

**ENCAPSULATED *BOLBOFORMA* (ALGAE, CHRYSOPHYTA) FROM LATE  
MIOCENE DEPOSITS IN THE NORTH ATLANTIC**

by

Dorothee Spiegler,  
Geologisches Institut und Museum der Universität Kiel,  
Kiel, F.R.G.

Spiegler, D., 1987. Encapsulated *Bolboforma* (Algae, Chrysophyta) from Late Miocene deposits in the North Atlantic. — Meded. Werkgr. Tert. Kwart. Geol., 24(1-2): 157-166, 3 pls. Leiden, June 1987.

Encapsulated *Bolboforma* have been detected in three species in Late Miocene deposits (DSDP Site 608, North Atlantic; OPD Site 642, Norwegian Sea). *Bolboforma* is considered to belong to the Algae (Chrysophyta). The new family Bolboformaceae and the new species *Bolboforma voeringensis* and *B. capsula* are introduced.

Mrs Dr D. Spiegler, Geologisches Institut und Museum der Universität Kiel, Olshausenstraße 40, D-2300 Kiel, Federal Republic of Germany.

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**SAMENVATTING**

*Bolboforma* (Algae, Chrysophyta) met inkapselingen uit laat-miocene afzettingen van het noord-atlantische gebied.

In laat-miocene afzettingen van het noord-atlantische gebied (DSDP Site 608, noordelijke Atlantische Oceaan; OPD Site 642, Noorse Zee) werden drie soorten van het geslacht *Bolboforma* gevonden, gekenmerkt door het bezit van ingekapselde cysten. *Bolboforma* wordt beschouwd te behoren tot de

Algae (Chrysophyta). De nieuwe familie Bolboformaceae en de nieuwe soorten *B. voeringensis* en *B. capsula* worden in dit artikel beschreven.

## ZUSAMMENFASSUNG

Eingekapselte *Bolboforma* aus spät-miozänen Ablagerungen im Nord-Atlantik.

Aus spät-miozänen Ablagerungen der Norwegischen See/Nord-Atlantik, erbohrt durch ODP Site 642 und DSDP Site 608, werden an drei *Bolboforma*-Arten Doppel-Gehäuse beschrieben, deren inneres Gehäuse als Zyste aufgefaßt wird. *Bolboforma* wird zu den Chrysophyta (Algen) gestellt. Neu eingeführt wird die Familie Bolboformaceae sowie die Arten *Bolboforma voeringensis* und *Bolboforma capsula*.

## INTRODUCTION

Since von Daniels & Spiegler (1974) introduced *Bolboforma* as genus incertae sedis, the origin and relationship of this microfossil group has not been clarified, although speculations about its affinities to protozoans (von Daniels & Spiegler, 1974; Odrzywolska-Bienkova, 1976; von Daniels, Spiegler & Bijvank, 1981) and algae (Rögl & Hochuli, 1976; Tappan, 1980; Müller, Spiegler & Pastouret, 1984; Murray, 1984; Echols, 1985; Hodgson & Funnell, 1987) have been presented.

*Bolboforma* are generally monocrystalline calcitic empty single bodies that exhibit a spheroid or bipolar flattened shape. They possess a simple aperture surrounded by a short neck. Surface ornamentation may be smooth, reticulate, cresty or spinous. Size ranges from 70 to 200 µm in diameter.

Usually the *Bolboforma* specimens are one-chambered; only occasionally they are two-chambered (von Daniels, Spiegler & Bijvank, 1981). Now specimens have been detected which contain still another inner test. Discovery of these encapsulated tests may help to clarify the systematic position of *Bolboforma*.

It has been shown that *Bolboforma* possesses considerable biostratigraphic and paleoenvironmental value in marine sediments. In Poag & Karowe (1986) the history, stratigraphic and paleogeographic distribution of *Bolboforma* is summarized. At present more than 40 *Bolboforma* species are recognized from Late Eocene to Early Pliocene deposits of temperate to cool regions in both the northern and southern hemisphere. They are not known from low latitudes.

