforma* species are known to encapsulate a smaller chamber within the exterior test (Spiegler, 1987). The wall of the outer test as well as the inner cyst are of monocrystalline structure. The wall texture of the hollow spheroidal to subspheroidal test ranges from smooth to strongly ornamented with different arrangements and combinations of spines, ribs, reticulations, and flanges. The tests display a simple aperture often situated at the end of a distinct neck. The specimens are usually single chambered, but double-chambered forms are also known.

MATERIALS AND METHODS

For *Bolboforma* investigations, core catcher (CC) samples from Holes 982A and 982B and splits of the "paleo" samples taken on board by the scientific party were used. Approximately 15–20 g of dry sediment (10 cm^3) per sample was analyzed. Twenty-six CC samples were studied for Hole 982A, from 8.14 to 245.77 meters below seafloor (mbsf) (Samples 162-982A-1H-CC through 26H-CC). Three hundred one samples were studied for Hole 982B, from 6.64 to ~605 mbsf (Samples 162-982B-2H-1, 114–116 cm, through 65X-CC). A re-examination of 71 samples from DSDP Hole 116 from Cores 1 through 28 (72.03 to 842.04 mbsf) is also given.

The preparation method used to obtain *Bolboforma* specimens was the same as that used for foraminifers. Soft sediments were soaked in water; slightly indurated sediments were soaked in diluted H_2O_2, then washed through a 63-µm mesh sieve. The samples were dried, and the *Bolboforma* specimens were picked under the binocular microscope. Additional isolated small specimens were observed under the electronic microscope to clarify specific characteristics. The abundance shown in the range charts is based on semiquantitative estimates as follows: A = abundant: >50 specimens; C = common: 25–50 specimens; R = rare: 2–24 specimens; T = tracers: one specimen; and B = barren of *Bolboforma*. The preservation of the specimens is good throughout the sequences in all holes, but most specimens are completely filled and heavily coated by calcareous nannoplankton. The list of samples and the ranges of *Bolboforma* species are given in Tables 1 through 5. The zone fossil columns are shaded in gray. The well-defined zonal boundaries are shown as full lines, and the tentative boundaries are given as dashed lines.

[1]Raymo, M.E., Jansen, E., Blum, P., and Herbert, T.D. (Eds.), 1999. *Proc. ODP, Sci. Results*, 162: College Station, TX (Ocean Drilling Program).

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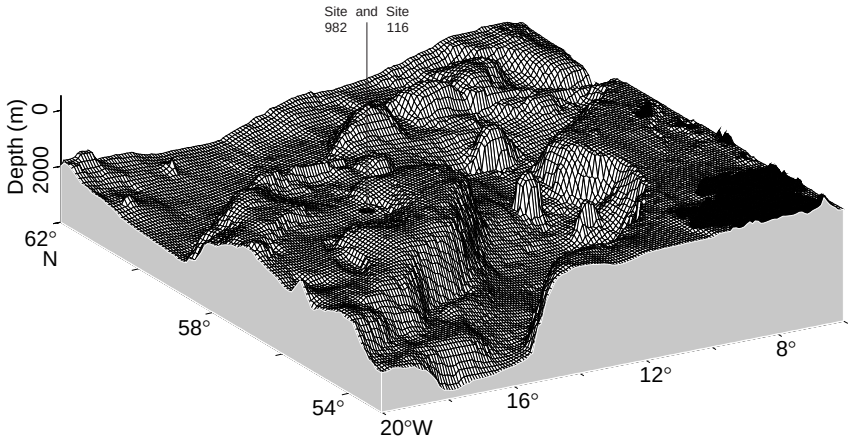

Figure 1. Bathymetric model (Jansen, Raymo, Blum, et al., 1996) showing the location of DSDP Site 116 and ODP Site 982.

The specimens and the samples described and investigated have been deposited in the Natural History Museum of Basel, Switzerland.

BOLBOFORMA BIOSTRATIGRAPHY

The major events used for identifying the *Bolboforma* zonal boundaries and zones are the same as those used in Spiegler and von Daniels (1991) and updated in Spiegler (in press b). They are reported from oldest to youngest.

The co-occurrence of *Bolboforma spiralis* and *B. vulgaris* characterizes the *B. spiralis* Zone in the early Miocene.
The co-occurrence of *B. spinosa* and *B. rotunda* marks the *B. rotunda* Zone in the early Miocene.
The first occurrence (FO) of *B. reticulata* tentatively defines the early Miocene/middle Miocene boundary at 17.5 Ma.
The total range (TR) of *B. reticulata* defines the lower *B. reticulata* Zone.
The TR of *B. platyreticulata* and the co-occurrence of *B. badenensis* define the upper *B. reticulata* Zone.
The TR of *B. danielsi* defines the *B. danielsi* Zone.
The last occurrence (LO) of *B. danielsi* and the LO of *B. badenensis* mark the *B. badenensis* Zone.
The TR of *B. atlantica* lies in the lower *B. badenensis* Zone.
The occurrence of the oblate *B. compressispinosa* indicates the upper part of the *B. compressispinosa* Zone.
The TR of the *B. subfragoris* s.l. ([sensu lato] includes *B. subfragoris*, *B. subfragoris magna*, and *B. fragori*) defines the *B. subfragoris* Zone.
The LO of *B. subfragoris* s.l. defines the middle Miocene/late Miocene boundary at 10.6 Ma.
The LO of *B. capsula* and the FO of *B. metzmacheri* define the top of the *B. capsula* Zone.
The TR of *B. metzmacheri* s.l. (includes *B. metzmacheri metzmacheri*, *B. metzmacheri ornata*, and *B. metzmacheri solida*) defines the *B. metzmacheri* Zone.
The TR of *B. metzmacheri solida* marks the lowermost part of the *B. metzmacheri* Zone.
The TR of *B. polygonalis* lies in the upper part of the *B. metzmacheri* Zone.
The TR of *B. intermedia* defines the *B. intermedia* Zone.
The TR of *B. lockeri* is contained in the upper part of the *B. intermedia* Zone.
The LO of *B. intermedia* and the FO of *B. costairregularis* s.l. (s.l. includes *B. costairregularis costairregularis* and *B. costairregularis variabilis*) lie near the late Miocene/early Pliocene boundary at 5.3 Ma.
The TR of *B. costairregularis variabilis* defines the lower *B. costairregularis* Zone.
The TR of *B. tenuis* lies in the middle part of the lower *B. costairregularis* Zone.
The TR of *B. costairregularis costairregularis* defines the upper *B. costairregularis* Zone.
The TR of *B. stella* lies in the lower part of the upper *B. costairregularis* Zone.
The TR of *B. alata* lies in the middle part of the upper *B. costairregularis* Zone.
The FO of *B. elegans* defines the early/late Pliocene boundary at 3.5 Ma.
The TR of *B. elegans* lies in the upper *B. costairregularis* Zone.
The LO of the genus *Bolboforma* lies in the late Pliocene at 2.84 Ma.

Site 982

The stratigraphic resolution of *Bolboforma* is high in Pliocene and Miocene sediments at the Hatton-Rockall Basin. The results from Hole 982A are in accordance with the observations made for Hole 982B. Therefore, they are not reported here in detail. The main observations concerning *Bolboforma* distribution were made at Hole 982B, where one sample per section and the CC samples were analyzed. For Hole 982B, the uppermost 33 samples of Holocene and Pliocene sediments investigated (Samples 162-982B-2H-1, 114–116 cm, through 7H-5, 18–20 cm, at 6.64 to 59.18 mbsf) are barren of *Bolboforma*. The LO of the genus *Bolboforma* is observed in Sample 162-982B-7H-5, 31 cm, at 59.31 mbsf. The Pliocene sequence down to 63.92 mbsf and again between 140.24 and 170.25 mbsf only contains sporadic *Bolboforma* specimens. In between this interval, *Bolboforma* specimens are constantly present in increasing quantities, and they are common to abundant in the upper and middle Miocene sediments down to Sample 162-982B-56X-CC at 527.90 mbsf. The sediments of the lower middle Miocene (from Core 162-982B-57X at 528 mbsf) and lower Miocene (through Core 60X at 561 mbsf) are generally barren of *Bolboforma.* The samples of Cores 162-982B-61X, 62X, and 65X contain sparse, poorly preserved lower Miocene *Bolboforma* assemblages.

At Hole 982B, the Pliocene assemblages consist of 10 taxa (Table 1). All Pliocene *Bolboforma* specimens display a slightly elongated oviform test, covered by elongated ribs and wings or spines of different length, but they show no reticulations. The rarely observed smooth tests are interpreted as cysts. The *B. costairregularis* Zone, spanning parts of the upper and lower Pliocene, can be subdivided into an upper and lower part by the TR of *B. costairregularis costairregularis* and *B. costairregularis variabilis*. The co-occurrence of *B. costairregularis costairregularis* and *B. elegans* characterizes upper Pliocene sediments. The upper/lower Pliocene boundary lies between Samples 162-982B-9H-1, 84–86 cm (72.84 mbsf), and 9H-3, 84–86 cm (75.84 mbsf). The successive LOs and FOs of *B. hispida*, *B. alata*, and *B. stella* as well as *B. carina*, *B. carinaspinosa*, *B. tenuis*, and *B.*

sphaerica observed downhole contain stratigraphic potential for further subdividing the lower Pliocene sequence. The Pliocene/Miocene boundary lies between the *B. costairregularis* Zone and the *B. intermedia* Zone and is documented between Samples 162-982B-18H-7, 24–26 cm, at 166.74 mbsf and 19H-4, 24–26 cm, at 171.74 mbsf. Three samples in this interval were barren of *Bolboforma*.

