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# 37. MIDDLE EOCENE TO EARLY PLIOCENE *BOLBOFORMA* (ALGAE?) FROM THE KERGUELEN PLATEAU, SOUTHERN INDIAN OCEAN[1]

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## ABSTRACT

*Bolboforma* were recovered from all sites of Ocean Drilling Program (ODP) Leg 120 to the Central Kerguelen Plateau in the southern Indian Ocean. Eight Paleogene taxa, ranging from middle Eocene through early Oligocene, and nine Neogene taxa, ranging from late middle Miocene through earliest Pliocene, were recognized.

A *Bolboforma* zonation recently proposed for the middle Paleogene of the Leg 114 sites from the southern Atlantic Ocean is applicable to the Leg 120 material from the southern Indian Ocean. The age of zonal boundaries is consistent within a resolution of ±1 m.y. The ranges of some marker species have been extended, causing a redefinition of some late Eocene zonal boundaries. The revised zonal scheme agrees well with the Paleogene occurrence of *Bolboforma* species from the Leg 113 sites in the eastern Weddell Sea. This and the consistent presence of *Bolboforma* in Paleogene cores from the Antarctic ODP legs promise that *Bolboforma* stratigraphy will become a useful tool for the subdivision of sequences across the Eocene/Oligocene boundary from southern high latitudes.

The stratigraphic subdivision of the Miocene and Pliocene based on a Neogene *Bolboforma* zonation from the Norwegian Sea proved to be difficult and of limited stratigraphic value for the Leg 120 sites.

## INTRODUCTION

On Ocean Drilling Program (ODP) Leg 120, we drilled one site on the northern and four sites on the southern Kerguelen Plateau in the southern Indian Ocean: the northern Site 747 (1696 m water depth; 54°48.68′S, 76°47.64′E) and the four southern Sites 748 (1288 m water depth; 58°26.45′S, 78°58.89′E), 749 (1070 m water depth; 58°43.03′S, 76°24.45′E), 750 (2030 m water depth; 57°35.54′S, 81°14.42′E), and 751 (1634 m water depth; 57°43.56′S, 79°48.89′E). These sites recovered 60–160-m thick Neogene sections of foraminifer diatom oozes and diatom nannofossil oozes, and 60- and 320-m thick Paleogene sections of foraminifer oozes and diatom nannofossil oozes (Schlich, Wise, et al., 1989). Leg 120 was the last of four ODP legs around Antarctica (113, 114, 119, and 120) that had one main objective in common: the reconstruction of the paleoceanographic and climatic changes that induced the onset of continental East Antarctic glaciation and the buildup of the Antarctic ice shield during the Cenozoic.

A period of particular interest is around the Eocene/Oligocene boundary, when major changes in benthic foraminifer assemblages (Douglas and Woodruff, 1981; Tjalsma and Lohmann, 1983; Mackensen and Berggren, this volume, among others), a worldwide shift to heavier values in the stable oxygen isotope composition of benthic foraminifers by about 1.5‰ (Savin, 1977; Miller et al., 1987), and findings of ice-rafted material as far north as on the Kerguelen Plateau (Schlich, Wise, et al., 1989; Ehrmann, 1991; Zachos et al., this volume; Breza and Wise, this volume) suggest a substantial cooling of bottom-water masses and probably the onset of continental East Antarctic glaciation.

In the Neogene, periods of particular interest are the early middle Miocene, when the formation of a major continental ice sheet on East Antarctica intensified (Shackleton and Kennett, 1975; Barker, Kennett, et al; 1988; Hambrey et al., 1989), as well as the late Miocene, when major ice shelves in the Weddell and Ross seas and in Prydz Bay probably were built up (Ciesielski et al., 1982; Mercer, 1983; Barrett, 1989; Hambrey et al., 1991).

During these periods of significant changes in Southern Hemisphere paleoceanography, abundant to frequent *Bolboforma* were deposited in the Leg 120 sediments (Fig. 1). *Bolboforma* von Daniels and Spiegler is a stratigraphically useful microfossil of uncertain origin similar in shape to the benthic foraminifer genus *Lagena;* in contrast to benthic foraminifers, however, it generally consists of monocrystalline low-magnesium calcite (von Daniels and Spiegler, 1974). *Bolboforma* is currently believed to be an algal cyst. Consequently, it is assigned an uncertain position within the Class Chrysophyceae (Tappan, 1980) and is informally grouped into the Family Bolboformaceae (Spiegler, 1987). However, as specimens with an inner encapsulated test have been found (Poag and Karowe, 1986, 1987; Spiegler, 1987), we suggest that, in comparison with other protophytes, the *Bolboforma* (outer test) seems to represent the vegetative stage and not the cyst stage of the organism (Spiegler, 1987). Generally, *Bolboforma* are rare in Oligocene sediments and absent in sediments older than the middle Eocene and younger than the early Pliocene.

During Leg 120, different *Bolboforma* species were found in Paleogene sediments of Holes 748B and 749B, ranging from the upper middle Eocene through the lower Oligocene (Mackensen and Spiegler, 1989). During the last few years, the number of new finds of *Bolboforma* rapidly increased, but its description from Paleogene samples is still rare. To date, the oldest *Bolboforma* is reported from the middle Eocene of ODP Legs 113 in the Weddell Sea (Kennett and Kennett, 1990) and 114 in the southern South Atlantic (Spiegler, 1991). Late Eocene *Bolboforma* spp. were found in the western North Atlantic and the western South Pacific on Deep Sea Drilling Project (DSDP) Legs 95 and 90 (Poag and Karowe, 1986, 1987), respectively, as well as in the Labrador Sea on ODP Leg 105 (Pallant and Kaminski, 1989).

