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39. *BOLBOFORMA* DANIELS AND SPIEGLER, FROM EOCENE AND LOWER OLIGOCENE SEDIMENTS, MAUD RISE, ANTARCTICA[1]

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ABSTRACT

Five species of *Bolboforma* have been found in middle Eocene to lower Oligocene sediments from Maud Rise, Weddell Sea, Antarctica (Leg 113, Holes 689B and 690B), the first reported *Bolboforma* from the Antarctic Paleogene. The previous oldest known occurrences of *Bolboforma* in the world's oceans were of late Eocene age and this study extends the known range to the middle middle Eocene (~44 Ma). Highest species diversity of *Bolboforma* in the Weddell Sea region of Antarctica occurred during the late Eocene, after which all but one important species disappeared before the Eocene/Oligocene boundary (36.5 Ma). The remaining species, *B. irregularis,* disappeared soon after, during the earliest Oligocene. The disappearance of *Bolboforma* in this region of Antarctica coincided with significant climatic cooling that occurred at the end of the Eocene and during the earliest Oligocene, when subpolar replaced temperate conditions. *Bolboforma* is not known from younger sediments in the Antarctic except for a brief interval during the late early Miocene, an interval of Neogene climatic warmth. The presence of *Bolboforma* in Eocene to lower Oligocene sequences in the Weddell Sea region of Antarctica is therefore consistent with this taxon's previously recognized association with temperate water masses. *Bolboforma* is of limited biostratigraphic value at present, because of relatively long stratigraphic ranges and diachronous extinctions. Previous suggestions that *Bolboforma* represents an encystment stage of phytoplankton require further critical study because the deposition, in large numbers, at paleodepths up to 2250 m in the open ocean, is an unlikely strategy for an encystment phase of a phytoplanktonic organism.

A new species, *Bolboforma antarctica*, is described, exhibiting a stratigraphic range from middle middle Eocene to the upper Eocene (~44 to 39 Ma).

INTRODUCTION

The genus *Bolboforma* Daniels and Spiegler 1974, was created to include a group of problematic marine, calcareous microfossils that were previously included with the benthic, foraminiferal genus *Lagena* (Clodius, 1922). The bulbous or pear-shaped tests differ from most foraminifers in exterior morphology, but more fundamentally by a lack of structure in the test wall which appears to consist of a single calcite crystal (Rögl and Hochuli, 1976). These authors were the first to recognize the possible planktonic-algal affinities of *Bolboforma* and Tappan (1980) considered that they may represent cysts of marine algae related to Chrysophytes. In addition to the northwest German location of Daniels and Spiegler, *Bolboforma* has been reported in deep-sea sediments from the North Atlantic and southwest Pacific (Müller et al., 1985; Echols, 1985; Murray, 1979; 1986; Poag and Karowe, 1986), the Arctic (McNeil, 1988), and Antarctica (Rögl and Hochuli, 1976). Widespread geographic distribution and limited stratigraphic range suggest the possible utility of some species as potential biostratigraphic, paleobiogeographic, and paleoenvironmental markers (Rögl and Hochuli, 1976; Murray, 1979; Müller et al., 1985; and Poag and Karowe, 1986). A summary of the sites where *Bolboforma* have been found and a history of investigation of the genus can be found in Poag and Karowe (1986; 1987).

This contribution describes the biostratigraphy of several species of *Bolboforma* from the richly fossiliferous Paleogene sequences drilled on Maud Rise, Weddell Sea, Antarctica (Fig. 1). At about 65°S, these sequences, as a composite, form the most southerly continuous calcareous sedimentary sequences in the world, thus representing a critical southern anchor for global biostratigraphic and biogeographic investigations.

MATERIALS AND METHODS

The samples studied were collected from Maud Rise, Antarctica (Fig. 1), an aseismic ridge located 700 km north of, and topographically isolated from, East Antarctica (Barker, Kennett, et al., 1988). Hole 689B was drilled at 64°31.01′S; 3°06.00′E at a water depth of 2080 m. Hole 690B was drilled at 65°09.63′S and 1°12.30′E at a water depth of 2914 m. Calcareous samples from the lower Eocene to lower Miocene sections in both holes were examined for the presence of *Bolboforma.* Generally two samples were examined for each core section. They were oven dried, weighed, soaked in water, and washed through a 63 μm sieve. The residue was dried, weighed again, and sieved into two fractions; a coarse fraction of >150 μm and a fine fraction (63–150 μm). The entire coarse fraction and one tray (5.5 × 9.5 cm) of the fine fraction were examined for each sample. The presence or absence of *Bolboforma* was noted and abundance estimated using the following criteria: R = rare, less than five specimens in the entire coarse and fine fraction examined; C = common, greater than five specimens in both fractions but not more than two in any quadrant; A = abundant, more than two specimens observed in most quadrants in any tray from either coarse or fine fraction. Individual species can be accurately differentiated using the light microscope. However, because of their small size (~74–200 μm), the scanning electron microscope (SEM) is vital for correct systematics. Specimens were subjected to ultrasonic cleaning for the purpose of SEM examination. Maud Rise specimens are coated with coccoliths, which appear to be cemented onto the *Bolboforma* tests. Substantial ultrasonic cleaning often eroded the surface ornamentation. Consequently, the resulting SEM photographs (Pl. 1) still have some coccoliths adhering to the surface.