The upper Miocene *Bolboforma intermedia*, *B. metzmacheri*, and *B. capsula* Zones are also recognized. The *B. intermedia* Zone is recorded down to 262.09 mbsf. The TR of *B. lockeri* between 192.19 and 201.69 mbsf marks an interval in the upper *B. intermedia* Zone, and *B. praeintermedia* is dominant in the lowermost part of this zone (Table 2). Single specimens of *B. metzmacheri metzmacheri* and *B. metzmacheri ornata* are present in Sample 162-982B-29H-3, 19–21 cm, indicating the transition to the underlying *B. metzmacheri* Zone, which extends to 331 mbsf. *B. polygonalis* marks a distinct horizon (from 287.57 to 292.49 mbsf), and *B. metzmacheri solida*, a thick-walled subspecies, characterizes the base of the *B. metzmacheri* Zone (Table 3). The *B. capsula* Zone is identified from 332.49 to 368.09 mbsf.

Single *Bolboforma* specimens of middle Miocene age, such as *B. badenensis*, *B. platyreticulata*, *B. danielsi*, and *B. subfragoris*, testify to the continuous redeposition of middle Miocene sediments from the Rockall Bank into the Hatton-Rockall Basin during the late Miocene and latest middle Miocene (from 195.19 to 390.29 mbsf; Tables 2 and 3). Sample 162-982B-29X-CC at 264.84 mbsf contains a mixed assemblage of few *B. metzmacheri* and common *B. subfragoris*, which were heavily encrusted by crystal overgrowths of calcite (Pl. 3, fig. 1). This fact indicates extensive redeposition of sediments containing the *B. subfragoris* Zone into sediments spanning the *B. metzmacheri* Zone. Logging data show a turbidite (Jansen, Raymo, Blum, et al., 1996) for the sedimentary sequence of Core 162-982B-30X, where only a single fragment of silica-cemented sand was recovered.

The assemblages in the middle Miocene contain abundant *Bolboforma* and therefore allow a high stratigraphic resolution (Table 4). All the middle Miocene *Bolboforma* zones defined by Spiegler and von Daniels (1991) are recognized in Hole 982B. The *B. subfragoris* Zone is present from 369.59 to 406.59 mbsf; the *B. compressispinosa* Zone, from 408.09 to 414.69 mbsf; and the *B. badenensis* Zone, from 416.19 to 435.39 mbsf. In the interval from 432.39 to 433.89 mbsf, the presence of *B. atlantica* marks the lowermost *B. badenensis* Zone. The TR of *B. danielsi* spans the interval from 436.89 to 438.20 mbsf.

The underlying *B. reticulata* Zone is present from 441.99 to 534.29 mbsf. The TRs of *B. platyreticulata* and *B. reticulata* allow a subdivision of the *B. reticulata* Zone into an upper subzone (down to 488.30 mbsf) and a lower subzone.

The boundary between the middle and lower Miocene at 534.29 mbsf is tentative because of the sparsity of small-sized round *Bolboforma* specimens of *B. rotunda*, *B. spiralis*, *B. spinosa*, and *B. vulgaris*, which characterize the lower Miocene sediments in Hole 982B.

Site 116

DSDP Site 116 is located 6.5 km east of ODP Site 982. At Site 116, two holes (Holes 116 and 116A) were rotary drilled. Hole 116 was only spot cored. In this hole, the first core was taken at 70 mbsf. Until 649 mbsf, cores were cut every 50 m; continuous coring then stopped at 854 mbsf in upper Eocene sediments. Hole 116A was finished at 99 mbsf in lower Pliocene sediments (Laughton, Berggren, et al., 1972).

Hole 116 was reinvestigated for *Bolboforma* studies. A determination of calcareous nannoplankton zones was given by Perch-Nielsen (1972). Spiegler and Müller (1992) further defined the results more precisely and correlated the nannoplankton zones with the *Bolboforma* zones. An updated version of the *Bolboforma* zonation of Hole 116 is given in Table 5.

In the Neogene sequence of Hole 116, 10 *Bolboforma* zones have been identified. The occurrence of *B. costairregularis variabilis* and

Table 1. Distribution of *Bolboforma* in the Pliocene sediments of Hole 982B.

Core, section, interval (cm)	Depth (mbsf)	Number of samples	*Bolboforma* (abundances)	*B. costa. costairregularis*	*B. elegans*	*B. hispida*	*B. alata*	*B. stella*	*B. costa. variabilis*	*B. carina*	*B. carinaspinosa*	*B. tenuis*	*B. sphaerica*	*B.* cyst	*Bolboforma* Zone/Subzone	Series
162-982B-																
7H-5, 31	59.31		R	T												
7H-5, 71, thr.*	59.71	2	B													
7H-6, 18-20	60.68		R	R												
7H-6, 21, thr.*	60.71	3	B													
8H-1, 142-144	63.92		R	R												
8H-2, 142-144	65.42		R	R												
8H-3, 142-144	66.92		C	C												
8H-4,142-144	68.42		R	R	T											
8H-5, 140-142	69.9		C		C											
8H-6, 140-142	71.4		R		R											
9H-1, 84-86	72.84		R	R	T											
9H-3, 84-86	75.84		T	T												
9H-5, 84-86	78.84		C	C		C								T		
10H-1, 30-32	81.8		C	C		T								T		
10H-2, 30-32	83.3		C	R			C							T		
10H-3, 30-32	84.8		A	R		T	A							T		
10H-4, 30-32	86.3		A	A			C									
10H-5, 30-32	87.8		R	R												
10H-6, 30-32	98.3		C	C										R		
10H-7, 30-32	90.8		A	A		T	R	T								
11H-1, 20-22	91.2		C	T				C								
11H-2, 20-22	92.7		C	T		T		C								
11H-3, 20-22	94.2		A	T		T		A								
11H-4, 20-22	95.7		R	R		T										
11H-5, 20-22	97.2		A	A												
11H-6, 20-22	98.7		C	R		C										
11H-7, 20-22	100.2		R	R										R		
12H-1, 20-22	100.7		B												?	
12H-2, 20-22	102.2		C						C					T		
12H-3, 20-22	103.7		C						C					T		
12H-4, 20-22	105.2		R	T		T			C							
12H-5, 20-22	106.7		C						C							
12H-6, 20-22	108.2		C						R					C		
12H-7, 20-22	109.7		T							T						
13H-1, 30-32	110.3		C			R				T						
13H-2, 30-32	111.8		B													
13H-3, 30-32	113.3		R							T	R					
13H-4, 30-32	114.8		A							T	A	R				
13H-5, 30-32	116.3		R									T				
13H-6, 30-32	117.8		C			T			T			C				
13H-7, 30-32	119.3		R									R				
14H-1, 30-31	119.79		R									R				
14H-2, 30-31	121.29		B													
14H-3, 30-31	122.79		C									C				
14H-4, 30-31	124.29		A									A				
14H-5, 30-31	125.79		R									R				
14H-6, 30-31	127.29		R									R				
14H-7, 30-31	128.79		R						R			T				
15H-1, 30-31	129.29		C						C				T			
15H-2, 30-31	130.79		B													
15H-3, 30-31	132.29		A						T				A	R		
15H-4, 30-31	133.79		C						C							
15H-5, 30-31	135.29		R						R							
15H-6, 30-31	136.79		T						T							
15H-7, 30-31	138.29		A						A					R		
16H-1, 24-26	138.74		C						C							
16H-2, 24-26, thr.*	140.24	5	B													
16H-7, 24-26	147.74		T										T			
17H-1, 24-26	148.24		T										T			
17H-2, 24-26	149.74		B													
17H-3, 24-26	151.24		T										T			
17H-4, 24-26, thr.*	152.74	9	B													
18H-7, 24-26, thr.*	166.74		R						T							
19H-3, 24-26	170.24	3	B												?	?

Notes: The subzonal markers are indicated by gray columns. Thr.* = through. In the interval before and after asterisk, author observed the number of barren samples equal to that given in the "Number of Samples" column. A = abundant, C = common, R = rare, T = tracers, B = barren. See text for details.

Table 2. Distribution of *Bolboforma* in the *Bolboforma intermedia* Zone of the upper Miocene of Hole 982B.