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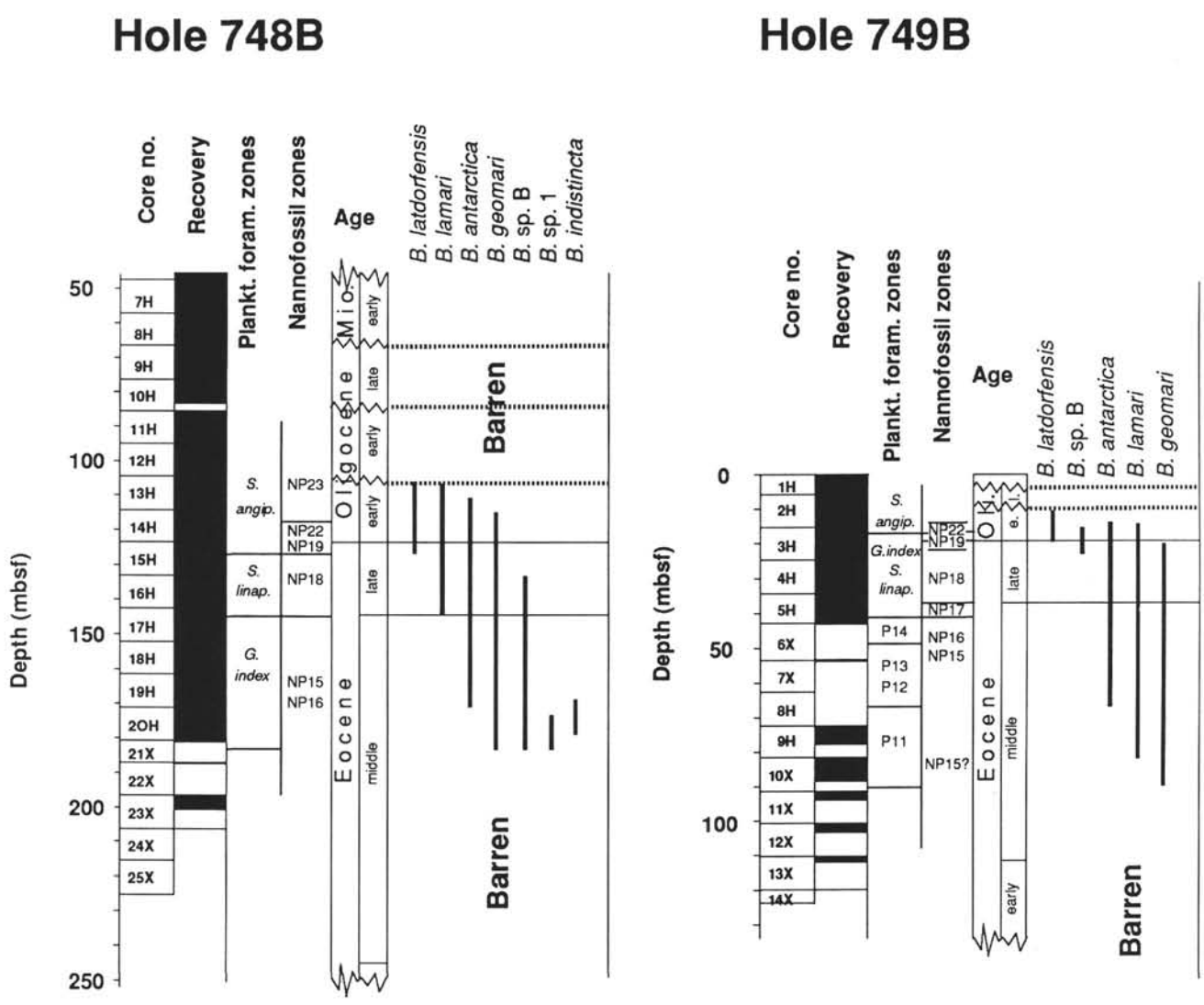


Figure 1. Ranges of Paleogene *Bolboforma* taxa plotted vs. core depth. Hiatuses and age estimates are from shipboard stratigraphy (Schlich, Wise, et al., 1989).

In the Neogene sediments of Holes 747B and 751A, *Bolboforma* were found from the middle Miocene through the lowermost Pliocene. Miocene *Bolboforma* spp. from northern and southern high latitudes are reported in Rögl and Hochuli (1976), Murray (1979, 1984, 1987), Müller et al. (1984), Echols (1985), McNeil (1988), Poag and Karowe (1986, 1987), Spiegler (1987), Qvale and Spiegler (1989), and Gazdzicki (1989).

## MATERIAL AND METHODS

We investigated 120 samples from lower Miocene through upper Pleistocene sections from Holes 747A, 748B, and 751A, and 88 samples from lower Paleocene through upper Oligocene sections from Holes 747A, 747C, 748B, 748C, 749B, and 750A for the occurrence of *Bolboforma*. Most of these samples were investigated previously for their benthic foraminifer content; thus, we refer to Mackensen (this volume) and Mackensen and Berggren (this volume) for a detailed listing of all of the samples. The samples were washed through a 63-$\mu$m mesh sieve and dried in an oven at 60°C. The residue was dry sieved over a 125-$\mu$m mesh sieve, and aliquots from this fraction were analyzed. In addition, the <125-$\mu$m size fraction was checked, and analyzed, if small *Bolboforma* were present.

