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18. OCCURRENCE OF *BOLBOFORMA* (ALGAE, CHRYSOPHYTA) IN THE SUBANTARCTIC (ATLANTIC) PALEOGENE[1]

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ABSTRACT

Sediments from ODP Holes 699A, 700B, 702B, 703A, and 704B were studied in order to determine and to understand the distribution of *Bolboforma*. Ten *Bolboforma* taxa were detected in the 294 samples analyzed. Based on *Bolboforma* species, a zonation correlated to the paleomagnetic record is proposed for the late middle Eocene to early Oligocene. Four biozones can be defined: the *Bolboforma indistincta* Zone for the lower part of the upper middle Eocene sequence, the *Bolboforma eocena* Zone for the upper part of the upper middle Eocene to upper Eocene, the *Bolboforma geomaris* Zone for the upper Eocene, and the *Bolboforma latdorfensis* Zone for the lower Oligocene sequence.

INTRODUCTION

During Ocean Drilling Program (ODP) Leg 114, 12 holes were drilled at seven sites along a west to east transect across the subantarctic region of the Atlantic Ocean (Fig. 1), providing an unique opportunity for obtaining long, undisturbed, continuous sequences of Paleogene sediments.

Leg 114 cores retrieved a complete high-quality data base with the aim of producing a biostratigraphic framework of planktonic fossils, such as planktonic foraminifers, calcareous nannofossils, diatoms, radiolarians, and silicoflagellates, that will provide an excellent Paleogene stratigraphic record for the southern part of the Atlantic Ocean. Well-preserved specimens of *Bolboforma* occur in many of the Paleogene samples from these core sites. These microfossils are abundant in the upper middle Eocene and upper Eocene sequences. *Bolboforma* are rare in Oligocene sediments, and they are absent in sequences older than middle Eocene.

Bolboforma are believed to belong to the Protophyta and are informally grouped within the Chrysophyceae (Algae) as the family *Bolboformaceae* Spiegler, 1987 (Spiegler, 1987). *Bolboforma* exhibit a generally spheroid shape, similar to that of the benthic foraminifer *Lagena*. In contrast to foraminifers, however, *Bolboforma* are generally composed of monocrystalline, low-magnesium calcite. Usually *Bolboforma* are single chambered, but a few are uniserial double chambered (Daniels et al., 1981), and some encapsulated specimens of different species have been detected (Poag and Karowe, 1986, 1987; Spiegler, 1987).

Bolboforma are a proven stratigraphic tool both in Neogene and Paleogene sediments. Their distribution in Neogene samples from the North Atlantic realm has been documented (Echols, 1985; McNeil, 1988; Müller et al., 1984; Murray, 1979, 1984, 1987; Poag and Karowe, 1986, 1987; Qvale and Spiegler, 1989; Spiegler, 1987). Rögl and Hochuli (1976) and Gazdzicki and Wrona (1986) described *Bolboforma* in lower Miocene sediments drilled on the continental rise of the antarctic Bellinghausen Sea. Knowledge of distribution patterns of *Bolboforma* in Paleogene sequences is still very limited. Up to now, the oldest known occurrence of *Bolboforma* extends to the middle part of the middle Eocene (~44 Ma) (Kennett and Kennett, in press). Poag and Karowe (1986, 1987) documented *Bolboforma* in upper Eocene sequences of Deep Sea Drilling Project (DSDP) Leg 95 (Site 612, in the western North Atlantic and Gulf Coast) and in upper Eocene sediments of DSDP Leg 90 (Site 592, in the western South Pacific). Pallant and Kaminski (1989) described the occurrence of *Bolboforma* in upper Eocene sediments of ODP Leg 105, from Site 647 in the Labrador Sea. *Bolboforma* of Oligocene age are more common than Eocene forms. For instance, *Bolboforma* are documented from outcrops in Mississippi and Virginia (Tappan, 1980; Poag and Karowe, 1986, 1987) and in United States Atlantic margin sites (Poag and Karowe, 1986, 1987) and have also been observed in the Oligocene of northwest Germany (Daniels and Spiegler, 1974). In this study *Bolboforma* are documented from strata of middle Eocene to early Oligocene age.

MATERIAL AND METHODS

I report results from analyses of Holes 699A, 700B, 702B, 703A, and 704B. Hole 698A contains no *Bolboforma*. Hole 701C was not analyzed. In general, I investigated the same samples that Nocchi et al. (this volume) used to study Paleogene planktonic foraminifers (i.e., one sample per section; 294 samples in the drilled Paleogene sediment). Samples of about 20 cm^3 were prepared by drying and soaking in water before being washed through a 40-μm screen. The analyses were carried out on the fraction >40 mm. Scanning electron microscopy (SEM) was used for detailed taxonomic studies. The 10 species observed in the Leg 114 material are described briefly in the captions of Plates 1 and 2. The full systematic descriptions are given in Spiegler and Daniels (in press).

RESULTS

Site 699

Hole 699A is located on the northeastern slope of the Northeast Georgia Rise (Fig. 1 and Table 1). One sample per section (140 samples) was analyzed in the interval between 80.56 and 439.75 m below seafloor (mbsf). Down to 250.54 mbsf the samples are barren of *Bolboforma*. The sequence between 251.78 to 285.28 mbsf contains *Bolboforma pustula*