Core, section, interval (cm)	Depth (mbsf)	*Bolboforma* (abundances)	*B. laevis*	*B. pisiformis*	*B. intermedia*	*B. pustulaintermedia*	*B. communis*	*B. aculeata*	*B. mutabilis*	*B. lockeri*	*B. groenlandica*	*B. trochospiralis*	*B. praeintermedia*	*B. gracilireticulata*	*B. metzmacheri metzmacheri*	*B. metzmacheri ornata*	Cyst	Two-chambered cyst	*B.* div. sp. (redeposited)	*Bolboforma* Zone	Series
162-982B-																					
19H-4, 24-26	171.74	R	T	T	T	T	T														
19H-5, 24-26	173.24	C	C				T														
19H-6, 24-26	174.74	A				T	A														
19H-7, 24-26	176.24	R			T		R	T													
20H-1, 23-26	176.73	C			T		C		T												
20H-2, 23-26	178.23	A	T				A														
20H-3, 23-26	179.73	A	A		T		A														
20H-4, 23-26	181.23	A	R		A													C			
20H-5, 23-26	182.73	A	R	T	A													R			
20H-6, 23-26	184.23	A	C	T	A		T											R			
20H-7, 23-26	185.79	A	R		A													R			
21H-1, 19-21	186.19	A			A		T		C									C			
21H-2, 19-21	187.69	A	R		A				R									C			
21H-3, 19-21	189.19	A			A				C									R			
21H-4, 19-21	190.69	A	R			A	T		T									C			
21H-5, 19-21	192.19	C	C			C	T			T											
21H-6, 19-21	193.69	C					T	T		C											
21H-7, 19-21	195.19	T				T	T			T									1		
22H-1, 19-21	195.69	C			T					C											
22H-2, 19-21	197.19	R								R									2		
22H-3, 19-21	198.69	R								R											
22H-4, 19-21	200.19	C			T					R									2		
22H-5, 19-21	201.69	R			T					T											
22H-6, 19-21	203.19	R	T		T														3		
23H-1, 19-21	205.19	R					R				R										
23H-2, 19-21	206.69	C	T				C														
23H-3, 19-21	208.19	C					C														
23H-4, 19-21	209.69	C	C				T														
23H-5, 19-21	211.19	C					C														
23H-6, 19-21	212.69	C	T				C														
24H-1, 19-21	214.69	R					R										T				
24H-2, 19-21	216.19	C					C														
24H-3, 19-21	217.76	C	T				C					T									
24H-3, 26-28	217.83	A	R				A														
24H-4, 19-21	219.19	A					A														
24H-5, 19-21	220.69	C					C														
24H-6, 19-21	222.19	A	R				A	T											3, 4		
24H-7,19-21	223.69	C	T	T		R	C				T										
24H-CC	223.96	C	T	T	T	T	C				T										
25H-1, 19-21	224.19	R			T	R	R														
25H-2, 19-21	225.69	R	T		T	R													3		
25H-3, 19-21	227.19	R	T			R		T													
25H-4, 19-21	228.69	C			T	T		T				C									
25H-5, 19-21	230.19	C		T	R	C															
25H-6, 19-21	231.69	R	T			R	T														
25H-7,18-20	233.18	C			C														2		
25H-CC	233.24	A	T		A														3		
26H-1, 19-21	233.69	R			R		T												2		
26H-2, 19-21	235.19	R	T	R	T		T														
26H-3, 19-21	236.69	R					R														
26H-4, 19-21	238.19	T	T																		
26H-5, 19-21	239.69	B																			
26H-6, 19-21	241.19	C	C																2, 3		
26H-7, 19-21	242.69	R	T			T	T									T					
26H-CC	242.76	R	T		T									T					2		
27X-1, 19-21	243.19	R	T																2		
27X-2, 19-21	244.69	R	T		T														2		
27X-3, 19-21	246.19	R	T		R							R							2, 3		
27X-4, 19-21	247.69	C	R		R								T	T							
27X-5,19-21	240.19	A	T	T	T								A								
27X-CC	249.3	A	T										A	R							
28X-1, 19-21	249.49	C	T										C	T							
28X-2, 19-21	250.99	C	R										C						2		
28X-3, 19-21	252.49	C	R		T								C								
28X-4, 19-21	253.99	R	T		R							T		T							
28X-5,19-21	255.49	C	T		T								T	T					2, 4, 5		
28X-CC	256.28	C	R	T	R								C	T					3		
29X-1, 19-21	259.09	R	R										T	T							
29X-2, 19-21	260.59	C	R		R							T	R					C	2, 6		
29X-3, 19-21	262.09	C			T							R	R		T	T				*Bolboforma intermedia*	upper Miocene

Notes: The zonal markers are indicated by gray columns. Various redeposited *Bolboforma* taxa of the middle Miocene are numbered as 1 = *B. capsula*, 2 = *B. badenensis*, 3 = *B. furcata*, 4 = *B. moravica*, 5 = *B. platyreticulata*, 6 = *B. danielsi*. Abbreviations as in Table 1.

Table 3. Distribution of *Bolboforma* in the *Bolboforma metzmacheri* Zone and in the *B. capsula* Zone of the upper Miocene of Hole 982B.

Core, section, interval (cm)	Depth (mbsf)	*Bolboforma* (abundances)	*B. laevis*	*B. metzmacheri metzmacheri*	*B. metzmacheri ornata*	*B. pentaspinosa*	*B. polygonalis*	*B. deformis*	*B. metzmacheri solida*	*B. contorta sculpturata*	*B. contorta contorta*	*B. gracilireticulata*	*B. furcata*	*B. capsula*	*B. robusta*	*B. superba*	*B. aculeata*	*B. verrucosa*	Cyst	Two-chambered cyst	*Bolbo.* div. sp. (redeposited)	*Bolboforma* Zone	Series
162-982B-																							
29X-4, 19-21	263.59	R	R	T	T																		
29X-CC	264.84	C	R	T	R																7		
31X-1, 19-21	278.39	C	C	C	R																		
31X-2, 19-21	279.89	C	C	C	C																		
31X-3, 19-21	281.39	C	C	C	R								T								8		
31X-4, 19-21	282.89	C	C	R	T		cf						T								2		
31X-5, 19-21	284.39	C	C	R	R	T													R	R			
31X-6, 19-21	285.89	C	C	R	R								T										
31X-7, 19-21	287.39	A	C	A	T																		
31X-CC	287.57	A	A	R	R	T	R																
32X-1, 19-21	287.99	A	R	C	R		A																
32X-2, 19-21	289.49	A	A		T	T													T		1		
32X-3, 19-21	290.99	C	C	T	T		T														2		
32X-4, 19-21	292.49	C	C	R	R		T														1		
33X-1, 19-21	297.59	C	C	C	R	T													R				
33X-2, 19-21	299.09	C	C	R	R	T		T													1		
33X-3, 19-21	300.59	C	C	C	C	T					T		R								2		
33X-4, 19-21	302.09	A	A	T	T																		
33X-5, 19-21	303.59	C	C	T		T							T										
33X-6, 19-21	305.09	C	C	T	T	T						T									2		
34X-1, 19-21	307.29	R	R	T	T	T							R								2		
34X-2, 19-21	308.79	C	C	T	T	T				R	T	T									1, 5		
34X-3, 19-21	310.29	C	C	R	T	T					T	T									2, 6		
34X-4, 19-21	311.79	C	C	R	T	R						R	R						T		2		
34X-5, 19-21	313.29	R	R	T		R															1, 6, 8		
34X-6, 19-21	314.79	C	C	R	R	R						T	T								2, 8		
35X-1, 19-21	316.89	A	R	A																	2, 8		
35X-2, 19-21	318.39	C	T	C	R														R		8		
35X-3, 19-21	319.89	A	C	A	C	R																	
35X-4, 19-21	321.39	C	C	T	T																		
36X-1, 19-21	326.49	A	A	T					T													*B. metzmacheri*	upper Miocene
36X-2, 19-21	327.99	A	A			T			T										R				
36X-3, 19-21	329.49	A	C			T			A										R		9		
36X-4, 19-21	330.99	A	T	T		T			A										R				
36X-5, 19-21	332.49	A				T			cf					A							2		
36X-CC	333.99	A	T			T							T	A									
37X-1, 19-21	336.19	A				T						T	R	A							2		
37X-2, 19-21	337.69	C												C							2		
37X-3, 19-21	339.19	A	R											A							2, 5, 8		
37X-4, 19-21	340.69	A	C											A							2, 9		
37X-5, 19-21	342.19	A				T								A							2		
37X-6, 19-21	343.69	A				R								A									
38X-1, 19-21	345.79	C				R								C							2		
38X-2, 19-21	347.29	A	C											A							8, 9, 10		
38X-3, 19-21	348.79	C												R	C								
38X-4, 19-21	350.29	A												R	A								
38X-5, 19-21	351.79	C	T											C	A						2, 9		
38X-6, 19-21	353.29	A										T			A						2		
39X-1, 19-21	355.39	C	R							R				R	C						2, 8		
39X-2, 19-21	356.89	C	C							T				C	C						2, 5, 8		
39X-3, 19-21	358.39	A	A							T				C							2, 8		
39X-4, 19-21	359.89	A	A														R				8, 9		
39X-5, 19-21	361.39	C	T							R	R					R	C		R	T	8, 9		
40X-1, 19-21	365.09	A															A						
40X-2, 19-21	366.59	A	R													R	T	A	R				
40X-3, 19-21	368.09	A	C		T									T		R	C	R					

Notes: The zonal markers are indicated by gray columns. Various redeposited *Bolboforma* taxa of the middle Miocene are numbered as 1 = *B. capsula*, 2 = *B. badenensis*, 5 = *B. platyreticulata*, 6 = *B. danielsi*, 7 = *B. subfragoris* (heavily recrystallized by carbonate), 8 = *B. fragori* and *B. subfragoris*, 9 = *B. compressispinosa*, 10 = *B. subfragoris magna*. Abbreviations as in Table 1.

B. tenuis in the samples of Core 12-116-2, between 109.19 and 118.10 mbsf, constrains the lower *B. costairregularis* Subzone (early Pliocene). Since *B. platyreticulata* and *B. reticulata* are here considered as separate species and *B. platyreticulata* is identified in Sample 12-116-9-2, 74–80 cm, it is possible to recognize the upper *B. reticulata* Zone in Core 12-116-9 (461.17 to 462.68 mbsf) and the lower *B. reticulata* Zone in Core 10 (511.99 to 517.70 mbsf). The early Miocene Zones *B. rotunda*, *B. spinosa*, and *B. spiralis* are well documented, whereas *Bolboforma* are sporadic in the sediments of the Oligocene and Eocene.

DISCUSSION

The biostratigraphic results obtained for the continuously cored sequence at ODP Site 982 agree well with the spot-cored intervals at DSDP Site 116. The identification of the *Bolboforma* zones permits the correlation as shown in Figure 2, where Holes 982A, 982B, and 116 are equated to mbsf. The short intervals containing the different *Bolboforma* zones at Site 116 occur at depths similar to those at Site 982, with the exception of the determination of the *B. danielsi* Zone in Sample 12-116-9-1, 51–55 cm, at 459.53 mbsf. A 23-m downhole

Table 4. Distribution of *Bolboforma* in the middle and lower Miocene sediment sequences of Hole 982B.