Our taxonomic concept is based on Qvale and Spiegler (1989), Spiegler (1991), and Spiegler and von Daniels (1991). All the species documented and figured in this study (Plates 1 and 2) are briefly described in Spiegler (1991) and Qvale and Spiegler (1989) and fully described and taxonomically discussed in Spiegler and von Daniels (1991). During the review process of this paper, we became aware of a study of Leg 113 *Bolboforma* by Kennett and Kennett (1990). These authors describe a new Paleogene species, *Bolboforma antarctica* Kennett and Kennett, which is equivalent to Spiegler's *B. eocena* from Leg 114 (Spiegler, 1991). Because *B. eocena* is not completely described in the Leg 114 paper, and the Leg 113 volume will be published first, we adopted *B. antarctica* as the correct name and considered *B. eocena* as a junior synonym. One new middle Eocene species is figured in this paper, but it is kept in open nomenclature because until now it has been found in only two samples of Hole 748B (Plate 2, Figs. 8–9).

The *Bolboforma* zonations proposed by Spiegler (1991) for the Paleogene and by Qvale and Spiegler (1989) for the Neogene were used in this paper, and were correlated to the planktonic foraminifer and calcareous nannofossil zonations, and radiolarian zonations, respectively (Schlich, Wise, et al.,

| Hole 748B | | *Bolboforma* species | | | | | | | *Bolboforma* Zones | Planktonic foram. zones | Calcareous nannof. zones | Epoch | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Core, section, interval (cm) | Depth (mbsf) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Spiegler (1991) | Schlich, Wise, et al. (1989) | | | |
| 13H- 2, 72-76 | 106.82 | Barren | | | | | | | | | | | |
| 13H- 5, 72-76 | 111.32 | | | | | | R | R | | | NP 23 | | O |
| 13H- CC | 114.10 | | | R | | | | | | S. | | | l |
| 14H- 2, 72-76 | 116.32 | | | R | | R | C | C | *B. latdorfensis* | *angiporoides* | | | i |
| 14H- 5, 72-76 | 120.82 | | | | | | C | C | | (AP13) | | early | g |
| 14H- CC | 123.60 | | | | | | | C | | | NP19-NP22 | | o |
| 15H- 2, 72-76 | 125.82 | | | | | | F | A | | | | | |
| 15H- 5, 72-76 | 130.32 | | | R | | | A | | | | | | |
| 15H- CC | 133.10 | | | | | R | A | | | | | | |
| 16H- 2, 72-76 | 135.15 | | | | F | A | R | | *B. geomari* | *S. linaperta* | NP 18 | late | |
| 16H- 5, 72-76 | 139.65 | | | | | R | | | | | | | |
| 16H- CC | 142.60 | | | A | | R | R | | | | | | E |
| 17H- 5, 72-76 | 149.32 | | | A | R | | | | | | | | o |
| 17H- CC | 152.10 | | | A | | R | | | | | | | c |
| 18H- 2, 72-76 | 154.32 | | | C | R | | | | *B. eocena* | | NP 16 | | e |
| 18H- 5, 72-76 | 158.82 | | | A | | | | | | | | | n |
| 18H- CC | 161.60 | | | A | | R | | | | *G. index* | | | e |
| 19H- 2, 72-76 | 163.82 | | | R | | | | | | | | | |
| 19H- 5, 72-76 | 168.32 | | | | | R | | | | | | | |
| 19H- CC | 171.70 | R | | R | R | A | R | | | | | | |
| 20H- 2, 72-76 | 173.32 | | F | | | | | | | | NP15/NP16 | | |
| 20H- 5, 72-76 | 177.82 | R | | | | | | | *B. indistincta* | | | middle | |
| 20H- CC | 180.60 | | F | | R | C | | | | | | | |
| 21X- CC | 187.10 | Barren | | | | | | | | | | | |

Figure 2. Stratigraphic distribution of *Bolboforma* in samples from Hole 748B. The correlation of proposed *Bolboforma* zones with planktonic foraminifer and calcareous nannofossil zones is indicated. The frequency estimation refers to a maximum number of about 100 specimens counted when the fraction >125 μm of a 20-cm$^3$ sample is spread on a counting tray. Rare (R) = <3 specimens; few (F) = 3–15 specimens; common (C) = 15–30 specimens; and abundant (A) = >30 specimens. 1 = *B. indistincta* Spiegler and von Daniels, 1991; 2 = *Bolboforma* sp. 1 (this study); 3 = *B. antarctica* Kennett and Kennett, 1990; 4 = *Bolboforma* sp. B. Spiegler and von Daniels, 1991; 5 = *B. geomari* Spiegler and von Daniels, 1991; 6 = *B. lamari* Mackensen and Spiegler, 1989; and 7 = *B. latdorfensis* Spiegler and von Daniels, 1991.

1989), which in turn were preliminarily calibrated to a geomagnetic polarity time scale (Berggren et al., 1985a, 1985b; Aubry et al., 1988). All age determinations and the positions of hiatuses are based on shipboard stratigraphy; thus, the ranges given are approximate ones.

## OCCURRENCE AND STRATIGRAPHIC DISTRIBUTION

### Paleogene

Although an extended Neogene sedimentary sequence was recovered at Site 748, no *Bolboforma* were found in sediments younger than the lower Oligocene. In Hole 748B, *Bolboforma* were found from Samples 120-748B-20H-CC (180.60 mbsf) through -13H-5, 72–76 cm (111.32 mbsf) (Fig. 2). This sediment sequence corresponds to a time span of about 13 m.y. from the middle middle Eocene through the lower Oligocene (Fig. 2), that is, from approximately 47.0 Ma (the first appearance datum of *Globigerapsis index*) to 34.0 Ma (Schlich, Wise, et al., 1989).