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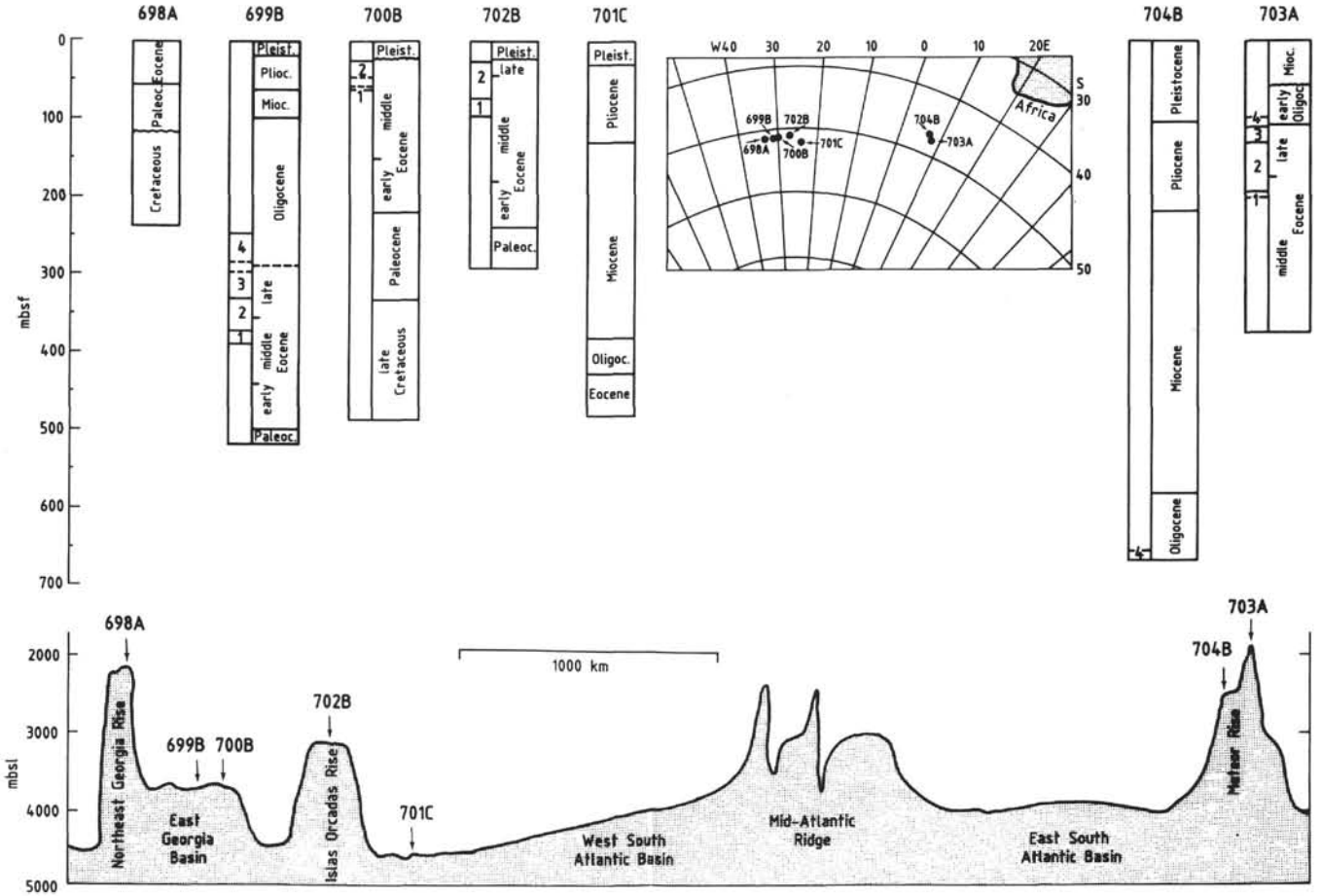

Figure 1. Locations and cross sections of Leg 114 sites. The composite columns for each site show age, stratigraphic thickness, and *Bolboforma* zones: 1 = *B. indistincta* Zone, 2 = *B. eocena* Zone, 3 = *B. geomaris* Zone, 4 = *B. latdorfensis* Zone. Hole 698A contains no *Bolboforma* and Hole 701C was not analyzed. (Modified from Leg 114 Scientific Drilling Party, 1987).

Table 1. Location and water depth of ODP Leg 114 holes containing *Bolboforma* in Paleogene sediments.

Hole	Latitude (S)	Longitude (W)	Water depth (m)
699A	51°32.537′	30°40.619′	3707.5
700B	51°31.992′	30°16.697′	3597.9
702B	50°56.786′	26°22.117′	3083.7
703A	47°03.042′	07°53.679′E	1806.6
704B	46°52.785′	07°25.231′E	2530.8

and *Bolboforma latdorfensis*, forms that are typically Oligocene in age (Spiegler and Daniels, in press). The strata from 286.78 to 296.64 mbsf are again barren of *Bolboforma*. Beneath 297.80 mbsf and down to 389.56 mbsf, 75% of the examined samples contains *Bolboforma* taxa. Abundant *Bolboforma* occur between 329.45 and 371.26 mbsf. The last occurrences (LO) of *Bolboforma geomaris* and *Bolboforma lamari* in Sample 114-699A-33X-1, 70–74 cm, are notable. The LO of *Bolboforma eocena*[3] in Sample 114-699A-37X-1, 124–126 cm, and the first occurrence (FO) of the same species in Sample 114-699A-40X-CC are important events for the zonation of the Eocene sequences by means of *Bolboforma* in the Leg 114 holes. The samples from 303.80 to 389.56 mbsf contain sporadic *Bolboforma indistincta*. From 391.22 to 439.75 mbsf the samples are barren of *Bolboforma* (Table 2).

Site 700

Hole 700B is located in the western region of the East Georgia Basin (Fig. 1 and Table 1). Twenty samples from between 26.81 and 72.17 mbsf were analyzed. The interval between 26.81 and 47.26 mbsf contains *Bolboforma eocena*, *Bolboforma geomaris*, *Bolboforma indistincta*, *Bolboforma lamari*, and small smooth forms, named *Bolboforma* sp. B. The strata from 47.26 to 60.15 mbsf are barren of *Bolboforma*, but the interval between 61.65 and 63.90 mbsf contains a few *B. indistincta* and is, in turn, underlain by sediments barren in *Bolboforma* down to 72.17 mbsf (Table 3). Spot-checking samples down to lower Eocene strata did not detect any *Bolboforma* specimens.