Sample 113-690B-12H-2, 110–114 cm, observed to contain the largest numbers of *Bolboforma*, was chosen to calculate

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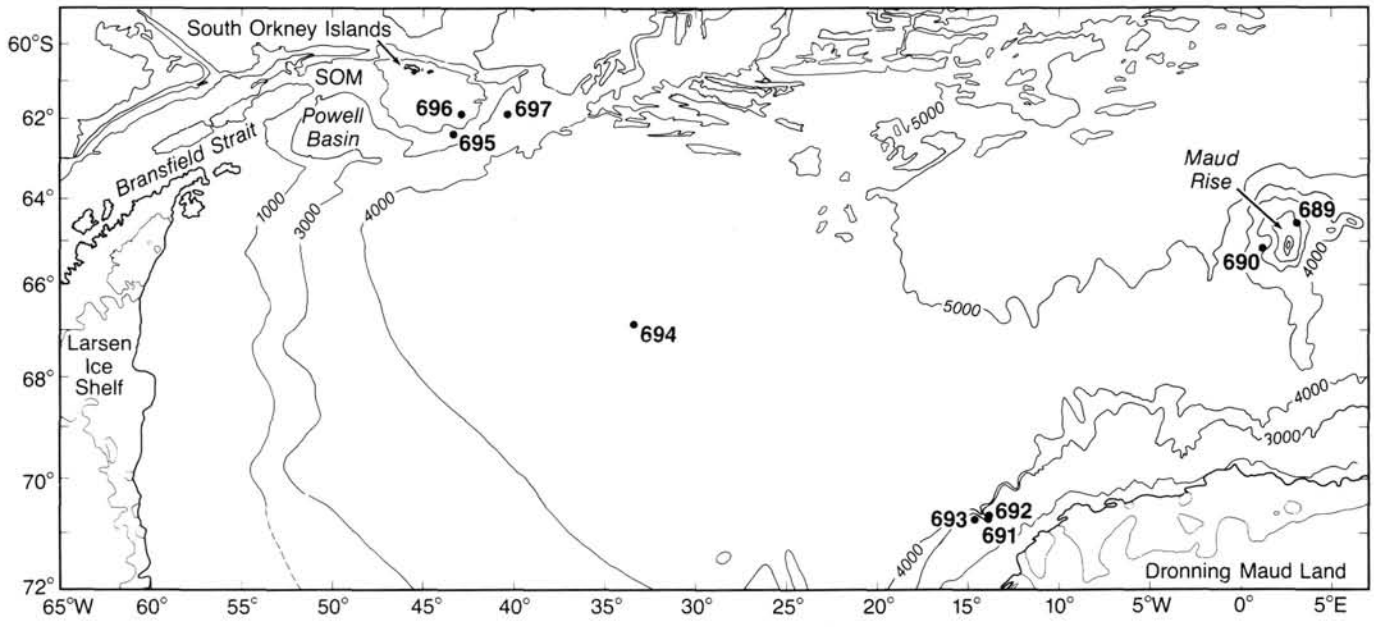

Figure 1. Location of Leg 113 Sites (689 to 697) in Weddell Sea. Sites 689 and 690 on Maud Rise. SOM = South Orkney microcontinent.

maximum flux rates (gm/cm^2/1000 yr) and the percentage of *Bolboforma* in the Eocene sediments of Maud Rise. A weighed, dried aliquot (>63 μm) of washed sample was separated into two fractions: *B. antarctica* and other material. The separated fractions were, in turn, weighed and flux rates calculated using sedimentation rates from Stott and Kennett, this volume, chapter 34.