In Hole 749B, *Bolboforma* were not as common as at Site 748. In many samples only a few specimens were found. Different species occurred from Samples 120-749B-10X-1, 72–76 cm (82.52 mbsf), through -2H-5, 72–76 cm (12.52 mbsf) (Fig. 3). This corresponds to a time span of about 15 m.y. from the middle middle Eocene through the lower Oligocene, that is, from approximately 46.5 to 31.8 Ma (Schlich, Wise, et al., 1989).

In Hole 750A, a typical middle Eocene *Bolboforma* fauna dominated by *B. antarctica* was found in Sample 120-750A-1R-CC (7.90 mbsf).

Four *Bolboforma* zones as defined in Spiegler (1991) were recognized in the Paleogene of Sites 748 and 749 (Figs. 2 and 3):

1. The nominate species of the *Bolboforma indistincta* Zone is found at Site 748 in Samples 120-748B-20H-5, 72–76 cm, and -19H-CC. The upper boundary of this partial range zone is below the first occurrence (FO) of *B. antarctica*, (i.e., between Samples 120-748B-20H-2, 72–76 cm, and -19H-CC [between 173.32 and 171.70 mbsf]). This corresponds to an age of approximately 44.5 ± 1.5 Ma. At Site 749, no *B. indistincta* were found, but the FO of *B. antarctica* is in Sample 120-749B-7X-CC. Therefore, the upper boundary of the *B. indistincta* Zone lies between Samples 120-749B-9H-CC and -7X-CC (between 81.80 and 62.80 mbsf). This corresponds to an age of between 45.0 ± 1.5 and 48.0 ± 1.5 Ma.

2. Spiegler (1991) defined the *Bolboforma antarctica* Zone as a total range zone. In this study, we need to redefine the upper boundary of this zone because of the scattered occurrence of the nominate species throughout the upper Eocene and lower Oligocene. Consequently, we chose the upper boundary of the *B. antarctica* Zone above the last common occurrence (LCO) of *B. antarctica*. In Hole 748B the upper boundary of this zone is found above Sample 120-748B-16H-CC (142.60 mbsf) and below Sample 120-748B-16H-5,

| Hole 749B | | *Bolboforma* species | | | | | | *Bolboforma* zones | Planktonic foram. zones | Calcareous nannof. zones | Epoch | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Core, section, interval (cm) | Depth (mbsf) | 3 | 4 | 5 | 6 | 7 | 8 | Spiegler (1991) | Schlich, Wise, et al. (1989) | | | |
| 2H- 2, 72-76 | 8,02 | Barren | | | | | | | | | | |
| 2H- 5, 72-76 | 12,52 | | | | | F | | | S. | NP23-NP25 | | O |
| 2H- CC | 15,30 | R | | | C | R | R | *B. latdorfensis* | *angiporoides* | | early | l |
| 3H- 2, 72-76 | 17,52 | | R | | F | C | | | | NP19-NP22 | | i |
| 3H- 5, 72-76 | 22,02 | R | R | R | F | | | | | | | g |
| 3H- CC | 24,80 | | | R | A | | | | | | | |
| 4H- 2, 72-76 | 27,02 | F | | R | C | | | *B. geomari* | G. index- | NP18 | late | |
| 4H- 5, 72-76 | 31,52 | F | | | | | | | S. linaperta | | | E |
| 4H- CC | 34,30 | F | | | C | | | | | | | o |
| 5H- 2, 72-76 | 36,52 | R | | | | | | | | NP17 | | c |
| 5H- 5, 72-76 | 41,02 | F | | | | | | | Acarinina | | | e |
| 5H- CC | 43,80 | A | | | | | | *B. eocena* | (P14) | | | n |
| 6X- CC | 53,30 | A | | | | | | | A. primitiva | NP15/NP16 | middle | e |
| 7X- CC | 62,80 | A | | | | | | | (P12/13) | | | |
| 9H- CC | 81,80 | | | R | C | | | | A. densa | | | |
| 10X- 1, 72-76 | 82,52 | | | R | | | | | (P11) | NP15? | | |
| 10X- CC | 91,30 | Barren | | | | | | | | | | |

Figure 3. Stratigraphic distribution of *Bolboforma* in samples from Hole 749B. See Figure 2 for an explanation of terms. The correlation of proposed *Bolboforma* zones with planktonic foraminifer and calcareous nannofossil zones is indicated. 3 = *B. antarctica* Kennett and Kennett, 1990; 4 = *Bolboforma* sp. B. Spiegler and von Daniels, 1991; 5 = *B. geomari* Spiegler and von Daniels, 1991; 6 = *B. lamari* Mackensen and Spiegler, 1989; 7 = *B. latdorfensis* Spiegler and von Daniels, 1991; and 8 = *B. spinosa* von Daniels and Spiegler, 1974.

72–76 cm (139.65 mbsf). This corresponds to an age of approximately 40.0 Ma. At Site 749 the top of the *B. antarctica* Zone is between Samples 120-749B-5H-2, 73–76 cm (36.52 mbsf) and -4H-CC (34.30 mbsf) and corresponds to an age of approximately 41.5 ± 1 Ma. According to the shipboard stratigraphy, there may be a hiatus between 34.30 and 43.80 mbsf corresponding to a time interval from 42.3 to 38.9 Ma (Schlich, Wise, et al., 1989, "Site 749" chapter).