Site 702

Hole 702B is located on the central part of the Islas Orcadas Rise (Fig. 1 and Table 1). One sample per section was analyzed for the interval between 26.87 and 108.10 mbsf (44 samples). Down to 75.00 mbsf, the samples contain frequent *Bolboforma eocena* accompanied by mostly rare *Bolboforma geomaris*, *Bolboforma lamari*, *Bolboforma indistincta*, and the small smooth form *Bolboforma* sp. B, interpreted as cysts of

[3] Kennett and Kennett (in press) described *Bolboforma antarctica* as a new species that is equivalent to *B. eocena* (Spiegler, in press). *B. eocena* thus becomes synonymous with *B. antarctica*. Therefore, the species name *B. eocena* as well as the *B. eocena* Zone name are replaced by *B. antarctica*.

Table 2. Distribution of *Bolboforma* in Hole 699A and correlation to the zonations of planktonic foraminifers (Nocchi et al., this volume) and calcareous nannofossils (Crux, this volume).

Hole 699A		*Bolboforma indistincta*	*Bolboforma* sp. *B*	*Bolboforma eocena*	*Bolboforma praespinosa*	*Bolboforma lamari*	*Bolboforma geomaris*	*Bolboforma* cf. *geomaris*	*Bolboforma latdorfensis*	*Bolboforma* sp. *A*	*Bolboforma pustula*	*Bolboforma* Zones	Planktonic Foram. Zones	Calcareous Nannofossil Zones	Age
Core, section, interval (cm)	Depth (mbsf)											Spiegler (this study)	Nocchi (this volume)	Crux (this volume)	
27X-6, 114-116	251.78										C				
-7, 3- 5	252.13													NP 22	
-CC	252.60												lower Oligocene		
28X-1, 50- 52	253.10														early Oligocene
30X-1, 59- 61	269.19														
-2, 13- 15	270.23														
-3, 47- 49	271.64														
-4, 104-106	274.11									R		*B. latdorfensis*			
31X-1, 120-122	279.30														
-2, 120-122	280.80														
-3, 120-122	282.30														
-4, 118-120	283.78									R					
-5, 118-120	285.28								C						
-6, 118-120	286.78														
32X-1, 67- 69	288.27													NP 21 - NP 19	?
-2, 21- 23	289.31														
-3, 12- 14	290.72											barren	Oligocene		
-5, 21- 23	293.81														
-6, 26- 28	295.36														
-7, 4- 6	296.64														
33X-1, 70- 74	297.80					r	R								
-2, 70- 74	299.30														
-3, 70- 74	300.80												to		
-4, 70- 74	302.30					F	R	R							
-5, 70- 74	303.80	R													
-6, 70- 74	305.30														
-CC	306.60														
34X-CC	316.10														
35X-1, 110-112	317.20								R	R			upper Eocene		late Eocene
-2, 110-112	318.70														
-3, 110-112	320.20														
-3, 120-122	320.30					R						*B. geomaris*			
-4, 110-112	321.70														
-5, 110-112	323.20														
-6, 110-112	324.70		R												
36X-1, 85- 87	326.45		R												
-2, 85- 87	327.95					F									
-3, 85- 87	329.45	R			R	A		R						NP 18	
-4, 85- 87	330.95					F									
-5, 85- 87	332.45	R				F							P 17 - P 15		
-6, 85- 87	333.95		r			C									
-7, 45- 47	335.05		R			C									
37X-1, 124-126	336.34			C		R	F	R							
-2, 94- 96	337.54	R	R	F											
-3, 94- 96	339.04	R		A											
-4, 94- 96	340.54			A			F								
39X-1, 66- 68	354.76	R		C											
-2, 68- 68	356.26			F			R								
-CC	363.60			R											
40X-1, 78- 80	364.38	R		A									P 14 - P 12		
-2, 78- 80	365.88	R		F			R								
-3, 78- 80	367.38	R		r											
-4, 78- 80	368.88			C											
-5, 42- 46	370.02			F											
-6, 16- 18	371.26	R		C										NP 16	middle Eocene
-CC	373.10	R		R											
41X-1, 119-121	374.29	R													
-1, 134-136	374.44														
42X-1, 90- 92	383.50												P 11 - P 10		
-2, 90- 92	385.00					R									
-3, 34- 36	385.94											*B. indistincta*			
-4, 90- 92	388.00														
-5, 96- 98	389.56	C												no data	
-6, 112-114	391.22														
-7, 34- 36	391.94													NP 16-14	
43X-4, 112-114	397.72														

Note: Rare (R), less than 3%; few (F), 3%-15%; common (C), 15%-30%; abundant (A), more than 30%.

(R): Transition *B. indistincta* to *B. lamari*.

Table 3. Distribution of *Bolboforma* in Hole 700B and correlation to the zonations of planktonic foraminifers (Nocchi et al., this volume) and calcareous nannofossils (Crux, this volume).

Hole 700B		*Bolboforma indistincta*	*Bolboforma* sp. *B*	*Bolboforma eocena*	*Bolboforma praespinosa*	*Bolboforma lamari*	*Bolboforma geomaris*	*Bolboforma* cf. *geomaris*	*Bolboforma latdorfensis*	*Bolboforma* sp. *A*	*Bolboforma pustula*	*Bolboforma* Zones	Planktonic Foram. Zones	Calcareous Nannofossil Zones	Age
Core, section, interval (cm)	Depth (mbsf)											Spiegler (this study)	Nocchi (this volume)	Crux (this volume)	
3R-1, 44- 46	26.81	R		A								*B. eocena*	P 13 – P 12	NP 16	middle Eocene
-CC	28.00	R	R	A		R									
4R-1, 59- 61	36.49			A			R							NP 16 – NP 14	
-CC	36.60	C	R	R			R								
5R-1, 105-107	46.15	R		R											
-2, 36- 38	47.26	F		R											
-3, 36- 38	48.76														
-4, 36- 38	50.26														
6R-1, 105-107	55.65														
-2, 75- 77	57.15														
-3, 75- 77	58.65														
-4, 75- 77	60.15														
-5, 75- 77	61.65	R										*B. indistincta*	P 11 – P 10		
-6, 75- 77	63.15	R													
-CC	63.90	R													
7R-2, 27- 29	66.17														
-3, 27- 29	67.67														
-4, 27- 29	69.17														
-5, 27- 29	70.67														
-6, 27- 29	72.17														

Note: Rare (R), less than 3%; few (F), 3%-15%; common (C), 15%-30%; abundant (A), more than 30%.

several different *Bolboforma* taxa. The FO of *B. eocena* was observed in Sample 114-702B-9X-2, 70–72 cm. Samples down to 96.05 mbsf contain mostly *B. indistincta*. The occurrence of *Bolboforma praespinosa* in Sections 114-702B-9X-5 and 114-702B-10X-1 to 114-702B-10X-2 is notable, because this species is typical of Eocene strata in the Northern Hemisphere.[4] The sequence from 97.55 to 108.10 mbsf is barren of *Bolboforma* (Table 4).