Core, section, interval (cm)	Depth (mbsf)	*Bolboforma* (abundances)	*B. subfragoris magna*	*B. subfragoris*	*B. fragori*	*B. clodiusi*	*B. furcata*	*B. superba*	*B. verrucosa*	*B. capsula*	*B. robusta*	*B. laevis*	*B. compressispinosa*	*B. oblongireticulata*	*B. badenensis*	*B. atlantica*	*B. danielsi*	*B. moravica*	*B. platyreticulata*	*B. fava*	*B. cf. laevis* (round)	*B. gracilireticulata*	*B. reticulata*	*B. rotunda*	*B. spinosa*	*B. spiralis*	*B. vulgaris*	Cyst	Two-chambered cyst	*B.* div. sp.(redeposited)	*Bolboforma* Zone	Series
162-982B-																																
40X-4, 19-21	369.59	A	A	A		R		R		T																		A		2		
40X-5, 19-21	371.09	A	R	C				R			A																			2		
41X-1, 19-21	374.69	A			R		A		R		A	R																R	R	2, 5		
41X-2, 19-21	376.19	A		R		C	A	R	T			A																		2, 6		
41X-3, 19-21	377.69	C		T			R		T			C																				
41X-4, 19-21	379.19	A		T	T	R			R			A																C				
41X-5, 19-21	380.69	A		A	C		T					C																R				
41X-CC	381.19	A	R	A		T																						R				
42X-1, 19-21	384.29	A		R	A		R		R			R																		2		
42X-2, 19-21	385.79	A	R	A																										2		
42X-3, 19-21	387.29	A		R				A	R			A																		2		
42X-4, 19-21	388.79	A		R			C	C	T			A																C		2		
42X-5, 19-21	390.29	R	R	R	R		R	R		R																				2		
42X-CC	390.31	A	A		R	T		C		T																		C				
43X-1, 19-21	393.99	A	A	T	C			R																								
43X-2, 19-21	395.48	A			R	T		A	R																							
43X-3, 19-21	396.99	C	C	C	C	R			R																							
43X-4, 19-21	398.49	A	R	C			A					R																				
44X-1, 19-21	403.59	A	T						A			R																C				
44X-2, 19-21	405.09	A					A					T																				
44X-3, 19-21	406.59	A		cf		R			A			R																R			*B. subfragoris*	
44X-4, 19-21	408.09	A				C				T	A		T																			
44X-5, 19-21	409.59	A				R		A				A																				
44X-CC	409.8	A				A			A																				C			
45X-1, 19-21	413.19	A	T			A						A																	C			
45X-2, 19-21	414.69	A										R	A																C			*B. compr.*	
45X-3, 19-21	416.19	A											R	A	A			T										T	R			
45X-4, 19-21	417.69	A												A	A													R	R			
45X-5, 19-21	419.19	A									A				A														C			
45X-6, 19-21	420.69	A													A													R	C			
45X-7, 19-21	422.19	A								T					A													T	R			
45X-CC	422.4	A								T	T				A													R		6		
46X-1, 19-21	422.79	A								T					A																	
46X-2, 19-21	424.29	A								T					A																	
46X-3, 19-21	425.79	A								C	R				A													C	R			
46X-4, 19-21	427.29	A													A													R				
46X-5, 19-21	428.79	A													A													R	R			
46X-CC	429.66	A								R	R				A													R				
47X-1, 19-21	432.39	A									A				A	T	T											R				
47X-2, 19-21	433.89	A									A				A	C												R	T			
47X-3, 19-21	435.39	A									A				A													R	R			
47X-4, 19-21	436.89	A							C		T				A		A											C	R			
47X-CC	438.2	A													A		A		T										R		*	
48X-1, 19-21	441.99	A													A			T	T										T			
48X-2, 19-21	443.49	A													A			C														
48X-3, 19-21	444.99	A										R			C			A														
48X-4, 19-21	446.49	A										R			C				R	R												
48X-5, 19-21	447.99	A										T			C					C												
48X-6, 19-21	449.49	A										R			A				A													
48X-CC	449.75	A										C			A																	
49X-1, 19-21	451.59	A													A																	
49X-2, 19-21	453.09	A													A				R													
49X-3, 19-21	454.59	A													A				R									A	R			
49X-4, 19-21	456.09	A													A				A													
49X-5, 19-21	457.59	A													A				A									R				
49X-CC	458.1	A													A				A													
50X-1, 19-21	461.19	A													A				C									R				
50X-2, 19-21	462.69	A													C				A									R				
50X-3, 19-21	464.19	A													C				C									R				
50X-4, 19-21	465.69	A													C				A													
50X-5, 19-21	467.19	A													T				A													
50X-CC	467.41	A													R				A									T				
51X-1, 19-21	470.79	A													A				A													
51X-2, 19-21	472.29	A													C				A													
51X-3, 19-21	473.79	A													C				A													
51X-4, 19-21	475.29	A													A				A													
51X-5, 19-21	476.79	A													R				A													
51X-6, 19-21	478.29	C													R				C									R				
51X-CC	478.65	A													T				A									R				
52X-1, 19-21	480.39	A																	A													
52X-2, 19-21	481.89	A																	A													
52X-3, 19-21	483.39	A																	A													
52X-4, 19-21	484.89	A																	A													
52X-5, 19-21	486.39	R																	A													
52X-6, 19-21	487.89	C																	C				R		T							
52X-CC	488.3	R																	T		T											
																															upper *B. reticulata*	middle Miocene

Table 4 (continued).

Core, section, interval (cm)	Depth (mbsf)	*Bolboforma* (abundances)	*B. subfragoris magna*	*B. subfragoris*	*B. fragori*	*B. clodiusi*	*B. furcata*	*B. superba*	*B. verrucosa*	*B. capsula*	*B. robusta*	*B. laevis*	*B. compressispinosa*	*B. oblongireticulata*	*B. badenensis*	*B. atlantica*	*B. danielsi*	*B. moravica*	*B. platyreticulata*	*B. fava*	*B.* cf. *laevis* (round)	*B. gracilireticulata*	*B. reticulata*	*B. rotunda*	*B. spinosa*	*B. spiralis*	*B. vulgaris*	Cyst	Two-chambered cyst	*B.* div. sp.(redeposited)	*Bolboforma* Zone	Series
53X-1, 19-21	489.89	R																				T	R									
53X-2, 19-21	491.39	R																					T									
53X-3, 19-21	492.89	R																			T		R									
53X-4, 19-21	494.39	R																				T										
53X-5, 19-21	495.89	R																					T									
53X-6, 19-21	497.39	R																					R									
53X-CC	498.27	C																				T	C					R				
54X-1, 40-42	499.7	R																			T		T									
54X-2, 21-23	501.01	R																					T					T				
54X-3, 21-23	502.51	R																				T	R					T				
54X-4, 19-21	503.99	R																					R					T	T			
54X-5, 19-21	505.51	B																														
54X-CC	505.86	A																					C					C	C			
55X-1, 19-21	509.09	A																		T	T		A								lower *B. reticulata*	middle Miocene
55X-2, 19-21	510.59	R																				T	R									
55X-3, 19-21	512.09	C																			R	T	C									
55X-4, 19-21	513.59	A																			R		A									
55X-5, 19-21	515.09	R																				R	R									
55X-6, 19-21	516.59	A																				T	A									
55X-7, 19-21	518.09	A																			A		A									
55X-CC	518.32	A																			A		A									
56X-1, 19-21	518.69	A																			C	R	A									
56X-2, 19-21	520.19	A																				A	C									
56X-3, 19-21	521.69	A																				C	A					R				
56X-4, 19-21	523.19	A																					A									
56X-5, 19-21	524.69	A																					A									
56X-6, 19-21	526.19	C																					C					R				
56X-7, 19-21	527.69	C																					C									
56X-CC	527.9	R																					T	T	cf			R				
57X-1, 19-21	528.29	B																														
57X-2, 19-21	529.79	B																														
57X-3, 19-21	531.29	B																														
57X-4, 19-21	532.79	B																														
57X-5, 19-21	534.29	R																					T									
57X-CC	535.38	B																														
58X-1, 19-21	537.89	B																														
58X-2, 19-21	539.39	R																							R		T	T			?	
58X-3, 25-28	540.95	B																														
58X-CC	541.28	B																														
59X-CC	547.4	B																														
60X-1, 19-21	557.19	B																														
60X-2, 19-21	558.69	B																														
60X-3, 19-21	560.19	B																														
60X-CC	560.84	B																														
61X-1, 19-21	566.89	R																						T	T							lower Miocene
61X-2, 19-21	568.39	C																							C		R				*B. rotunda* *B. spinosa*	
61X-CC	569.93	B																														
62X-1, 19-21	576.59	C																						R			A					
62X-CC	576.87	A																							A	T	A					
65X-CC	605.3	R																							R		R					

Notes: The zonal markers are indicated by gray columns. * = *B. danielsi* Zone. Redeposited taxa occur in the *B. subfragoris* Zone and are numbered as 2 = *B. badenensis*, 5 = *B. platyreticulata*, 6 = *B. danielsi*. Abbreviations as in Table 1.

contamination may be the reason for this discrepancy. Based on the results obtained for Hole 982B, at Site 116 the *B. costairregularis* Zone as well as the *B. reticulata* Zone will subdivide into an upper and a lower part.

The distribution of 52 *Bolboforma* species in Neogene sediments at the Hatton-Rockall Basin is outlined in Tables 1–5. The various assemblages reflect 14 *Bolboforma* zones/subzones spanning the early Miocene to late Pliocene interval. Figure 3 summarizes the stratigraphic range of 30 well-defined *Bolboforma* index species, which are common and easy to recognize. Also shown are the determined *Bolboforma* zones and their correlation with nannoplankton and planktonic foraminifer biostratigraphy at the Hatton-Rockall Basin. These biostratigraphies are correlated with the standard nannoplankton zonations as well as with the time scale of Berggren et al. (1995).