3. Based on the ODP Leg 114 material, the *Bolboforma geomari* Zone of Spiegler (1991) was defined between the last occurrence (LO) of *B. antarctica* and the LOs of *B. geomari* and *B. lamari*. In this study we redefine the lower boundary of the *B. geomari* Zone just above the last common occurrence (LCO) of *B. antarctica* and the upper boundary below the FO of *B. latdorfensis*. At Site 748 the top of the *B. geomari* Zone is found between Samples 120-748B-15H-5, 72–76 cm (130.32 mbsf), and -15H-2, 72–76 cm (125.82 mbsf), and corresponds to an age from <37.3 to >35.9 Ma. At Site 749 this boundary is situated between Samples 120-749B-3H-5, 72–76 cm (22.02 mbsf), and -3H-2, 72–76 cm (17.52 mbsf), corresponding to an age of approximately 37.7 Ma.

4. The youngest Paleogene *Bolboforma* Zone, the *B. latdorfensis* Zone, was defined by Spiegler (1991) between just below the FO of the nominate species and somewhere in the upper lower or upper Oligocene where the occurrence of *Bolboforma* spp. is extremely rare or the sediments are barren of *Bolboforma*. At Sites 748 and 749, this zone includes Samples 120-748B-15H-2, 72–76 cm, through -13H-5, 72–76 cm (125.82 to 111.32 mbsf), and Samples 120-749B-3H-2, 72–76 cm, through -2H-5, 72–76 cm (17.52 to 12.52 mbsf), respectively.

## Neogene

Neogene sediments of Hole 747A contain *Bolboforma* from Samples 120-747A-7H-4, 72–76 cm (61.72 mbsf), through -4H-2, 0–4 cm (29.50 mbsf). This corresponds to a time span of about 8 m.y. from the late middle Miocene through the early Pliocene, that is, from 12.5 to ≈3.9 Ma (Schlich, Wise, et al., 1989).

Although a densely spaced set of Miocene samples from Hole 751A was investigated, *Bolboforma* were found in only three samples, with only about three specimens each, randomly distributed in time between late early and early late Miocene: Samples 120-751A-8H-6, 36–40 cm (69.56 mbsf); -11H-4, 72–76 cm (95.42 mbsf); and -14H-2, 36–40 cm (120.56 mbsf).

Three of seven *Bolboforma* zones established by Qvale and Spiegler (1989) in the Norwegian Sea were recognized in the Neogene of Hole 747A (Fig. 4):

1. The nominate species of the *B. compressispinosa* Zone is abundant in Sample 120-747A-7H-4, 72–76 cm (61.72 mbsf), and occurs rarely in Sample 120-747A-6H-4, 72–76 cm (52.22 mbsf). Qvale and Spiegler (1989) defined the base of this zone with the LO of *B. reticulata*. As this species is not present in our material, we preliminarily chose the FO of the nominate species *B. compressispinosa* as the base of the zone. Similarly, the top of this zone was defined under the abundant occurrence of *B. fragori* (Qvale and Spiegler, 1989). It is difficult to differentiate between *B. fragori*, *B. subfragori*, and an additional phenotypic variation *B.* cf. *subfragori*, which was found in this study in significantly younger sediments; thus, we decided to chose the LCO of *B. compressispinosa* as the top of this zone. This corresponds to an age of ≈11.5 Ma (Schlich, Wise, et al., 1989, "Site 747" chapter, p. 122).

2. In the Norwegian Sea, the *B. metzmacheri* Zone was established as a total range zone. At Site 747, *B. metzmacheri* is found from Samples 120-747A-4H-7, 72–76 cm (37.72 mbsf), through -4H-6, 36–40 cm (35.86 mbsf), interrupted by one barren sample at 37.36 mbsf. This sequence corresponds to the middle late Miocene from ≈8.0 Ma at its base to 5.4 ± 0.4 Ma at its top (Schlich, Wise, et al., 1989, "Site 747" chapter). More detailed investigation based on diatom stratigraphy (Harwood and Maruyama, written comm., 1990) revealed several hiatuses in the upper Miocene and Pliocene; as a result a much shorter time span from ≈7.5 to 6.9 Ma (or from ≈7.5 to ≈5.5 Ma) is calculated to correspond to the sedimentary sequence between 38 and 35 mbsf.