Site 703

Hole 703A is positioned on the Meteor Rise (Fig. 1 and Table 1). The Paleogene sediments from 39.74 to 97.80 mbsf are barren of *Bolboforma*. Samples down to 110.60 mbsf contain *Bolboforma latdorfensis* and *Bolboforma pustula*, both of which are typically Oligocene in age (Spiegler and Daniels, in press). In the samples from deeper than 112.10 mbsf *Bolboforma geomaris*, *Bolboforma lamari*, and *Bolboforma indistincta* are present. The sequence containing *B. eocena* extends from 131.65 to 193.80 mbsf. In Sample 114-703A-23X-1, 46–48 cm, only *B. indistincta* is present. All underlying samples are barren of *Bolboforma* (Table 5). A total of 71 samples was examined.

Site 704

Hole 704B is situated on the central southern part of the Meteor Rise (Fig. 1 and Table 1). Nineteen samples from the interval between 577.32 and 663.90 mbsf were analyzed. Only Samples 114-704B-71X-2, 12–14 cm, and 114-704B-72X-1, 20–22 cm, contain very few *Bolboforma* sp. A (Table 6), a smooth, broad spherical form that is contained in the lower Oligocene sequences of Holes 699A and 703A and also in the upper Eocene sediments of the latter.

ZONATION

The high quality of the Paleogene sediment cores recovered during Leg 114 provided the chance to construct a biostratigraphic zonation by means of *Bolboforma*. I have divided the *Bolboforma*-bearing sediments into four *Bolboforma* zones, spanning the late middle Eocene to early Oligocene. Well-defined species, which are easy to recognize, were chosen to define the zones.

Eocene

The Eocene sequences were divided by the *Bolboforma* taxa into three zones: the oldest zone is the *Bolboforma indistincta* Zone, followed in time by the *Bolboforma eocena* Zone and *Bolboforma geomaris* Zone.

Bolboforma indistincta Partial Range Zone

Age. Early part of late middle Eocene.

Definition. Top: FO *B. eocena*. Base: FO *B. indistincta*.

Occurrences. Samples 114-699A-41X-1, 119–121 cm, to 114-699A-42X-5, 96–98 cm; depth, 374.29 to 389.56 mbsf. Samples 114-700B-6R-5, 75–77 cm, to 114-700B-6R-CC; depth, 61.65 to 63.90 mbsf. Samples 114-702B-9X-3, 70–72 cm, to 114-702B-11X-3, 125–127 cm; depth, 76.50 to 96.05 mbsf. Samples 114-703A-23X-1, 46–48 cm; depth, 200.80 mbsf.

Bolboforma eocena Total Range Zone

Age. Late part of late middle Eocene to late Eocene.

Definition. Top: LO *B. eocena*. Base: FO *B. eocena*.

Occurrences. Samples 114-699B-37X-1, 124–126 cm, to 114-699B-40X-CC; depth, 336.34 to 373.10 mbsf. Samples 114-700B-3R-1, 44–46 cm, to 114-700B-5R-2, 36–38 cm; depth, 26.81 to 47.26 mbsf. Samples 114-702B-4X-2, 7–9 cm, to 114-702B-9X-2, 70–72 cm; depth, 26.87 to 75.00 mbsf. Samples 114-703A-15H-3, 25–27 cm, to 114-703A-22X-CC; depth, 131.65 to 193.80 mbsf.

[4] The occurrence of *Bolboforma praespinosa* is cited from the upper Eocene (NP19/20) Headon Beds, the Isle of Wight, and Emery Down, Lyndhurst, Hampshire, both of which were kindly collected by Dennis Curry/Itchenor, U.K. (Spiegler and Daniels, in press).

Bolboforma geomaris Partial Range Zone

Age. Latest late Eocene.

Definition. Top: upper limit of *B. geomaris* and *B. lamari*. Base: LO *B. eocena*.

Occurrences. Samples 114-699B-33X-1, 70–74 cm, to 114-699B-36X-7, 45–47 cm; depth, 297.80 to 335.05 mbsf. Samples 114-703A-13H-2, 120–123 cm, to 114-703A-15H-2, 25–27 cm; depth, 112.10 to 130.15 mbsf.

Oligocene

The *Bolboforma latdorfensis* Zone characterizes most parts of early Oligocene time.

Bolboforma latdorfensis Partial Range Zone

Age. Early Oligocene.

Definition. Top: unknown. Base: upper limit of *B. geomaris* and of *B. lamari*.

Occurrences. Samples 114-699B-27X-6, 114–116 cm, to 114-699B-31X-5, 118–120 cm; depth, 251.78 to 285.28 mbsf. Samples 114-703A-11H-6, 140–142 cm, to 114-703A-13H-1, 120–123 cm; depth, 99.30 to 110.60 mbsf. Samples ?114-704B-71X-2, 12–14 cm, to 114-704B-72X-1, 20–22 cm; depth, 654.32 to 662.40 mbsf.

Table 7 shows the distribution of the different *Bolboforma* zones in the Leg 114 holes investigated.

BOLBOFORMA ZONATION AND PALEOMAGNETIC CONTROL

Available biostratigraphic datums of planktonic foraminifers (Nocchi et al., this volume) and calcareous nannofossils (Crux, this volume) allow identification of magnetozones (Hailwood and Clement, this volume) in the Leg 114 holes. From the cross-correlation of these zones and the absolute ages (proposed by Berggren et al., 1985), it is possible to date the newly established *Bolboforma* zones approximately.