RESULTS

Bolboforma species are found in sediments ranging in age from middle Eocene to early Oligocene (Tables 1, 2; Fig. 2). The most common form is *B. antarctica* n. sp., which occurs persistently and often abundantly throughout the upper part of the middle Eocene to the upper Eocene in both Holes 689B and 690B. The last occurrence of this form is within the upper Eocene. Planktonic foraminifers associated with *B. antarctica* n. sp. in the middle Eocene are *Acarinina primitiva* (Finlay) and *Subbotina linaperta* (Finlay). The last appearance of the latter species marks the boundary between the middle and upper Eocene within the upper part of Chron 17 (Stott and Kennett, this volume, chapter 34). In the upper Eocene, *B. antarctica* is associated with typical upper Eocene foraminiferal species such as *Subbotina angiporoides* (Hornibrook) and *Globorotaloides suteri* Bolli together with *Globigerinatheka index* (Finlay). In addition to *B. antarctica,* both holes contain other less abundant species of *Bolboforma.* These are as follows:

Hole 689B

Bolboforma reticulata Daniels and Spiegler occurs over a narrow interval in the middle middle Eocene and reappears again in the upper Eocene where it is most abundant (Table 1). *Bolboforma irregularis* Daniels and Spiegler ranges from the upper Eocene to the lower Oligocene. *Bolboforma* sp. is found with a very narrow range in the upper Eocene, at a level where *Bolboforma* diversity is the highest.

Hole 690B

B. spinosa Daniels and Spiegler was found in one sample of lowest Oligocene age, being present in small numbers only in the <150 μm size fraction (Table 2). The absence of most other species found in Hole 689B is partly attributed to a significant unconformity that removed much of the upper Eocene and lower Oligocene, approximately equivalent to Paleomagnetic Chrons 12–15 (Fig. 2).

TAXONOMIC NOTES

Genus *Bolboforma* Daniels and Spiegler, 1974

Bolboforma antarctica n. sp.
(Pl. 1, Figs. 1–7)

Description. Single chambered, robust, pear-shaped test, slightly laterally compressed (Pl. 1, Fig. 3). Aboral end rounded, not distinctly flattened. Occurs in both coarse and fine fraction. Length 75–200 μm, but most specimens <160 μm. Each specimen with aperture at end of neck. Neck usually protrudes distinctly but may occasionally be less conspicuous, especially on larger specimens. Neck usually about 20 μm in diameter and about 10 μm long. (Pl. 1, Fig. 2). Tiny circular oral aperture (1–3 μm in diameter) surrounded by heavily-thickened, smooth calcite of the neck (Pl. 1, Fig. 3). Surface ornamentation consists of distinctive polygonal depressions separated by ridges. Patterning is usually distinctly pentagonal or hexagonal (12–30 μm in diameter) or can be slightly irregular. As observed under the SEM, there are sometimes short, thickened processes at the intersection of polygons (Pl. 1, Fig. 1), although these are not observed under the light microscope. Wall thick (10–13 μm) and has no apparent ultrastructure (Pl. 1, Fig. 5). Tests sometimes abraded with polygonal ridges smoothed close to body of test. Otherwise this species exhibits little variation.

Remarks. However, a very rare form (two specimens among many thousands observed) is quite different (see Pl. 1, Fig. 6) being larger (about 200 μm in length) and having ornamentation that is even more distinctly hexagonal with deep polygons separated by fine, unthickened ridges. Also, the neck is pointed. These two specimens were found in Samples 113-689B-16H-4, 110–114 cm, and -18H-3, 36–38 cm.

Bolboforma antarctica n. sp. differs from *B. reticulata* Daniels and Spiegler in having finer reticulation. It differs from *B. metzmacheri* Clodius in lacking the broadly flattened aboral region and in being evenly rather than unevenly laterally compressed. *Bolboforma badenensis* Szczechura differs from *B. antarctica* by being circular in cross section, with oblong lateral profile, little or no neck and with an aboral end lacking ornamentation (McNeil, 1988).

Stratigraphic Range. middle to upper Eocene.

Occurrence. Thousands of well-preserved specimens from Hole 113-690B and Hole 113-689B.

Table 1. Range chart for *Bolboforma* in Hole 113-689B. A = abundant, C = common, R = rare.