| Hole 747A | | *Bolboforma* species | | | | | | | | | *Bolboforma* zones | Planktonic foram. zones | Radiolarian zones | Epoch | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Core, section, interval (cm) | Depth (mbsf) | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | Qvale and Spiegler (1989) | Schlich, Wise, et al. (1989) | | | |
| 4H-1, 144-148 | 29.44 | Barren | | | | | | | | | | | | | |
| 4H-2, 0-4 | 29.50 | | | | | | | | R | | | | | | |
| 4H-2, 72-76 | 30.22 | | | | | | | | F | R | | *N. pachyderma-G. bulloides* | Upper Tau | early | P l i o c e |
| 4H-2, 108-112 | 30.58 | | | | | | | | F | | | | | | |
| 4H-3, 72-76 | 31.72 | | | | | | | | R | | | | | | |
| 4H-3, 108-112 | 32.08 | Barren | | | | | | | | | *B. intermedia* | | | | |
| 4H-4, 72-76 | 33.22 | | | | | | | | R | | | | | | |
| 4H-4, 108-112 | 33.58 | | | | | | | | R | | | | Lower Tau | | |
| 4H-5, 72-76 | 34.72 | | | | | | | | R | | | | | | |
| 4H-5, 108-112 | 35.08 | | | | | | | | R | | | *G. scitula-G. bulloides* | | | |
| 4H-6, 36-40 | 35.86 | | | | | | | R | | | | | | | |
| 4H-6, 108-112 | 36.58 | | | | | | | R | | | | | | | |
| 4H-6, 144-148 | 36.94 | | | | | | | R | | | | | | late | |
| 4H-7, 36-40 | 37.36 | Barren | | | | | | | | | *B. metzmacheri* | | Upper *C. spongothorax* | | M i o c e n e |
| 4H-CC | 37.50 | | R | | | | | A | | | | | | | |
| 4H-7, 72-76 | 37.72 | | | | | | | R | | | | | | | |
| 5H-6, 72-76 | 45.72 | Barren | | | | | | | | | | | | | |
| 5H-CC | 47.00 | | | | | | | | | | | | | | |
| 6H-2, 72-76 | 49.22 | | | | | F | R | | | | | | | | |
| 6H-4, 72-76 | 52.22 | R | | | A | | | | | | Unzoned | | *C. spongo.* | | |
| 6H-CC | 56.50 | Barren | | | | | | | | | | *N. nympha* | Lower *C. spongo.* | middle | |
| 7H-2, 72-76 | 58.72 | | | | R | | | | | | | | | | |
| 7H-4, 72-76 | 61.72 | A | R | R | R | | | | | | *B. compressispinosa* | | | | |
| 7H-CC | 66.00 | Barren | | | | | | | | | | | Unzoned | | |

Figure 4. Stratigraphic distribution of *Bolboforma* in samples from Hole 747A. See Figure 2 for an explanation of terms. The correlation of proposed *Bolboforma* zones with planktonic foraminifer and radiolarian zones is indicated. 9 = *B. compressispinosa* Spiegler and von Daniels, 1991; 10 = *B. laevis* von Daniels and Spiegler, 1974; 11 = *B. pentaspinosa* Spiegler and von Daniels, 1991; 12 = *B. subfragori* Spiegler and von Daniels, 1991; 13 = *B. capsula* Spiegler, 1987; 14 = *B. clodiusi* von Daniels and Spiegler, 1991; 15 = *B. metzmacheri* (Clodius, 1922); 16 = *B.* cf. *subfragori*; and 17 = *B. intermedia* von Daniels and Spiegler, 1974.

3. According to the zonal scheme of Qvale and Spiegler (1989), the next younger zone above the *B. metzmacheri* Zone is the *B. intermedia* Interval Zone, with a defined base above the LO of *B. metzmacheri*. Consequently, this zone includes Samples 120-747A-4H-5, 108–112 cm (35.08 mbsf), through -4H-2, 0–4 cm (29.50 mbsf), only interrupted by one sample barren of *Bolboforma* at 32.08 mbsf. If there is no hiatus at the Miocene/Pliocene boundary (compare controversial documentation in Schlich, Wise, et al., 1989, "Site 747" chapter), the beginning of this zone corresponds to 5.4 ± 0.4 Ma, and it ranges into the early Pliocene.

## DISCUSSION AND CONCLUSIONS

### Paleogene

The zonation of the middle Paleogene by Spiegler (1991) based on Leg 114 material from the southern Atlantic Ocean was found to be applicable on two Leg 120 Kerguelen sites (748 and 749). Spiegler (1991) tied her zonation to the geomagnetic polarity record, whenever possible. She calculated an age of approximately 44.5 Ma for the base of the *B. indistincta* Zone. According to the shipboard stratigraphy, this base is at approximately 46.5 Ma on the Kerguelen Plateau. In the southern Atlantic, the age of the base of the *B. antarctica* Zone was given at approximately 43.0 Ma (*B. eocena* Zone in Spiegler, 1991). Our study indicates an age of about 45.0 Ma. This agrees well with the appearance of *B. antarctica* at ≈44.5 Ma in the Weddell Sea (Kennett and Kennett, 1990). The age of the base of the *B. geomari* Zone is given by Spiegler (1991) between 39.2 and 38.1 Ma. Our data corroborate this datum and indicate an age of ≈39 Ma. Similarly, in the southern Atlantic, the base of the *B. latdorfensis* Zone is dated at approximately 36.0 Ma; at the Kerguelen Plateau this boundary is between 35.9 and 37.3 Ma.

In summary, the age estimates of the lower boundaries of the two middle Eocene *Bolboforma* zones based on southern Atlantic material are 1–2 m.y. younger than those derived from the Kerguelen Plateau and the eastern Weddell Sea samples. The southern Atlantic age estimates for the two late Eocene and early Oligocene zones are confirmed by the southern Indian Ocean material.

### Neogene

The zonation for the middle Miocene through early Pliocene proposed by Qvale and Spiegler (1989), based on Leg 104 material from the Norwegian Sea, was only of limited use for a detailed stratigraphic subdivision of the middle to late Miocene and the early Pliocene at the Kerguelen Plateau in the southern Indian Ocean. According to Leg 120 shipboard stratigraphy, the *B. compressispinosa* Zone is found in sediments older than ≈11.5 Ma, which is in contrast to the stratigraphic occurrence in the Norwegian Sea, where Qvale and Spiegler (1989) defined this zone as late Miocene. Therefore, we refrained from further application of the Norwegian Sea zonation to ages near the middle/late Miocene boundary (Fig. 4). The Kerguelen Plateau range of the nominate species of the *B. metzmacheri* Zone from ≈7.5 to ≈5.5 Ma agrees well with the range given by Qvale and Spiegler (1989) as being from 7.4 Ma to somewhere between 5.89 and 5.4 Ma. In summary, the zonation of the middle and late Miocene from the Norwegian Sea may be applicable to the southern Indian Ocean material, but more work is needed to erect a Neogene southern high-latitude scheme and correlate this with the zonation from the Northern Hemisphere.