Table 4. Distribution of *Bolboforma* in Hole 702B and correlation to the zonations of planktonic foraminifers (Nocchi et al., this volume) and calcareous nannofossils (Crux, this volume).

Hole 702B		*Bolboforma indistincta*	*Bolboforma* sp. *B*	*Bolboforma eocena*	*Bolboforma praespinosa*	*Bolboforma lamari*	*Bolboforma geomaris*	*Bolboforma* cf. *geomaris*	*Bolboforma latdorfensis*	*Bolboforma* sp. *A*	*Bolboforma pustula*	*Bolboforma* Zones	Planktonic Foram. Zones	Calcareous Nannofossil Zones	Age
Core, section, interval (cm)	Depth (mbsf)											Spiegler (this study)	Nocchi (this volume)	Crux (this volume)	
4X-2, 7- 9	28.87	C	R	R			R	R				*B. eocena*	P 15	NP 18	late Eocene
-3, 7- 9	28.37	R	R	R		R									
-4, 7- 9	29.87		F	R				R							
-5, 7- 9	31.37	R		C											
-6, 7- 9	32.87	R		A											
5X-1, 40- 42	35.20	R	F	C											
-2, 5- 7	36.35		R	R											
-3, 5- 7	37.85			R											
-4, 5- 7	39.35	R	R	F		F									
-5, 5- 7	40.85	R	R	F											
-6, 5- 7	42.35	R		A											
6X-1, 25- 27	44.55	R		A		R	R	R							
-2, 25- 27	46.05	C	R	A				R							
7X-1, 130-132	55.10	R	R	C				R							
-2, 40- 42	55.70	R		C											
8X-1, 60- 62	63.90	F		F									P 14	NP 16	middle Eocene
-2, 60- 62	65.40	F		F											
-3, 60- 62	66.90	R		R											
-4, 60- 62	68.40	R		F											
-5, 62- 62	68.90	R	R	A				R							
-6, 60- 62	71.40	R		A											
9X-1, 70- 72	73.50	F		R				R					P 13 - P 12	no data	
-2, 70- 72	75.00			R		R									
-3, 70- 72	76.50	C	R									*B. indistincta*			
-4, 70- 72	78.50	R													
-5, 70- 72	79.50	R			R										
-6, 70- 72	81.00	R	R					F							
10X-1, 120-122	83.50	A	R	R	R			R							
-2, 120-122	85.00	A		R	R	R									
-3, 120-122	86.50	F													
-4, 120-122	88.00							R							
-5, 120-122	89.50		R			R									
-6, 120-122	91.00	R													
11X-1, 125-127	93.05													NP 16 - NP 14	
-2, 125-127	94.55														
-3, 125-127	96.05	F													
-4, 125-127	97.55														
-5, 125-127	99.05														
-6, 125-127	100.55														
12X-1, 80- 82	102.10														
-2, 80- 82	103.60														
-3, 80- 82	105.10														
-4, 80- 82	106.10														
-5, 80- 82	108.10														

Note: Rare (R), less than 3%; few (F), 3%-15%; common (C), 15%-30%; abundant (A), more than 30%.

(R): Transition *B. eocena* to *B. indistincta*.

Table 5. Distribution of *Bolboforma* in Hole 703A and correlation to the zonations of planktonic foraminifers (Nocchi et al., this volume) and calcareous nannofossils (Crux, this volume).

Hole 703A		*Bolboforma indistincta*	*Bolboforma* sp. *B*	*Bolboforma eocena*	*Bolboforma praespinosa*	*Bolboforma lamari*	*Bolboforma geomaris*	*Bolboforma* cf. *geomaris*	*Bolboforma latdorfensis*	*Bolboforma* sp. *A*	*Bolboforma pustula*	*Bolboforma* Zones	Planktonic Foram. Zones	Calcareous Nannofossil Zones	Age
Core, section, interval (cm)	Depth (mbsf)											Spiegler (this study)	Nocchi (this volume)	Crux (this volume)	
11H-5, 140-142	97.80											*B. latdorfensis*	P 20 – P 18	NP 24-NP 25	early Oligocene
-6, 140-142	99.30										A			NP 22	
12H-1, 140-142	103.30														
-3, 140-142	104.30								R		C				
-5, 140-142	107.30								F	R	F				
-6, 140-142	108.80								R	R	R			NP 21 – NP 19	
-7, 55- 57	109.55										R				
13H-1, 120-123	110.60	R							C		R				
-2, 120-123	112.10		A			C	R	R		F		*B. geomaris*			late Eocene
-4, 120-123	115.10					R		R							
15H-2, 25- 27	130.15	R				A				R		*B. eocena*	P 17 – P 16		
-3, 25- 27	131.65			R		R									
-4, 25- 27	133.15	R		R		F				R					
-5, 25- 27	134.65	R		R		F				R					
-6, 25- 27	136.15			F		F									
16X-1, 90- 92	138.80		R	C		A									
17X-1, 85- 87	144.25	R		A					r				P 15	NP 18	
-2, 85- 87	144.75			A					R						
-3, 85- 87	147.25			F											
18X-1, 110-112	154.00			F											
-2, 110-112	155.50	R		F				R							
-3, 110-112	157.00		F	A		R			R						
-4, 110-112	159.20	R	R	C					R						
19X-CC	162.40			R		R							P 14 – P 12	no data	middle Eocene
20X-1, 60- 62	172.50			C		C			R						
-2, 60- 62	174.00	R	R	F					R					NP 16	
-3, 60- 62	175.50	R		R		F			R						
-4, 60- 62	177.00		R	F											
-5, 60- 62	178.50	R	R	C											
21X-1, 80- 82	182.20	R	R	C											
-2, 80- 82	183.70	R	R	C											
-3, 80- 82	185.20	R		F											
-4, 80- 82	186.70	R		F											
-5, 80- 82	188.20	R	R	R											
22X-CC	193.80	R		R											
23X-1, 46- 48	200.80	R										*B. indistincta*	?	NP 16-NP 14	
-CC	201.90														
26X-1, 140-142	236.00														

Note: Rare (R), less than 3%; few (F), 3%-15%; common (C), 15%-30%; abundant (A), more than 30%.