Epoch	Chron	HOLE 689B core-section	*B. antarctica*	*B. reticulata*	*B. irregularis*	*Bolboforma* sp.
lower Oligocene	10	11H-5, 35-39 cm				
	11	12H-2, 35-39 cm				
	12	12H-5, 35-39 cm				
		13H-1, 110-115 cm				
		13H-3, 35-39 cm				
	13	13H-5, 34-38 cm				
		13H-6, 34-38 cm				
		14H-1, 37-39 cm			R	
		14H-1, 110-114 cm			R	
		14H-2, 36-40 cm			R	
upper Eocene		14H-2, 110-114 cm			R	
	15	14H-3, 36-40 cm			A	
		14H-3, 110-114 cm			C	
		14H-4, 36-40 cm			C	
		14H-4, 110-114 cm			A	
		14H-5, 36-40 cm			R	
		14H-5, 110-114 cm			R	
	16	14H-6, 36-40 cm			R	
		14H-6, 110-114 cm			R	
		15H-1, 35-39 cm			A	
		15H-1, 107-112 cm			C	
		15H-2, 35-39 cm			R	
		15H-2, 107-112 cm			A	
		15H-3, 35-39 cm	R		C	
		15H-3, 107-112 cm	C		A	
		15H-4, 35-39 cm	C	C	R	
		15H-4, 107-112 cm	C	C	R	R
		15H-5, 35-39 cm	C	R	R	
	17	15H-5, 107-112 cm	C	C	C	
		15H-6, 35-39 cm	C	A		
		15H-6, 107-112 cm	C	A	R	R
		15H-7, 35-39 cm	C	A		A
		16H-1, 35-37 cm	C	C	R	
		16H-1, 110-114 cm	C	R		
		16H-2, 35-37 cm	C		R	
middle Eocene		16H-3, 35-37 cm	A			
		16H-3, 110-114 cm	A			
		16H-4, 35-37 cm	A			
		16H-4, 110-114 cm	A			
		16H-5, 35-37 cm	A			
		16H-5, 110-114 cm	C			
		16H-6, 35-37 cm				
		16H-6, 110-114 cm	A			
		16H-7, 35-37 cm	A			
		17H-1, 35-37 cm	A			
		17H-1, 87-89 cm	A			
		17H-1, 110-112 cm	A			
		17H-2, 35-37 cm	A			
		17H-2, 87-89 cm	A			
		17H-2, 110-112 cm	C			
		17H-3, 35-37 cm	A			
		17H-3, 87-89 cm	A			
		17H-3, 110-112 cm	C			
		17H-4, 35-37 cm	A			
		17H-4, 87-89 cm	A			
		17H-4, 110-112 cm	A			
		17H-5, 35-37	C			
		17H-5, 87-89 cm	C			
	18	17H-5, 110-112 cm	C			
		17H-6, 35-37 cm				
		17H-6, 110-112 cm				
		17H-7, 35-37 cm	C			
		18H-1, 36-38 cm	C			
		18H-2, 36-38 cm	C			
		18H-2, 110-113 cm	C	R		
		18H-3, 36-38 cm	C	R		
		18H-3, 110-113 cm		C		
		18H-4, 36-38 cm	R	C		
	19	18H-4, 110-113 cm	R	C		
		18H-5, 36-38 cm				
		18H-5, 110-113 cm				
		18H-6, 36-38 cm				
		19H-1, 110-114 cm				
		19H-3, 110-114 cm				
	20	20H-3, 35-39 cm				
		21H-1, 35-39 cm				

Table 2. Range chart for *Bolboforma* in Hole 113-690B. A = abundant, C = common, R = rare.

Epoch	Chron	HOLE 690B core-section	*B. antarctica*	*B. spinosa*
lower Oligocene	11	10H-4, 35-40 cm		
		10H-5, 35-40 cm		
		10H-6, 35-40 cm		
		10H-7, 35-40 cm		
		11H-1, 35-39 cm		
		11H-1, 110-114 cm		
		11H-2, 35-39 cm		
		11H-2, 110-114 cm		C
upper Eocene	16	11H-4, 35-39 cm	C	
		11H-4, 110-114 cm	C	
		11H-5, 110-114 cm	A	
		11H-6, 110-114 cm	A	
	17	12H-1, 36-40 cm	A	
		12H-1, 110-114 cm	A	
		12H-2, 36-40 cm	A	
		12H-2, 110-114 cm	A	
		12H-3, 36-40 cm	A	
		12H-3, 110-114 cm	C	
		12H-4, 36-40 cm	C	
		12H-4, 70-72 cm	C	
	18	12H-4, 110-114 cm	C	
		12H-5, 36-40 cm	C	
		12H-5, 69-74 cm	C	
		12H-5, 110-114 cm	C	
		12H-5, 138-141 cm	C	
middle Eocene		12H-6, 36-40 cm	C	
		12H-6, 112-114 cm		
		12H-7, 36-40 cm		
		13H-1, 36-40 cm		
		13H-1, 110-114 cm		
		13H-2, 36-40 cm		
	20	13H-2, 110-114 cm		
		13H-3, 110-114 cm		
		13H-4, 110-114 cm		
		13H-6, 36-40cm		
		14H-1, 110-114 cm		
		14H-2, 110-114 cm		
	21	14H-4, 110-114 cm		
		14H-6, 110-114 cm		
lower Eocene	22	15H-3, 36-40 cm		
		15H-7, 36-40 cm		
	23	16H-1, 110-114 cm		
		16H-3, 110-114 cm		
upper Paleo.	24	17H-1, 110-114 cm		
		17H-4, 110-114 cm		
		17H-7, 36-40 cm		

Size. 74–200 μm in length; holotype (Pl. 1, Fig. 2) 85 μm long, 71 μm wide. Paratype (Pl. 1, Fig. 1) 87 μm long, 77 μm wide. Paratype (Pl. 1, Fig. 7) 88 μm long, 63 μm wide.

Types are deposited in the United States National Museum, Washington, D.C.