The Matuyama/Gauss paleomagnetic event (with an age of 2.581 Ma, according to Berggren et al., 1995) is determined at the Hatton-Rockall Basin in Hole 982B at 52.55 mbsf (Jansen, Raymo, Blum, et al., 1996). The LO of the genus *Bolboforma* lies at 59.31 mbsf (Sample 162-982B-7H-5, 31 cm). This is located 6.76 m below the Matuyama/Gauss event. In accordance with the age/depth curve (Jansen, Raymo, Blum, et al., 1996), the LO of *Bolboforma* can be dated at 2.84 Ma, ~0.6 Ma younger than previously known (Spiegler and von Daniels, 1991).

The following events define the stage/substage boundaries. The late/early Pliocene boundary at 3.5 Ma is defined by the FO of *Bolboforma elegans*. The Pliocene/Miocene boundary at 5.3 Ma lies near the FO of *B. costairregularis costairregularis* at 5.61 Ma and the LO of *B. intermedia* at 5.68 Ma. The late/middle Miocene boundary is defined by the NN9/NN8 (CN7/CN8) nannoplankton zonation and the *B. capsula*/*B. subfragoris* zonal boundaries according to Spiegler and Müller (1992), and it is dated according Berggren et al. (1995) at 10.6 Ma. The middle/early Miocene boundary lies tentatively at the base of the *B. reticulata* Zone at 17.5 Ma.

The succession of the *Bolboforma* zones in the Neogene sediments at the Hatton-Rockall Basin agrees with that described by Spiegler and von Daniels (1991) and Spiegler (in press b). Moreover,

Table 5. Distribution of *Bolboforma* in DSDP Hole 116 samples.

Core, section, interval (cm)	Depth (mbsf)	*Bolboforma* (abundances)	*B. costa. variabilis*	*B. tenuis*	*B. intermedia*	*B. pustulaintermedia*	*B. laevis*	*B. aculeata*	*B. metzm. metzmacheri*	*B. metzmacheri ornata*	*B. clodiusi*	*B. capsula*	*B. robusta*	*B. badenensis*	*B. pentaspinosa*	*B. oblongireticulata*	*B. robustabadenensis*	*B. danielsi*	*B. voeringensis*	*B. platyreticulata*	*B. gracilireticulata*	*B. fava*	*B. reticulata*	*B. rotunda*	*B. spinosa*	*B. spiralis*	*B. vulgaris*	*B.* cf. *praespinosa*	*B.* cyst	*Bolboforma* Zone/Subzone	*Nannoplankton* Zone	Series
12-116-																																
1-2, 51-56	72.03	B																														
1-4, 51-55	75.03	B																													NN18/NN16	
1-6, 51-55	78.03	B																														
2-1, 12-26	109.19	R	R																													
2-2, 24-38	110.81	R	R																											lower *B. costa-irregularis*	NN15?	lower Pliocene
2, CC	118.1	R	R	R																								R				
3-2, 51-55	161.03	B																														
3-4, 43-47	163.95	B																													NN12	
3-6, 50-54	167.02	B																														
4-2, 76-80	211	C			C	R																										
4-4, 90-104	214.47	R					R																									
4-6, 100-104	217.52	B																														
5-1, 40-54	259.47	R			R		R																						*B. intermedia*	NN11	upper Miocene
5-2, 105-109	262.54	C			C	T		R																				R				
5-4, 76-90	264.33	R			R	R																										
5-5, 103-107	266.05	C			C		T																									
6-1, 46-50	309.48	C					C		R	R																						
6-3, 66-89	312.79	C					R		R	C	T																		*B. metzmacheri*		
6-4, 51-55	314.03	A					C		C	A	T																			NN9	
7-1, 85-99	359.92	R										R																				
7-3, 40-54	362.47	C						T				C								T									*B. capsula*		
7-6, 47-51	366.99	A									T	A	R																			
8-2, 80-94	411.37	A					R							A															*B. badenensis*		
8-3, 84-88	412.86	A												R	A																	
9-1, 51-55	459.53	A												A		R	T	T										C	*B. danielsi*	NN7/NN6	middle Miocene
9-2, 70-74	461.17	A												A					T	T								A	upper *B. reticulata*		
9-3, 46-50	462.68	A												A														R				
10-2, 148-150	511.99	R												R																		
10-4, 42-46	513.94	C												R							T	R	R						lower *B. reticulata*	NN5	
10-6, 113-117	517.7	R																					R									
11-2, 63-67	561.15	R																						R					*B. rotunda*	NN4	lower Miocene
11-6, 53-57	567.07	R																						R								
12-1, 100-115	600.07	C																							C							
12-3, 58-60	602.58	A																							A				*B. spinosa*	NN3		
12-6, 103-107	607.56	A																							A							
13, CC	649.1	B																														
15-1, 43-47	662.45	A																							T	R	A					
15-3, 56-60	665.58	A																								R	A					
15-5, 45-49	668.47	R																									R					
16-2, 40-54	672.97	R																									R					
16-4, 43-47	675.96	C																								R	C		*B. spiralis*	NN2/NN1		
17-4, 92-96	686.44	C																								R	C					
17-6, 91-106	688.48	C																								C	C					
18-4, 54-58	694.08	R																								R						
19-2, 33-37	699.85	B																														
19-4, 26-29	700.3	B																														
20-1, 46-50	701.48	T																									T					
20-5, 88-102	707.95	R																													NP25/NP23	upper Oligocene
21-3, 45-49	713.47	B																														
21-4, 145-149	715.97	B																														
22-6, 196-110	727.58	T																										T				
23-2, 131-136	752.33	B																														
23-6, 56-60	758.06	R																									T	R				
23-6, 134-138	758.86	B																													NP22/NP21	lower Oligocene
24-1, 60-54	759.52	R																										R				
25-5, 95-99	812.97	B																														
26-2, 50-52	827.01	C																									C					
26-4, 50-52	830.01	B																														
27-1, 122-126	832.23	B																													NP20/NP18	upper Eocene
27-3, 52-55	834.53	R																									R					
28-2, 52-56	842.04	B																														

Notes: The zonal markers are indicated by gray columns. Abbreviations as in Table 1.

the LOs and FOs of different and additional *Bolboforma* species give further zonal subdividing potential.

Excellent regionally widespread marker species with a short TR are *B. danielsi*, *B. atlantica*, and *B. polygonalis*. The TR of *B. danielsi*, identified in Hole 982B between 436.89 and 438.20 mbsf, characterizes a horizon dated to ~12 Ma at several sites in the North Atlantic (Spiegler and von Daniels, 1991; Spiegler and Müller, 1992; Spezzaferri and Spiegler, 1998) and also in the shelf area of northern Europe (Spiegler and von Daniels, 1991; Spiegler and Rusbült, 1994; Spiegler and Gürs, 1996; Gürs and Spiegler, in press). The TR of *B. atlantica*, observed in Hole 982B between 432.39 and 433.89 mbsf, lies above the TR of *B. danielsi* at the Rockall Basin as well as at the Reykjanes Ridge (Spiegler and Müller, 1992) and in the South Atlantic at the Meteor Rise (Spiegler and von Daniels, 1991). The TR of *B. polygonalis* in Hole 982B from 287.57 to 292.49 mbsf lies in the upper *B. metzmacheri* Zone. This short interval is also documented in

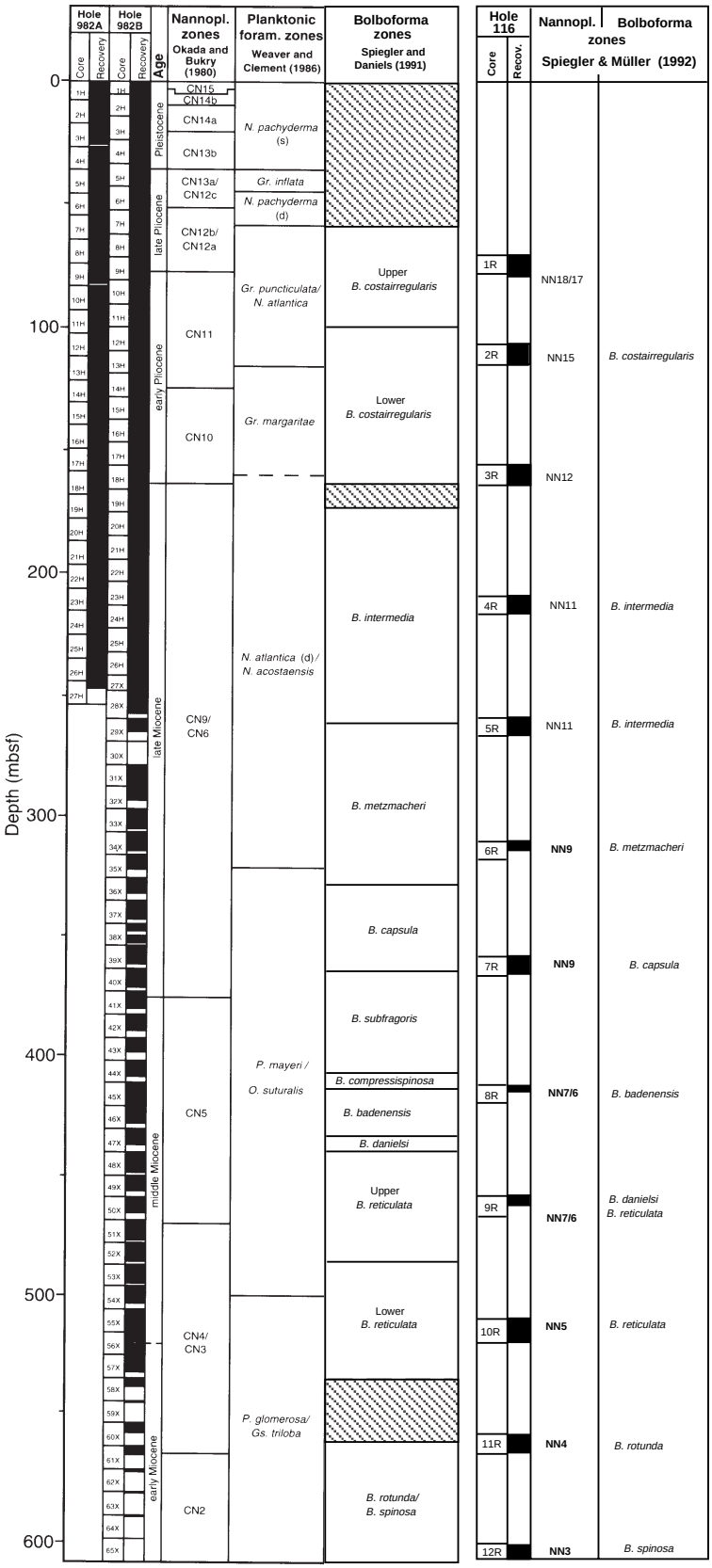

Figure 2. Correlation of *Bolboforma* zones in ODP Holes 982A and 982B and in DSDP Hole 116. Calcareous nannoplankton and planktonic foraminifer biostratigraphy at Site 982 by Jansen, Raymo, Blum, et al. (1996). Hatched intervals = absence of *Bolboforma*.