Even though the boundary definitions of *Bolboforma* zones are somewhat preliminary because of the still limited knowledge of the distribution of *Bolboforma* in space and time, and the different species concepts used by different authors, one main conclusion is justifiable: *Bolboforma* biostratigraphy seems to become a useful complementary tool for the stratigraphic subdivision of sequences at the Eocene/Oligocene boundary of southern high latitudes.

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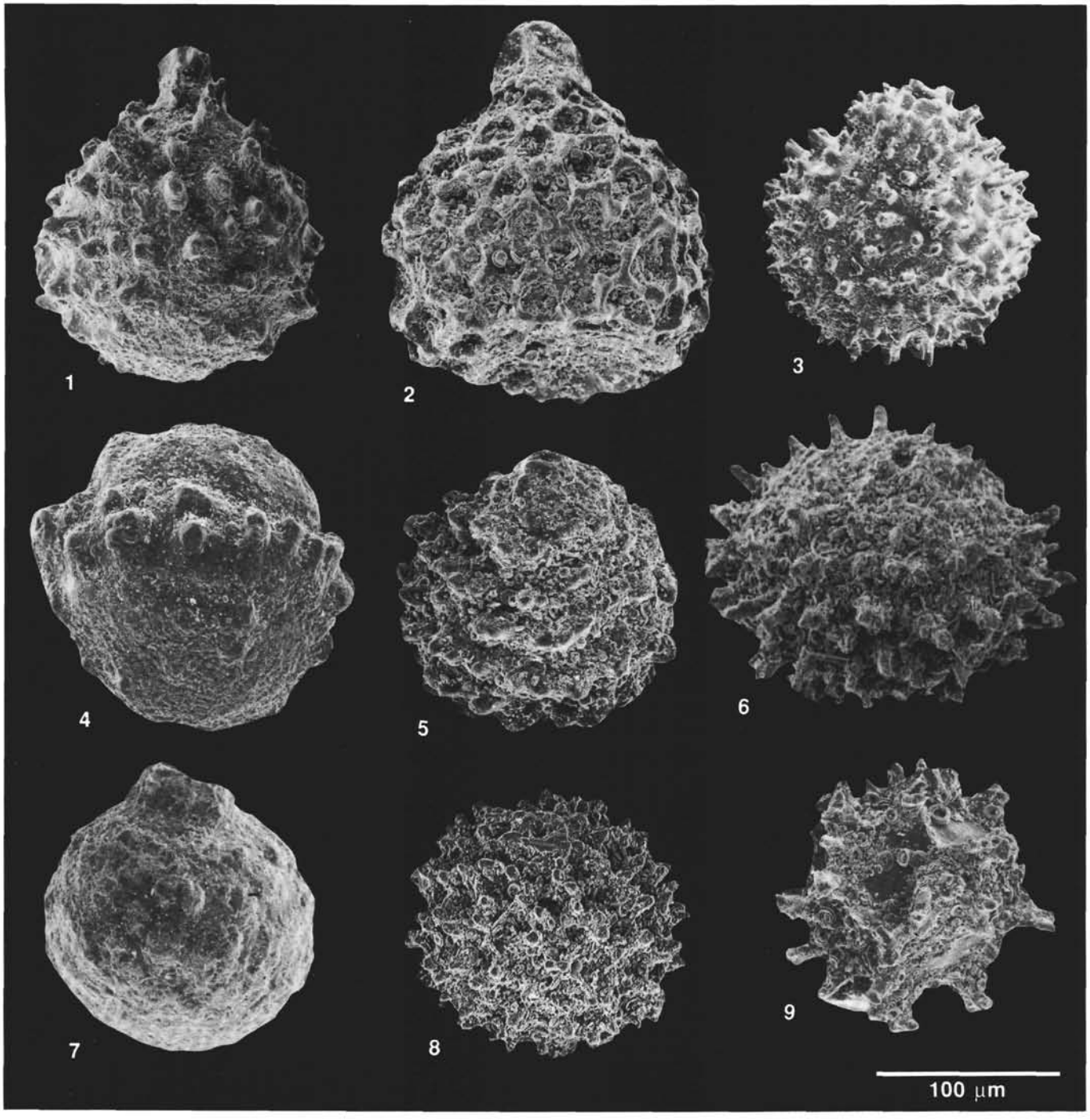


Plate 1. **1.** *Bolboforma* cf. *subfragori* (transition to *B. clodiusi*), Sample 120-747-4H-4, 108–112 cm. **2.** *Bolboforma metzmacheri* (Clodius, 1922), Sample 120-747-4H-7, 72–76 cm. **3.** *Bolboforma clodiusi* von Daniels and Spiegler, 1974, Sample 120-747A-4H-7, 72–76 cm. **4.** *Bolboforma capsula* Spiegler, 1987, Sample 120-747A-6H-2, 72–76 cm. **5.** *Bolboforma subfragori* Spiegler and von Daniels, 1991, Sample 120-747A-6H-2, 72–76 cm. **6.** *Bolboforma compressispinosa* Spiegler and von Daniels, 1991, Sample 120-751A-11H-4, 72–76 cm. **7.** *Bolboforma laevis* von Daniels and Spiegler, 1974, Sample 120-747A-7H-4, 72–76 cm. **8.** *Bolboforma spinosa* von Daniels and Spiegler, 1974, Sample 120-751A-14H-2, 36–40 cm. **9.** *Bolboforma latdorfensis,* Spiegler and von Daniels, 1991, Sample 120-748B-14H-5, 72–76 cm.