Holotype. USNM 441435 (Pl. 1, Fig. 2).

Paratypes. USNM 441436 (Pl. 1, Fig. 1); USNM 441437 (Pl. 1, Fig. 7)

Holotype locality. Maud Rise, Antarctica, Sample 113-690B-11H-4, 110–114 cm.

Bolboforma spinosa Daniels and Spiegler, 1974
(Pl. 1, Figs. 8–10)

Remarks. Small numbers of specimens of *Bolboforma spinosa*, all of which occur in the size fraction < 150 μm, were observed in only one sample. The specimens appear translucent under the light microscope because the walls are not covered with coccoliths like the other species. *B. spinosa* is characterized by a spherical test with flat aboral end, oral neck, and with an ornamentation of short, thick, well-separated spines. The spines appear solid where abrasion has revealed their internal structure (Pl. 1, Fig. 10).

Stratigraphic Range. lower Oligocene, Hole 113-690B.

Occurrence. Sample 113-690B-11H-2, 110–114 cm; fewer than 50 specimens.

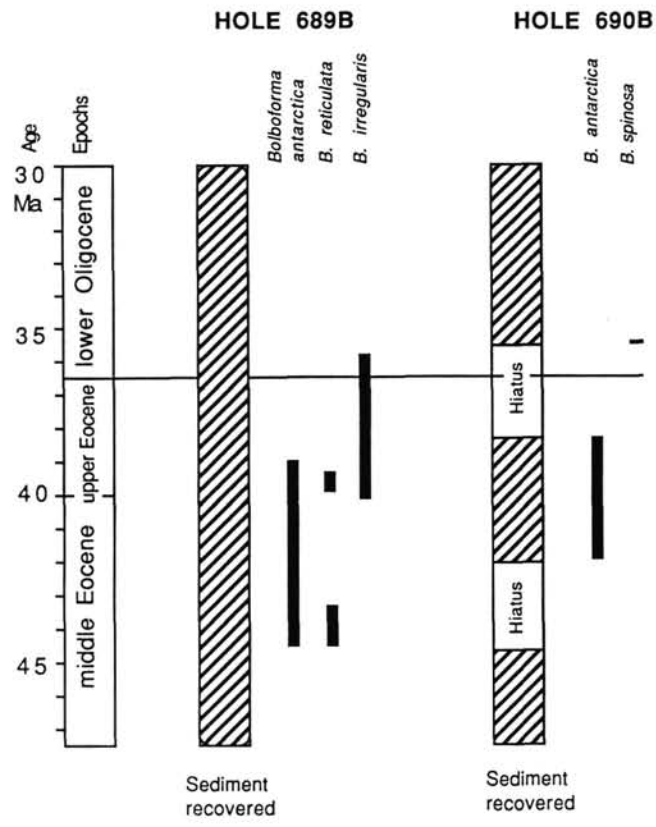

Figure 2. Comparison figure showing age, core recovery, and hiatuses together with first and last occurrences of *Bolboforma* species in Holes 689B and 690B.

Bolboforma reticulata Daniels and Spiegler, 1974
(Pl. 1, Figs. 11–14)

Remarks. The test of *Bolboforma reticulata* is almost spherical, with a neck having a circular to slit-like aperture. Ornamentation consists of large polygons (Pl. 1, Figs. 11–13) with depth up to 15 μm (Pl. 1, Fig. 14). There is no tendency for spines at polygonal corners as figured, but not described, in the original description of Daniels and Spiegler (1974). Other authors (Murray, 1984; Poag and Karowe, 1987) have published figures of *B. reticulata* without spines and this may therefore be a non-conservative feature of the species. The test ranges in length from exclusively < 150 μm in the middle Eocene to exclusively > 150 μm in the upper Eocene.

Stratigraphic Range. Discontinuous in middle and upper Eocene.

Occurrence. Limited occurrences in Hole 113-689B; a total of a few hundred specimens was observed.

Bolboforma irregularis Daniels and Spiegler, 1974
(Pl. 1, Figs. 15–16)

Remarks. All specimens of *B. irregularis* are distinctly spinose and some are so heavily coated with coccoliths that it is impossible to see the reticulate structure beneath. A circular aperture 6 μm in diameter is surrounded by a smooth, flat lip 2 μm in width. This species has very deep (up to 30 μm), reticulate polygons with spines on the ridges. Where two spines meet, bifurcated tips can be formed. Spines can extend up to 16 μm from the polygon ridge.

Poag and Karowe (1987), described a wall composed of three layers of calcite for this species, but there was no evidence for this in the Maud Rise specimens (Pl. 1, Fig. 16). Ultrasonic cleaning breaks the spines and produces individuals that look more like those figured by Daniels and Spiegler (1974). Maud Rise specimens conform more to the type figured in Poag and Karowe (1986) (fig. 3, (E)).