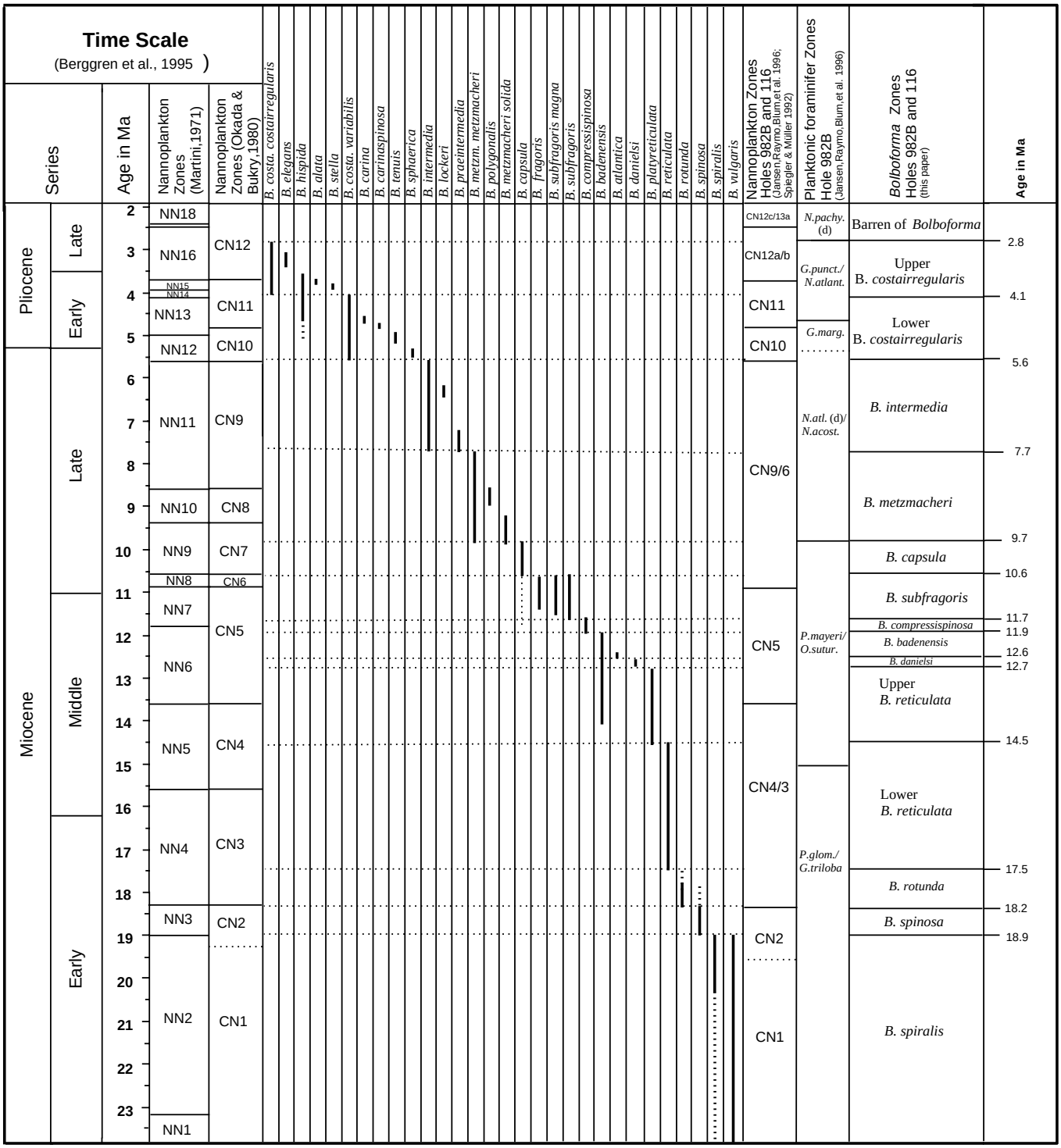

Figure 3. *Bolboforma* zonation at the Hatton-Rockall Basin.

the *B. metzmacheri* Zone in the Nieder Ochtenhausen well, drilled in northwest Germany (Spiegler, in press a).

SUMMARY

Fourteen *Bolboforma* zones/subzones were identified at the Hatton-Rockall Basin spanning the interval from early Miocene to late Pliocene. Age determinations for the different *Bolboforma* zones are given. *Bolboforma* assemblages show good potential for Neogene biostratigraphy, whereas only six zones of planktonic foraminifers and nine zones of calcareous nannoplankton were determined during the above-mentioned time span at the Hatton-Rockall Basin. The genus *Bolboforma*, although containing fossils of uncertain origin, is therefore the best calcareous microfossil group for Neogene biostratigraphy in the North Atlantic.

Continuous redeposition of middle Miocene *Bolboforma* species from the Rockall Bank into the Hatton-Rockall Basin is documented

during the latest middle Miocene and late Miocene sediment. Extensive redeposition is observed on the top of a turbidite in the uppermost upper Miocene sequence.

TAXONOMIC NOTES

Faunal Reference List

Type references are given for each species recognized.

B. alata Spiegler, in press b, pl. 1, figs. 9, 10.
B. aculeata von Daniels and Spiegler, 1974, p. 65, pl. 8, figs. 1–3.
B. atlantica Spiegler, see Spiegler and von Daniels, 1991, p. 133, pl. 10, figs. 1–5.
B. badenensis Szczechura, 1982, p. 33, pl. 6, figs. 1–4.
B. capsula Spiegler, 1987, p. 162, pl. 2, figs. 4–6; pl. 3, figs. 1–4.
B. carina Spiegler, in press b, pl. 2, figs. 17, 18.
B. carinaspinosa Spiegler, in press b, pl. 2, figs. 19–22.
B. clodiusi von Daniels and Spiegler, 1974, p. 63, pl. 7, figs. 4–6.
B. communis Spiegler, in press b, pl. 4, figs. 11, 12.
B. compressispinosa Spiegler, see Spiegler and von Daniels, 1991, p. 134, pl. 2, figs. 5, 6.
B. contorta Spiegler, see Spiegler and Gürs, 1996, p. 160, pl. 6, figs. 3–6.
B. contorta sculpturata Spiegler, in press b, pl. 5, figs. 12, 13.
B. costairregularis costairregularis (Toering and Voorthuysen, 1973), p. 50, pl. 2, figs. 6–9.
B. costairregularis variabilis Spiegler, pl. 2, figs. 14, 15.
B. danielsi Murray, 1984, p. 538, pl. 1, figs. 13–15.
B. deformis Spiegler, in press a, pl. 1, figs. 7–10.
B. elegans Spiegler, in press b, pl. 1, figs. 11–13.
B. fava Spiegler, in press b, pl. 6, fig. 5.
B. fragori Powell, 1986, p. 71, pl. 1, figs. 1–4.
B. furcata Spiegler, see Spiegler and von Daniels, 1991, p. 135, pl. 6, figs. 8–10.
B. gracilireticulata Spiegler, in press b, pl. 5, figs. 14, 15.
B. groenlandica Spezzaferri and Spiegler, 1998, p. 205, pl. 1, figs. 1, 2, 4.
B. hispida Spiegler, in press b, pl. 2, figs. 5–9.
B. intermedia von Daniels and Spiegler, 1974, pp. 66–67, pl. 8, figs. 7–9.
B. laevis von Daniels and Spiegler, 1974, p. 64, pl. 7, figs. 7–9; pl.10, fig. 6.
B. lockeri Spiegler, in press b, pl. 4, figs. 14–16.
B. metzmacheri metzmacheri (Clodius, 1922), p. 108, pl. 1, fig. 2.
B. metzmacheri ornata Spiegler, in press b, pl. 5, figs. 3, 4.
B. metzmacheri solida Spiegler, in press b, pl. 5, figs. 5–7.
B. moravica Redinger, 1992, p. 468, pl. 3, figs. 1–4.
B. mutabilis Spiegler, in press b, pl. 4, figs. 5–7.
B. oblongireticulata Spiegler, in press b, pl. 6, figs. 8, 9.
B. platyreticulata Spiegler, in press b, pl. 6, figs. 6, 7.
B. pentaspinosa Spiegler, see Spiegler and von Daniels, 1991, p. 138, pl. 6, figs. 5–7.
B. pisiformis (Margarel, 1968), p. 60, pl. 9, figs. 8, 9; pl. 35, figs. 1–4.
B. polygonalis Spiegler, in press a, pl. 1, figs. 11–14.
B. praeintermedia Spiegler, in press b, pl. 4, figs. 19, 20.
B. pustulaintermedia Spiegler, in press b, pl. 4, figs. 8–10.
B. reticulata von Daniels and Spiegler, 1974, p. 64, pl. 7, figs. 10, 11.
B. robusta Spiegler, see Spiegler and von Daniels, 1991, p. 139, pl. 9, figs. 1–6.
B. robustabadenensis Spiegler, see Spiegler and Gürs, 1996, p. 156, pl. 5, figs. 7–10.
B. rotunda von Daniels and Spiegler, 1974, p. 67, pl. 8, fig. 10; pl. 9, figs. 1, 2.
B. sphaerica Spiegler, in press b, pl. 3, figs. 14–17.
B. spinosa von Daniels and Spiegler, 1974, pp. 67–68, pl. 9, figs. 3, 4.
B. spiralis von Daniels and Spiegler, 1974, p. 68, pl. 9, figs. 5–8; pl. 10, figs. 1–3.
B. stella Spiegler, in press b, pl. 2, figs. 1–4.
B. subfragoris Spiegler, see Spiegler and von Daniels, 1991, p. 140, pl. 11, figs. 3–6.
B. subfragoris magna Spiegler, in press b, pl. 6, figs. 3, 4.
B. superba Spiegler, in press b, pl. 5, figs. 17–19.
B. tenuis Spiegler, in press b, pl. 3, figs. 7–10.
B. trochospiralis Spiegler, in press b, pl. 4, figs. 17, 18.
B. verrucosa Spiegler, in press b, pl. 6, figs. 1, 2.
B. vulgaris Spiegler, in press b, pl. 6, figs. 14, 15.