In Hole 699A, Cores 114-699A-42X to 114-699A-27X contain *Bolboforma*, but the sediments in Cores 114-699A-46X to 114-699A-24X are unsuitable for paleomagnetic analysis because of extensive drilling disturbance and poor core recovery. However, the identification of Chrons C13N and C13R in the depth interval from 306 to 270 mbsf is possible. *Bolboforma latdorfensis* is common at 285.28 mbsf, dated by the paleomagnetic control as ~36 Ma. The LO of *Bolboforma geomaris* and *Bolboforma lamari* at 297.80 mbsf falls into Chron C13R at the postulated Eocene/Oligocene boundary.

In Hole 700B the middle Eocene sequence from 63.90 to 26.81 mbsf contains *Bolboforma*, but downhole contamination in the upper 270 m of the record prevents paleomagnetic analysis.

In Hole 702B the *Bolboforma indistincta* and the *Bolboforma eocena* Zones are present. The *B. indistincta* Zone extends from Samples 114-702B-11X-3, 125–127 cm, to 114-702B-9X-3, 70–72 cm, and the younger *B. eocena* Zone from Samples 114-702B-9X-2, 70–72 cm, up to 114-702B-4X-2, 7–9 cm. The magnetostratigraphic record in Cores 114-702B-13X to 114-702B-8X is well defined with Chrons C20R to C18N. The paleomagnetic shift from C20N to C19R, dated as 44.7 Ma according Berggren et al. (1985), is documented in the lower part of Core 114-702B-11X. In Sample 114-702B-11X-3, 125–127 cm, the FO of *B. indistincta* lies approximately 250 cm higher in the sequence and, thus, according to the sedimentation rate during this period of 12 m/m.y. (Ciesielski, Kristoffersen, et al., 1988), it is 0.2 Ma younger than the C20N/C19R shift. *B. indistincta* is the stratigraphically oldest known *Bolboforma* taxon. For this reason, the presently known first appearance of the genus *Bolboforma* can be dated as approximately 44.5 Ma. The boundary between the *B. indistincta* Zone and the *B. eocena* Zone lies between Samples 114-702B-9X-3, 70–72 cm, and 114-702B-9X-2, 70–72 cm. The paleomagnetic shift between C18R and C18N dated as 42.7 Ma is documented between Cores 114-702B-9X and 114-702B-8X. Consequently, the boundary between the *B. indistincta* and *B. eocena* Zones can be equal to ~43 Ma. The *B. eocena* Zone extends up to Sample 114-702B-4X-2, 7–9 cm. The upper half of Core 114-702B-4X is correlated with Chron C16N (38.1 to 39.2 Ma). Therefore, the LO of *B. eocena* in Hole 702B is younger than 39.2 Ma and older than 38.1 Ma.

In Hole 703A the zones of *B. indistincta* (Sample 114-702B-23X-1, 46–48 cm; 200.80 mbsf), *B. eocena* (193.80 to 131.65 mbsf), *B. geomaris* (130.15 to 112.10 mbsf), and *B. latdorfensis* (110.60 to 99.30 mbsf) are present. Beneath 115 mbsf, drilling disturbance and/or poor recovery of the se-

Table 6. Distribution of *Bolboforma* in Hole 704B and correlation to the zonations of planktonic foraminifers (Nocchi et al., this volume) and calcareous nannofossils (Crux, this volume).

Hole 704B		*Bolboforma indistincta*	*Bolboforma* sp. *B*	*Bolboforma eocena*	*Bolboforma praespinosa*	*Bolboforma lamari*	*Bolboforma geomaris*	*Bolboforma* cf. *geomaris*	*Bolboforma latdorfensis*	*Bolboforma* sp. *A*	*Bolboforma pustula*	*Bolboforma* Zones	Planktonic Foram. Zones	Calcareous Nannofossil Zones	Age	
Core, section, interval (cm)	Depth (mbsf)											Spiegler (this study)	Nocchi (this volume)	Crux (this volume)		
63X-1, 62- 64	577.32															
-2, 61- 63	578.81															
-3, 60- 62	580.30															
-4, 61- 63	581.81															
-4, 61- 63	583.31															
64X-1, 100-102	587.20												P 22	NP 25	late	Oligocene
-2, 100-102	588.70															
-3, 100-102	590.20															
65X-1, 110-112	596.80											barren				
-2, 110-112	598.30															
67X-1, 80- 82	615.50															
68X-1, 90- 92	625.10												P 21b	NP 24 - NP 23	early	
-2, 90- 92	626.50															
69X-1, 40- 42	631.18															
70X-1, 29- 31	643.49															
71X-1, 103-105	653.73															
-2, 12- 14	654.32									R		*B. latdorfensis*	P 21a			
72X-1, 20- 22	662.40									R						
-2, 20- 22	663.90											barren				

Note: Rare (R), less than 3%; few (F), 3%-15%; common (C), 15%-30%; abundant (A), more than 30%.

Table 7. Zonation of Bolboforma in Leg 114 holes investigated.

Bolboforma zone	Depth (mbsf) Hole 699A	Hole 700B	Hole 702B	Hole 703A	Hole 704B
B. latdorfensis	251.78–285.28			99.30–110.60	654.32–662.40
B. geomaris	297.80–335.05			112.10–130.15	
B. eocena	336.34–373.10	26.81–47.26	26.87–75.00	131.65–193.80	
B. indistincta	374.29–389.56	61.65–63.90	76.50–96.05	200.80	

quence prevent paleomagnetic analysis. Only the C15N(?)/C13R datum (37.24 Ma) is well documented, between 85 and 75 cm in Section 114-703A-15H-2 (130.75 and 130.65 mbsf, respectively) (Hailwood and Clement, this volume). This date falls between samples at 131.65 and 130.15 mbsf, which document the boundary between the *B. eocena* and *B. geomaris* Zones. In comparison with Hole 699A, parts of the *B. geomaris* Zone seem to be missing from Hole 703A. The next well-established paleomagnetic datum is the C12R/C12N shift (32.90 Ma) at 95.74 mbsf, which lies in a sequence barren of *Bolboforma*.