Stratigraphic Range. upper Eocene through lower Oligocene.

Occurrence. Hole 113-689B; a total of several hundred specimens was observed.

Bolboforma sp.
(Pl. 1, Figs. 17–19)

Description. *Bolboforma* sp. is heavily calcified with coarse, blade-like appendages. It is >150 μm in length. The aperture is at the end of the neck surrounded by a distinct flange (Pl. 1, Fig. 17). The aboral end is usually marked by at least one thin, long, distinct, flat-topped projection. The species was abundant in only one sample (Sample 113-689B-15H-7, 35–39 cm) and rare in two others (Samples 113-689B-15H-4, 107–112 cm, and -15H-6, 107–112 cm).

Remarks. We are not completely certain that this is a *Bolboforma*. Cross-sectional views and close examination with the SEM show no discernible wall structure even under high magnification (>2000×) suggesting placement with *Bolboforma*. In contrast, the neck flange and general shape are not typical of the genus but are more characteristic of dinoflagellates.

Stratigraphic Range. upper Eocene.

Occurrence. Hole 113-689B: Over 100 specimens were observed.

DISCUSSION

The ranges of species of *Bolboforma* for the Weddell Sea region of the Antarctic Paleogene are best determined in Hole 689B, which contains a nearly complete stratigraphic record from middle middle Eocene to the middle Oligocene. In Hole 690B the uppermost Eocene and earliest Oligocene are missing at an unconformity. This unconformity partially explains the lower diversity of *Bolboforma* in Hole 690B compared with Hole 689B. In addition, an unconformity is present in Hole 690B just before the first appearance of *B. antarctica* in the middle middle Eocene (Stott and Kennett, this volume, chapter 34). Therefore, in Hole 690B, the first and last appearance of *Bolboforma* coincides with the presence of unconformities.

The Maud Rise sequences establish the earliest known appearance of species of *Bolboforma* in Antarctica and in the world's oceans (*B. antarctica* and *B. reticulata*) in the middle middle Eocene within Paleomagnetic Chron 19 (~44 Ma; Stott and Kennett, this volume, chapter 34). Previous reports have documented *Bolboforma* as no older than the late Eocene (Poag and Karowe, 1986). The last appearance of *Bolboforma* on Maud Rise occurred during the earliest Oligocene within Paleomagnetic Chron 13 (~36 Ma).

Murray (1986) noted that most species of *Bolboforma* are long-ranging and hence of limited value as biostratigraphic markers. Two of the Maud Rise forms, *Bolboforma* sp. and *B. spinosa,* appear only fleetingly within the late Eocene or early Oligocene. Three of the five Maud Rise *Bolboforma* species are long-ranging. Both *B. antarctica* and *B. reticulata* have a total range from the middle middle Eocene to the early late Eocene, a range of 5.5 m.y., while *B. irregularis* ranges from early late Eocene to the earliest Oligocene, a range of 4 m.y. (Fig. 2). The last appearance of all but one of these species (*B. irregularis*) of *Bolboforma* is within the upper Eocene. The range of *B. irregularis* continued across the Eocene/Oligocene boundary and disappeared in the Maud Rise area during the earliest Oligocene.

The highest diversity of *Bolboforma* in the study area occurred during the late Eocene. The disappearance of all but one important form in the late Eocene was almost certainly associated with the cooling of surface waters at that time (Kennett and Shackleton, 1976; Barker, Kennett, et al., 1988). The slightly later disappearance of *B. irregularis* during the earliest Oligocene seems to have been due to a continuation of this cooling trend. A younger occurrence of *Bolboforma* (including *B. spinosa*) in the Antarctic region is known from latitudes similar to the Maud Rise (65°S) in the Bellingshausen Basin. Here four or five species of *Bolboforma* were reported by Rögl and Hochuli (1976) from one short interval in the upper lower Miocene (N6–N7). This interval was a time of relative warmth in the Antarctic (Shackleton and Kennett, 1975; Kennett, 1977, 1978) and it is likely that *Bolboforma* reappeared briefly in Antarctic waters then, in response to this warmth. A search of the Maud Rise materials failed, however, to reveal any *Bolboforma* younger than the earliest Oligocene. The Neogene sequence is dominantly biosiliceous on Maud Rise, but even samples containing calcareous microfossils do not contain *Bolboforma*.