ACKNOWLEDGMENTS

I wish to thank the Shipboard Scientific Party of Leg 162, especially Bill Austin and Maureen Raymo, for providing the samples. For technical assistance I thank Amelie Winkler, Tjard Kusche, Albert von Doetinchem, and Jutta Heinze (all from Kiel). Silvia Spezzaferri and Christian Betzler kindly reviewed the manuscript. Financial support was given by the Deutsche Forschungsgemeinschaft Bonn.

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Date of initial receipt: 16 September 1997
Date of acceptance: 2 March 1998
Ms 162SR-013

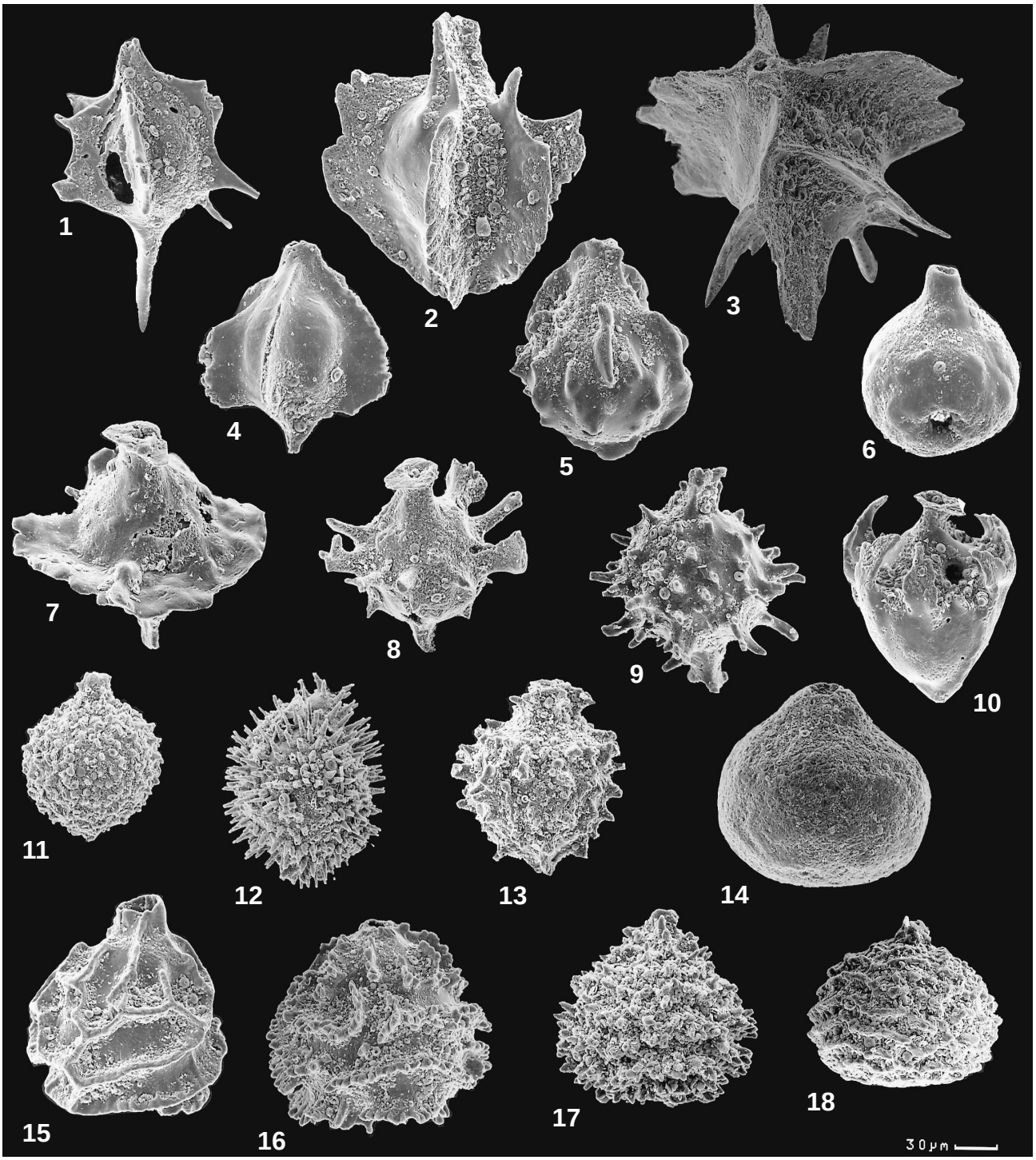

Plate 1. *Bolboforma* species at Site 982. **1.** *B. elegans* Spiegler, Sample 162-982B-8H-5, 140–142 cm. **2, 3.** *B. alata* Spiegler. (2) Sample 162-982A-9H-CC; (3) Sample 162-982B-10H-3, 30–32 cm. **4.** *B. costairregularis costairregularis* (Toering and Voorthuysen), Sample 162-982B-9H-5, 84–86 cm. **5.** *B. costairregularis variabilis* Spiegler, Sample 162-982B-12H-5, 20–22 cm. **6.** Cyst, Sample 162-982B-19H-5, 24–26 cm. **7.** *B. carina* Spiegler, Sample 162-982B-13H-4, 30–32 cm. **8.** *B. carinaspinosa* Spiegler, Sample 162-982B-13H-4, 30–32 cm. **9.** *B. stella* Spiegler, Sample 162-982B-11H-3, 20–22 cm. **10.** *B. tenuis* Spiegler, Sample 162-982B-14H-4, 29–31 cm. **11, 12.** *B. hispida* Spiegler. (11) Sample 162-982B-13H-1, 30–32 cm (corroded specimen); (12) Sample 162-982B-9H-5, 84–86 cm. **13.** *B. sphaerica* Spiegler, Sample 162-982B-15H-3, 29–31 cm. **14.** *B. laevis* von Daniels and Spiegler, Sample 162-982B-20H-3, 23–26 cm. **15.** *B. intermedia* von Daniels and Spiegler, Sample 162-982B-21H-3, 19–21 cm. **16.** *B. pustulaintermedia* Spiegler, Sample 162-982B-21H-7, 19–21 cm. **17.** *B. communis* Spiegler, Sample 162-982B-24H-CC. **18.** *B. groenlandica* Spezzaferri and Spiegler, Sample 162-982B-23H-1, 19–21 cm.