Sediments from Cores 114-704B-71X to 114-704B-72X contain *Bolboforma*, but no paleomagnetic data are available.

According to previously mentioned datums it is possible to date approximately the zones defined here:

~36 Ma—base of *B. latdorfensis* Zone
>38.1-<39.2 Ma—base of *B. geomaris Zone*
~43.0 Ma—base of *B. eocena* Zone
~44.5 Ma—base of *B. indistincta* Zone.

CONCLUSIONS

1. *Bolboforma* taxa are present in Paleogene sediments of the subantarctic Atlantic. The stratigraphic range of *Bolboforma* extends down into the middle Eocene.

2. The results of *Bolboforma* analysis of ODP Leg 114 Holes 699A, 700B, 702B, 703A, and 704B enable us to establish a fourfold biostratigraphic zonation from the late middle Eocene to early Oligocene.

3. The *Bolboforma* zones are correlated to the paleomagnetic record and dated for approximate age.

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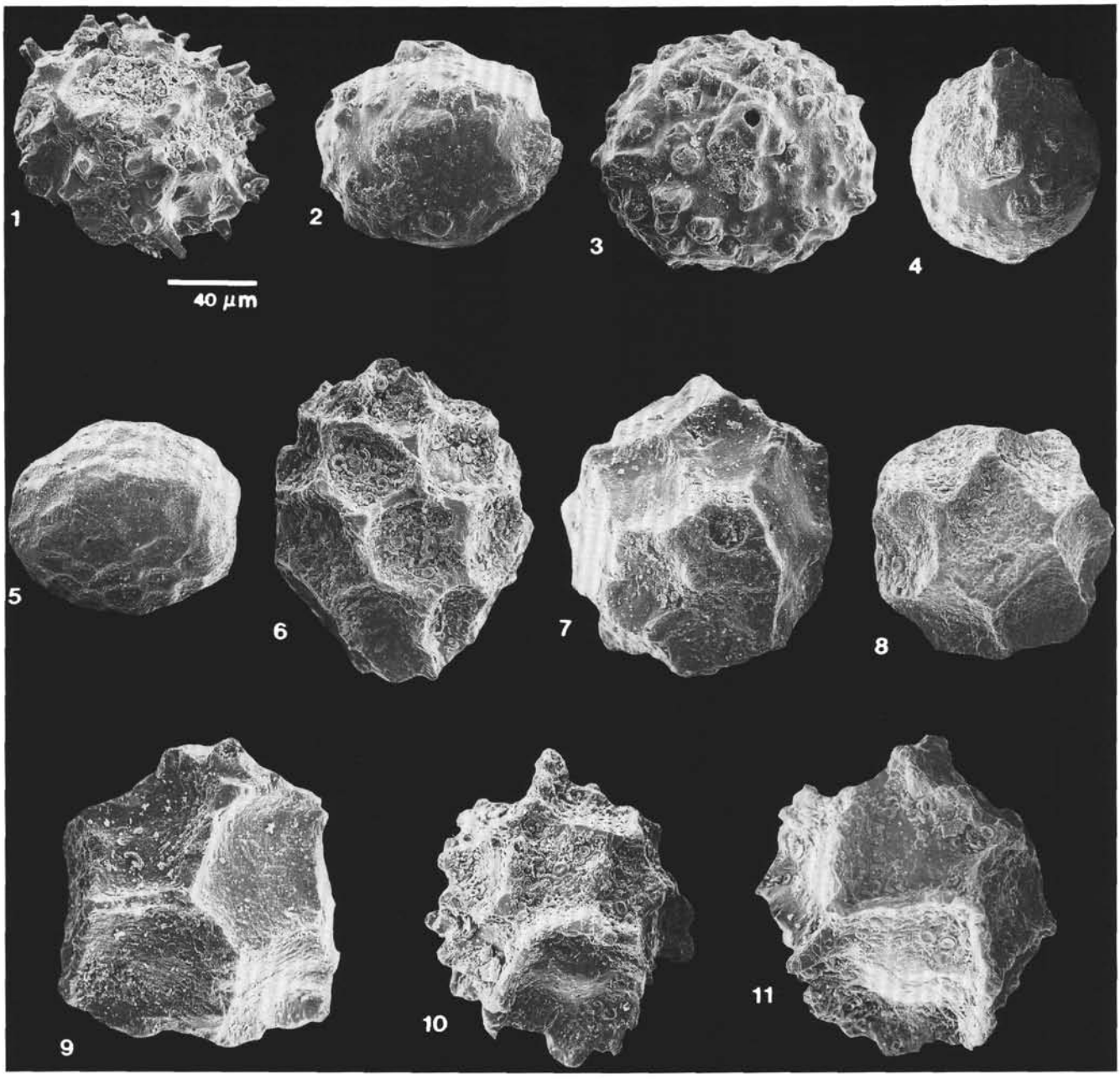

Plate 1. *Bolboforma*, Leg 114. **1.** *Bolboforma latdorfensis* Spiegler, in press. Empty spheroid outer test, coarsely reticulated and ornamented by long irregularly arranged spines. Sample 114-699A-31X-5, 118–120 cm. **2–4.** *Bolboforma pustula* Spiegler, in press. Empty spheroid bipolarly flattened test with irregularly arranged blunt spines. 2, 3. Sample 114-699A-27X-6, 114–116 cm; 4. Sample 114-703A-13H-1, 120–123 cm. **5.** *Bolboforma* sp. A. Spheroid bipolarly flattened test, smooth or ornamented by weak reticulations (cyst?). Sample 114-699A-30X-4, 104–106 cm. **6, 7.** *Bolboforma geomaris* Spiegler, in press. Empty elongated test ornamented by five to eight reticulations in equatorial diameter, no spines. 6. Sample 114-703A-13H-2, 120–123 cm; 7. Sample 114-699A-33X-4, 70–74 cm. **8, 9.** *Bolboforma* cf. *geomaris* Spiegler, in press. Very coarse reticulated with three to four reticulations in equatorial as well as polar diameter 8. Sample 114-703A-20X-1, 60–62 cm; 9. Sample 114-699A-33X-4, 70–74 cm. **10, 11.** *Bolboforma lamari* Mackensen and Spiegler, 1989. Empty pear-shaped test with coarse reticulation. Knobs and spines of different length are situated on the ridges. The aboral part of the test is bordered by a circular thickening with spines. Sample 114-703A-13H-2, 120–124 cm.