Three of the species found in Maud Rise sediments (*Bolboforma spinosa, B. irregularis,* and *B. reticulata*) have also been reported from Miocene sediments at lower latitudes (Poag and Karowe, 1986). Thus the last appearance of these species in the Maud Rise area, as presently known, is earlier than at lower latitudes. However, the distribution of *Bolboforma* is poorly known and further research may reveal different stratigraphic ranges than the sites studied to date. We suggest that the upper ranges here were controlled by cooling of surface waters at the end of the Eocene and during the earliest Oligocene. The lowermost occurrence of *B. reticulata* and *B. irregularis* during the latest middle Eocene is similar to those previously reported near the base of the upper Eocene for *B. reticulata* in the southwest Pacific (Poag and Karowe, 1986), and for *B. irregularis* in eastern and western North Atlantic and from northwest Germany (Poag and Karowe, 1986). It is possible therefore that the first appearances of all the common and persistent species on Maud Rise (*B. antarctica, B. reticulata,* and *B. irregularis*) resulted from evolution and were not climatically controlled.

This investigation extends the known Antarctic range of *Bolboforma* into the middle to late Paleogene. Previous documentation of *Bolboforma* in Antarctic waters was restricted to the late early Miocene (Rögl and Hochuli, 1976). *Bolboforma* has not yet been reported in tropical to warm subtropical waters between 30°S and 30°N (Poag and Karowe, 1986). In the North Atlantic, diversity of *Bolboforma* was highest in temperate areas during the Miocene (Poag and Karowe, 1986). *Bolboforma* seems to have been restricted to temperate water masses throughout its evolution (Murray, 1984; Müller et al., 1985; Echols, 1985; Poag and Karowe, 1986). The Antarctic Ocean was temperate until the earliest Oligocene at which time surface water temperatures dropped giving rise to subpolar to polar conditions (Kennett, 1977). *Bolboforma* therefore seems also to have been associated with temperate surface waters in the Antarctic and disappeared upon cessation of these conditions. *Bolboforma* reappeared briefly (Rögl and Hochuli, 1976) in the lower Miocene at a time of relatively warmer conditions.

Bolboforma has usually been reported from continental margin areas or in shallower bathyal depths (Poag and Karowe, 1987). The Maud Rise samples are clearly remote from a continental margin setting, being located in the open-ocean pelagic realm 700 km north of the East Antarctic margin. The depth of deposition during the middle Eocene for Hole 689B was 1400 m while that of Hole 690B was 2250 m (Kennett and Stott, this volume). Thus the distribution of *Bolboforma* appears to be no different than that of planktonic foraminifers or calcareous nannofossils. However, they may be found abundantly and in a well-preserved state in deep-sea sediments where carbonate dissolution has all but eliminated foraminifers (Müller et al., 1985; Echols, 1985). *Bolboforma*, during the Paleogene, withstood the long, seasonal, dark and light periods characteristic of the Antarctic at latitudes of 65°S. The high abundance of *Bolboforma* in many Maud Rise samples (calculated to form up to 55% by weight of the sediment size fraction greater than 63 μm) suggests that the genus may have produced large plankton blooms, probably during the summer or spring months. Conversely, low flux rate (0.004 gm/cm^2/1000 yr) as calculated in Sample 113-690B-12H-2, 110–114 cm, would preclude annual blooms but instead suggests that *Bolboforma* is produced dur-

ing intermittent blooms or perhaps even by slow accumulation. Some previous workers have suggested that *Bolboforma* is a phytoplankton cyst or resting stage formed to withstand unfavorable conditions (Tappan, 1980; Murray, 1984). If this is correct, why does *Bolboforma* occur in large numbers at depths as great as 2250 m in the open Antarctic Ocean? Tests with a diameter the size of *Bolboforma* (74–200 μm) would be expected to sink to the ocean floor in just a few weeks, transporting them to deep ocean regions far removed from the photic zone. The possibility that *Bolboforma* represents an algal encystment stage remains an open question.