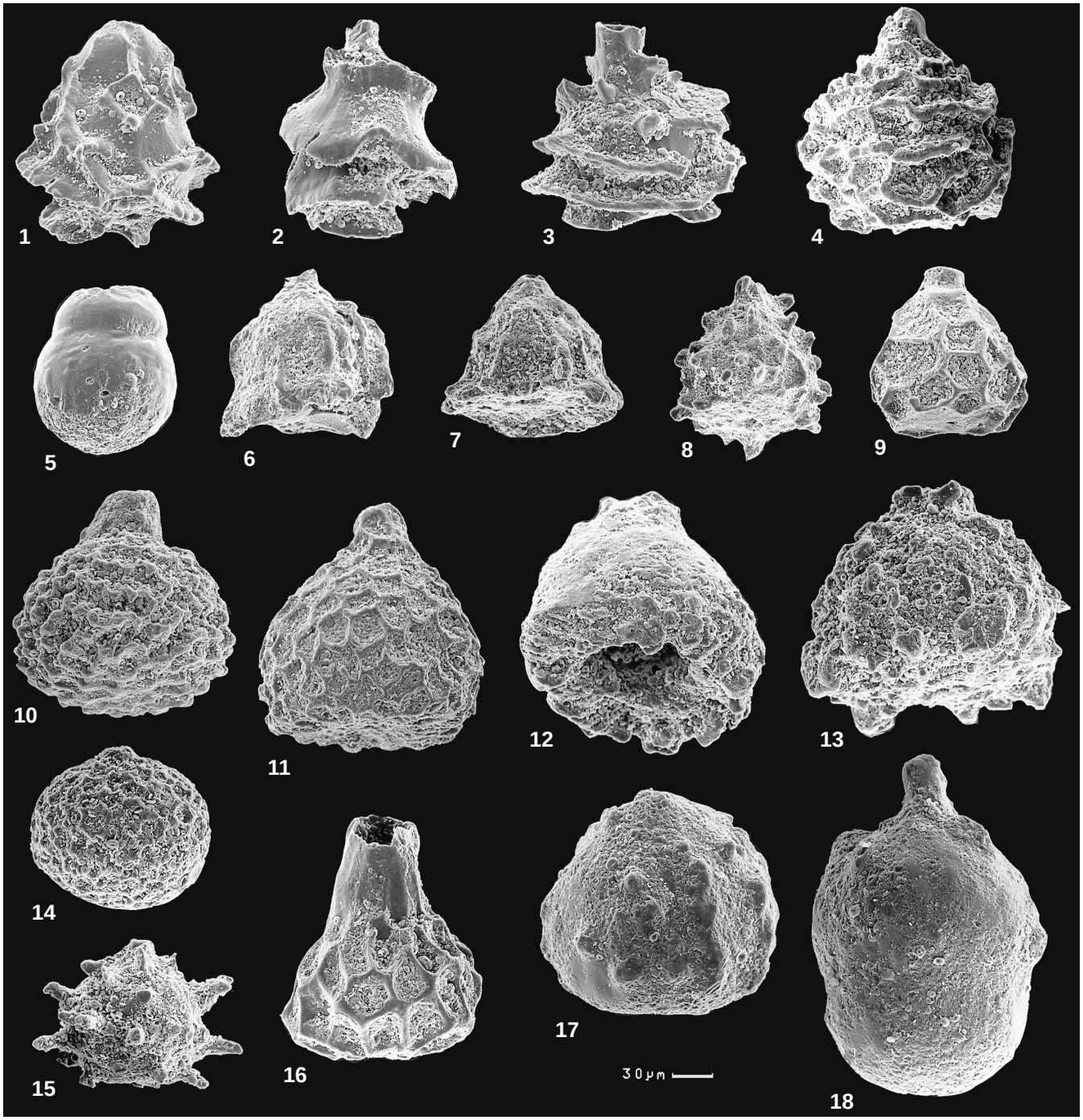

Plate 2. *Bolboforma* species at Site 982. **1.** *B. mutabilis* Spiegler, Sample 162-982B-21H-1, 19–21 cm. **2.** *B. lockeri* Spiegler, Sample 162-982B-22H-3, 19–21 cm. **3.** *B. trochospiralis* Spiegler, Sample 162-982B-27X-3, 19-21 cm. **4.** *B. praeintermedia* Spiegler, Sample 162-982B-27X-5, 19–21 cm. **5.** Cyst, Sample 162-982B-21H-1, 19–21 cm. **6.** *B. deformis* Spiegler, Sample 162-982B-33X-2, 19–21 cm. **7.** *B. contorta contorta* Spiegler, Sample 162-982B-33X-3, 19–21 cm. **8.** *B. contorta sculpturata* Spiegler, Sample 162-982B-34X-2, 19–21 cm. **9.** *B. pisiformis* (Margarel), Sample 162-982B-19H-4, 24–26 cm. **10.** *B. metzmacheri ornata* Spiegler, Sample 162-982B-35X-3, 19–21 cm. **11.** *B. metzmacheri metzmacheri* (Clodius), Sample 162-982B-35X-1, 19–21 cm. **12, 13.** *B. metzmacheri solida* Spiegler. (12) Sample 162-982B-36X-3, 19–21 cm; (13) Sample 162-982B-36X-4, 19–21 cm. **14.** *B. gracilireticulata* Spiegler, Sample 162-982B-34X-4, 19–21 cm. **15.** *B. superba* Spiegler, Sample 162-982B-43X-1, 19–21 cm. **16.** *B. polygonalis* Spiegler, Sample 162-982B-32X-1, 19–21 cm. **17.** *B. capsula* Spiegler, Sample 162-982B-37X-4, 19–21 cm. **18.** *B. robusta* Spiegler, Sample 162-982B-44X-4, 19–21 cm.

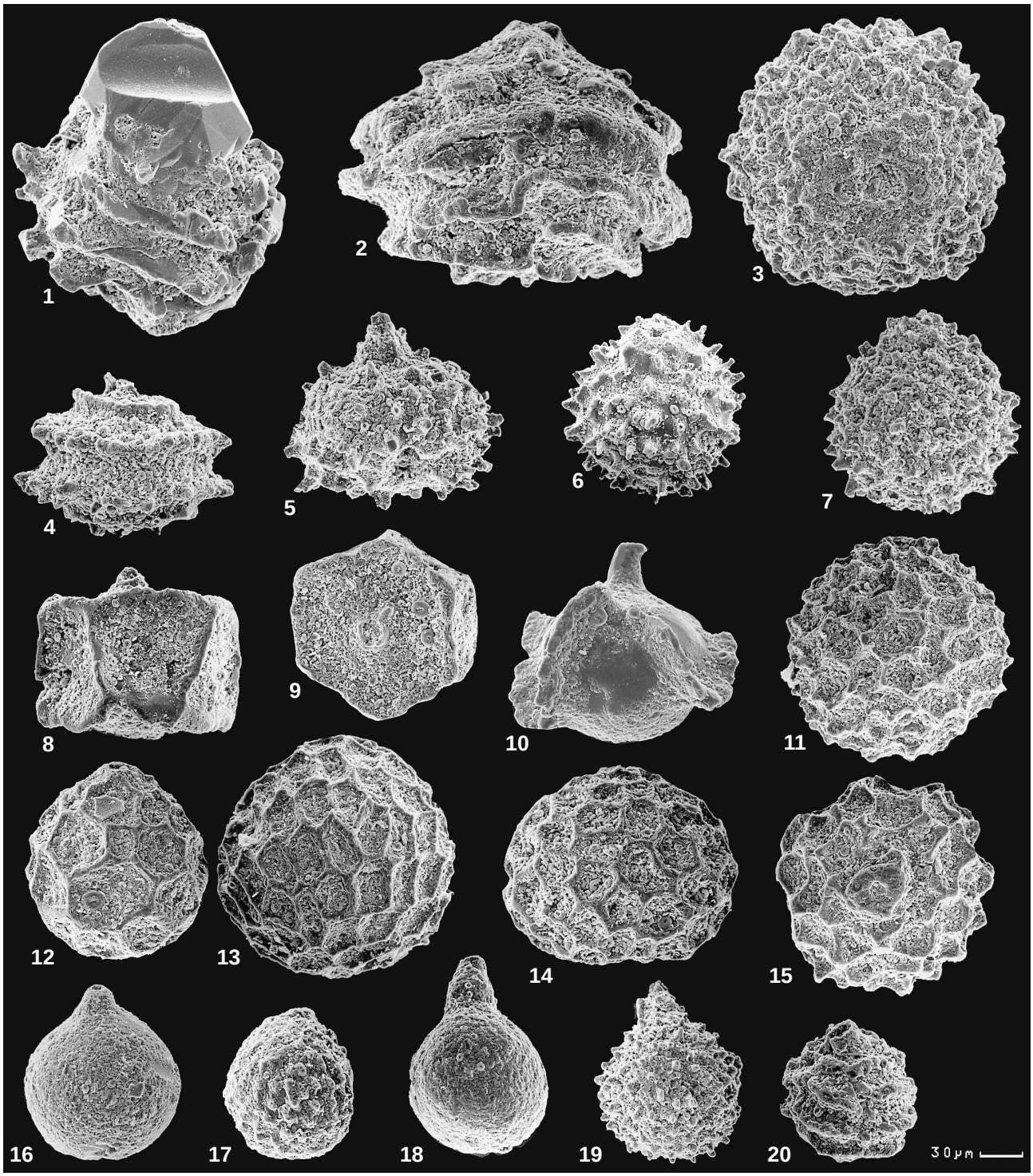

Plate 3. *Bolboforma* species at Sites 982 and 116. **1.** *B. subfragoris* Spiegler, Sample 162-982B-29X-CC, specimen overgrown by calcitic crystals. **2.** *B. subfragoris magna* Spiegler, Sample 162-982B-40X-4, 19–21 cm. **3.** *B. verrucosa* Spiegler, Sample 162-982B-47X-4, 19–21 cm. **4.** *B. fragori* Powell, Sample 162-982B-42X-1, 19–21 cm. **5.** *B. compressispinosa* Spiegler, Sample 162-982B-45X-2, 19–21 cm. **6.** *B. pentaspinosa* Spiegler, Sample 162-982B-48X-1, 19–21 cm. **7.** *B. badenensis* Szczechura, Sample 162-982B-47X-CC. **8, 9.** *B. atlantica* Spiegler, Sample 162-982B-47X-2, 19–21 cm. **10.** *B. danielsi* Murray, Sample 162-982B-47X-CC. **11.** *B. moravica* Redinger, Sample 162-982B-45X-3, 19–21 cm. **12.** *B. fava* Spiegler, Sample 162-982B-48X-5, 19–21 cm. **13.** *B. oblongireticulata* Spiegler, Sample 162-982B-45X-3, 19–21 cm. **14.** *B. platyreticulata* Spiegler, Sample 162-982B-50X-3, 19–21 cm. **15.** *B. reticulata* von Daniels and Spiegler, Sample 162-982B-55X-1, 19–21 cm. **16.** *B.* cf. *laevis* von Daniels and Spiegler, Sample 162-982B-55, CC. **17.** *B. rotunda* von Daniels and Spiegler, Sample 162-982B-62X-1, 19–21 cm. **18.** *B. vulgaris* Spiegler, Sample 162-982B-62X-CC. **19.** *B. spinosa* von Daniels and Spiegler, Sample 162-982B-62X-CC. **20.** *B. spiralis* von Daniels and Spiegler, Sample 12-116-15-1, 42–44 cm.