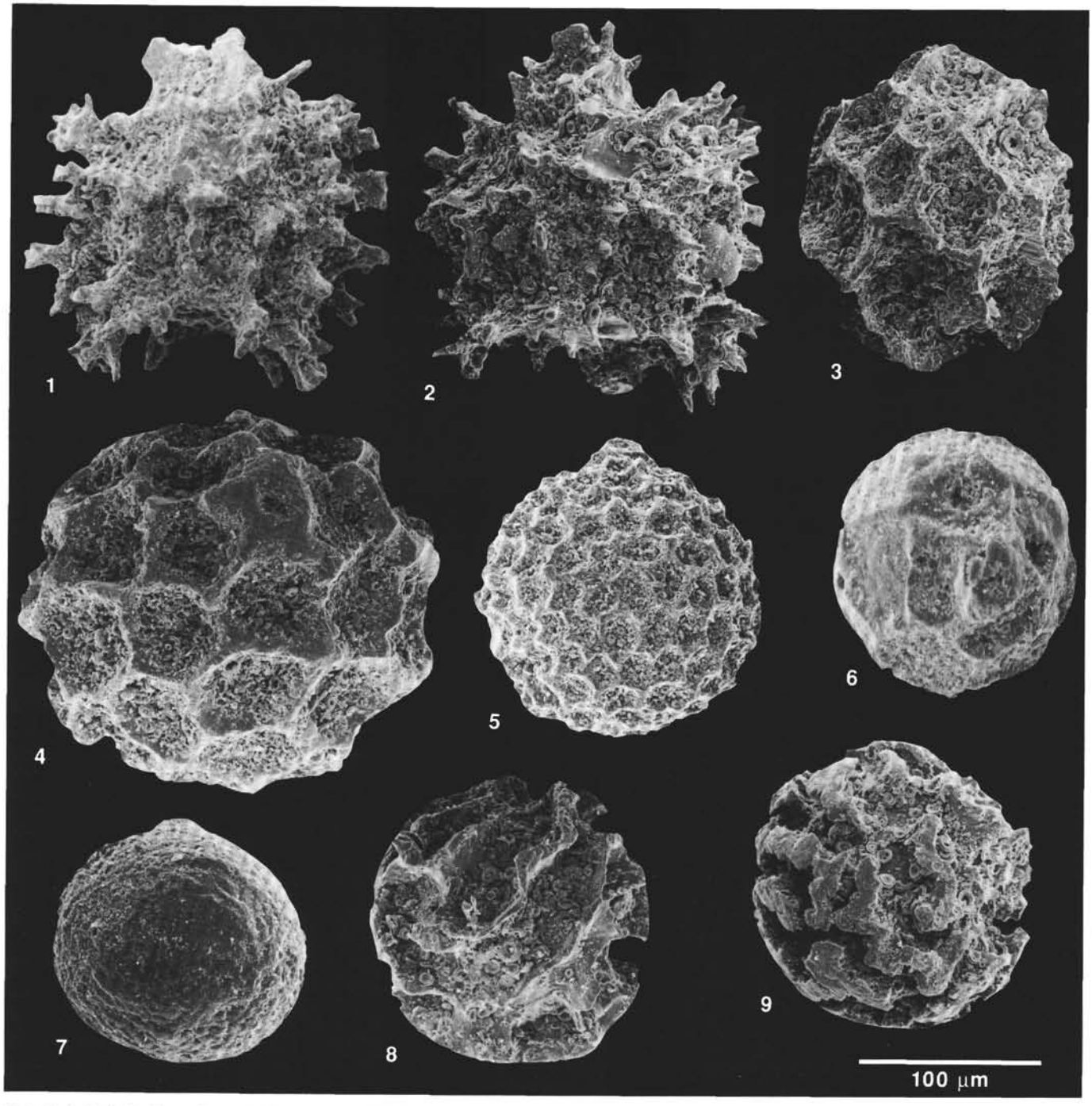


Plate 2. **1–2.** *Bolboforma lamari* Mackensen and Spiegler 1989; (1) Sample 120-748B-15H-5, 72–76 cm; (2) Sample 120-749B-3H-2, 72–76 cm. **3–4.** *Bolboforma geomari,* Spiegler and von Daniels, 1991; (3) Sample 120-748B-16H-2, 72–76 cm; (4) 120-748B-20H-5, 72–76 cm. **5.** *Bolboforma antarctica,* Kennett and Kennett, 1990, Sample 120-749B-5H-5, 72–76 cm. **6.** *Bolboforma indistincta,* Spiegler and von Daniels, 1991, Sample 120-749B-3H-5, 72–76 cm. **7.** *Bolboforma* sp. B, Spiegler and von Daniels, 1991, Sample 120-749B-3H-5, 72–76 cm. **8–9.** *Bolboforma* sp. 1, Sample 120-748B-20H-2, 72–76 cm.