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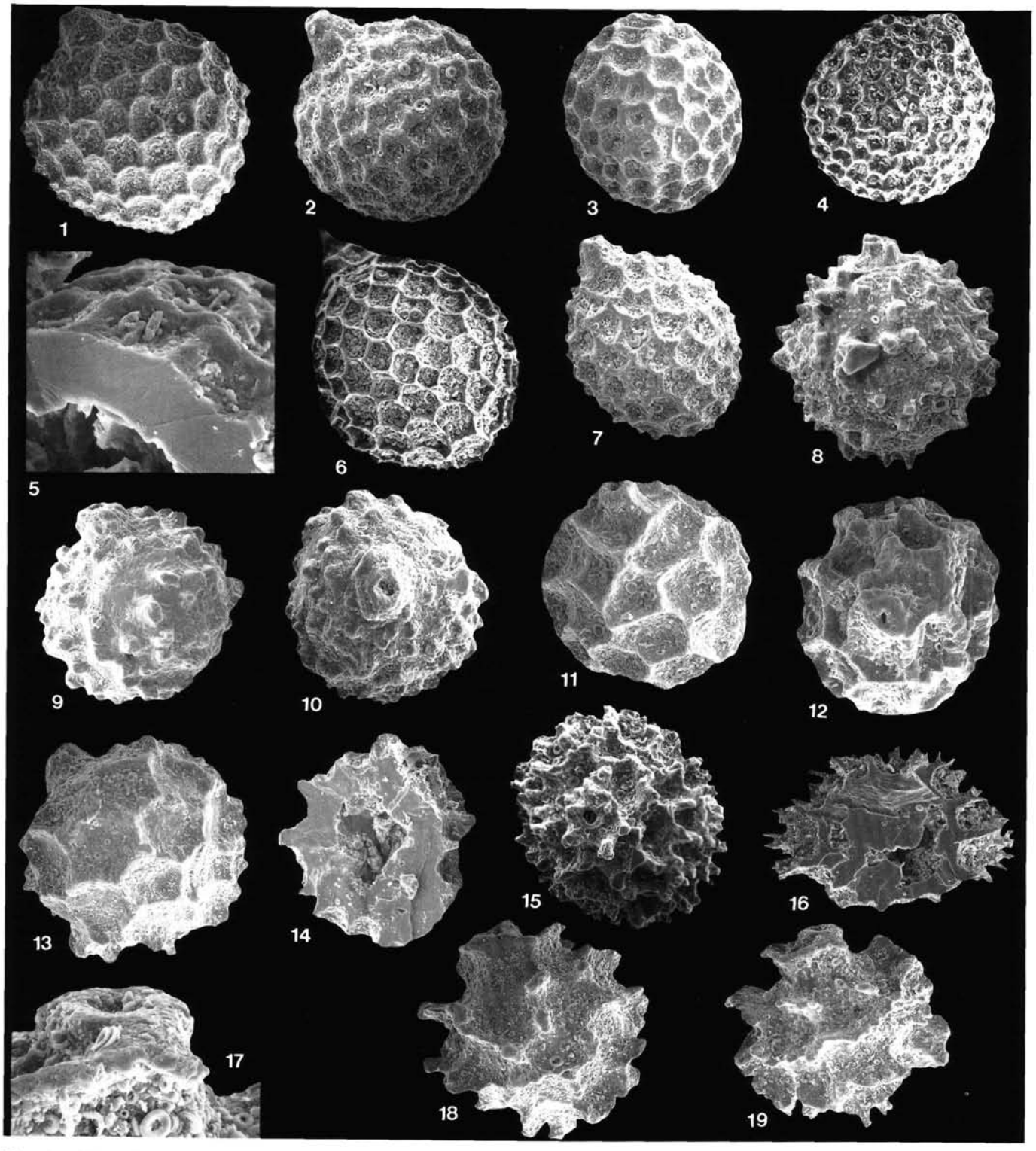

Plate 1. **1–7.** *Bolboforma antarctica* n. sp. (1) Paratype, lateral view, ×520, Sample 113-690B-11H-4, 110–114 cm; (2) Holotype, lateral view, ×520, Sample 113-690B-11H-4, 110–114 cm; (3) Oral view, ×340, Sample 113-690B-12H-2, 110–114 cm; (4) Oral/lateral view of specimen without distinct neck, ×200, Sample 113-689B-17H-1, 110–112 cm; (5) Wall cross section, ×1200, Sample 113-689B-18H-2, 36–38 cm; (6) Aboral/lateral view, rare form, ×200, Sample 113-689B-16H-4, 110–114 cm; (7) Paratype, lateral view, ×480, Sample 113-689B-17H-3, 87–89 cm. **8–10.** *Bolboforma spinosa* Daniels and Spiegler. (8) Aboral? view, ×580, Sample 113-690B-11H-2, 110–114 cm; (9) Lateral view, ×520, Sample 113-690B-11H-2, 110–114 cm; (10) Oral view, ×560, Sample 113-690B-11H-2, 110–114 cm. **11–14.** *Bolboforma reticulata* Daniels and Spiegler. (11) Oral/lateral view, ×520, Sample 113-689B-15H-6, 35–39 cm; (12) Oral view, ×520, Sample 113-689B-18H-4, 35–39 cm; (13) Lateral view, ×360, Sample 113-689B-15H-6, 35–39 cm; (14) Cross section through walls showing central cavity, ×328, Sample 113-689B-15H-6, 107–112 cm. **15–16.** *Bolboforma irregularis* Daniels and Spiegler. (15) Oral view, ×360, Sample 113-689B-15H-1, 35–39 cm; (16) Cross section at tangential angle, showing bifurcated spines and deep reticulations, ×320, Sample 113-689B-15H-1, 35–39 cm. **17–19.** *Bolboforma* sp. (17) Apertural view, ×1040, Sample 113-689B-15H-7, 35–39 cm; (18) Lateral view, ×376, Sample 113-689B-15H-5, 107–112 cm. (19) Lateral view, ×320, Sample 113-689B-15H-7, 35–39 cm.