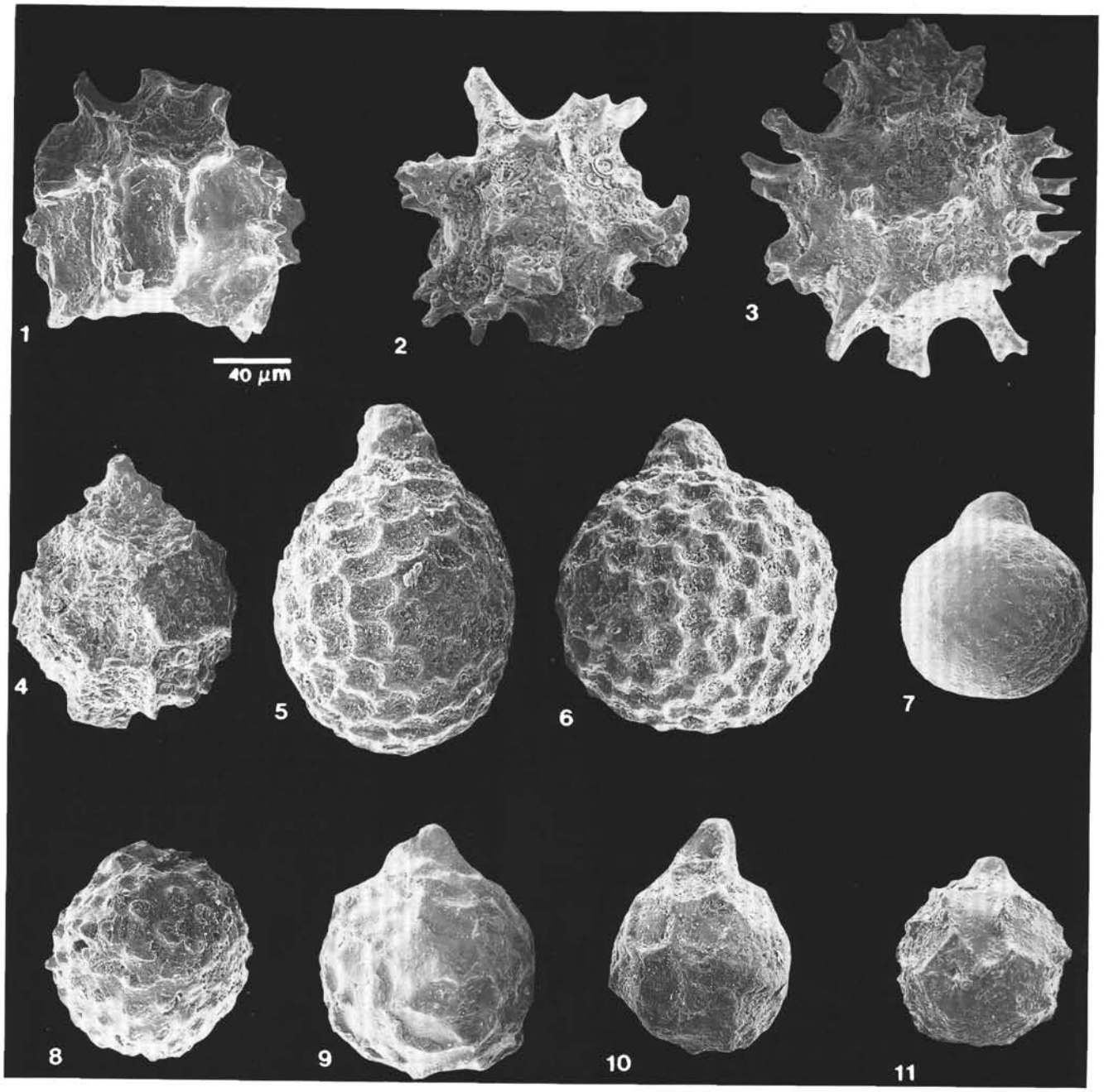

Plate 2. *Bolboforma*, Leg 114. **1–3.** *Bolboforma lamari* Mackensen and Spiegler, 1989. 1. Sample 114-699A-36X-6, 85–87 cm; 2. Sample 114-703A-19H-CC; 3. Sample 114-699A-36X-7, 45–47 cm. **4.** Transitional form between *Bolboforma indistincta* and *Bolboforma lamari*. Sample 114-699A-40X-3, 78–80 cm. **5, 6.** *Bolboforma eocena* Spiegler, in press. Empty spheroid to elongated test with a pronounced thick neck, ornamented by fine reticulations. 5. Sample 114-703A-17X-2, 85–87 cm; 6. Sample 114-703A-18X-3, 110–120 cm. **7.** *Bolboforma* sp. B. Small smooth test with a thick neck (cyst?). Sample 114-699A-36X-7, 45–47 cm. **8.** *Bolboforma praespinosa* Spiegler, in press. Small spheroid test ornamented by regularly arranged blunt spines. Sample 114-699A-36X-3, 85–87 cm. **9–11.** *Bolboforma indistincta* Spiegler, in press. Spheroid test with a pronounced thick neck and ornamented by indistinct reticulations. 9. Sample 114-699A-42X-5, 96–98 cm; 10. Sample 114-703A-21X-1, 80–82 cm; 11. Sample 114-699A-40X-2, 78–80 cm.