## STRUCTURES OF ENCAPSULATED TESTS

At present these encapsulated tests are observed in three species only, viz. *Bolboforma voeringensis*, *Bolboforma pseudohystrix* and *Bolboforma capsula*. In each of these species the outer test completely envelopes the inner one. From outside the inner test is not visible. Special investigations have shown that both tests consist of pure low Mg-calcite. The outer and inner tests are distinguished by several features. The inner capsule generally exhibits a weaker ornamentation than the outer one. In *Bolboforma voeringensis* the outer test is covered with spines and reticulations, but the inner one only shows an

indistinct reticulation. In *Bolboforma pseudohystrix* the same relations may be observed. In *Bolboforma capsula* the inner test is more or less smooth. Regarding the arrangement of encapsulated tests, two modes are known. The inner test may either lie free within the outer test or it may be firmly attached to the inside base of the outer test. The fixed modus is observed in *Bolboforma capsula* where a single spheroid chamber is situated in the outer test (pl. 2, figs 5-6; pl. 3, figs 1-2). In *Bolboforma voeringensis* and *Bolboforma pseudohystrix* the free inner test comprises two chambers, a small chamber sitting on a larger main chamber. Both chambers are separated by a smooth wall and connected by a small opening in the center. The openings of the inner and outer tests are aligned. The outer test is generally penetrated by irregularly arranged small pores (pl. 2, figs 2-3). The inner one may also be distinguished by the absence of true pores.

## NATURE OF THE ENCAPSULATED TESTS

The genus *Bolboforma* has been introduced as a protozoan incertae sedis (von Daniels & Spiegler, 1974), but now its affinities to protophytes are commonly accepted. This assumption is confirmed in general by the detection of the encapsulated tests. In comparison with other protophytes the outer test seems to represent the vegetative stage of the organism and the inner test a cyst stage. Organic-walled dinoflagellates also form a cyst stage (= cyst) within the vegetative test (= theca). But the encystation in *Bolboforma* is unique because the vegetative test in dinoflagellates decays after cyst formation, whereas it persists in *Bolboforma*.

In a small group of dinoflagellates (Calciodinellaceae) calcareous cysts are known, but they are quite different from *Bolboforma*. Calcareous dinoflagellate cysts are constructed of 1 to 3 layers of irregular or radially orientated calcitic crystals. In *Bolboforma* the inner test also seems to be monocristalline (pl. 1, fig. 4; pl. 2, fig. 1; pl. 3, fig. 1). It is remarkable that the bulk of *Bolboforma* does not contain inner cysts. Encapsulated tests are only observed in the following samples: Site 642 B, 18-1-114 = 148.96 m and Site 642 C, 19-5-64 = 155.24 m, both Voering Plateau in early Late Miocene; Site 608, 217.96 m, Late Miocene from Kings Trough and from the Middle Miocene of Site 106 B in the western North Atlantic (Poag & Karowe, 1986, fig. 2F).

## TAXONOMY

The characteristic monocristalline calcareous structure of the test and the formation of encapsulated tests are unique features of *Bolboforma*. Monocristalline tests are observed in the protozoan order Foraminifera, family Spirillinidae, but Foraminifera do not secrete such cysts. Monocristalline elements are also formed in Echinodermata, but there are no other relationships to *Bolboforma*. Cysts are well-known in Protophyta, but as yet not with monocristalline structure.

Tappan (1980, p. 528) was the first author who placed *Bolboforma* as an unnamed cyst family within the class Chrysophyceae. Poag & Karowe (1986, p. 163) stated that *Bolboforma* probably should be elevated to a higher taxonomic level than genus. The detection of encapsulated tests in *Bolboforma* justifies their conclusion.

**Bolboformaceae n. fam.**

*Type genus* — *Bolboforma* von Daniels & Spiegler, 1974.

*Diagnosis* — Calcareous, optically monocristalline, free subspheroid bodies, 70 to 200  $\mu\text{m}$  in diameter.

***Bolboforma* von Daniels & Spiegler, 1974**

*Type species* — *Lagen a metzmacheri* Clodius, 1922.

*Diagnosis* (emended) — Free subspheroid tests; single, double and encapsulated chamber arrangement with a simple aperture surrounded by a neck. Encapsulated bodies formed by an outer and an inner calcareous test (cyst). Outer test perforated by small and irregularly arranged pores; inner test without pores. Cyst free or attached to the outer test, single or two-chambered.

*Stratigraphic distribution* — Late Eocene to Early Pliocene.

*Ecology* — Marine, temperate.

***Bolboforma voeringensis* n. sp.**

Pl. 1, figs 1-6; pl. 2, figs 1-3

*Holotype* — Pl. 1, fig. 3.

*Type locality* — ODP Leg 104, Site 642 B; Voering Plateau, Norwegian Sea.

*Type horizon* — Late Miocene, *acostaensis*-Zone.

*Syntypes* — Pl. 1, figs 1-2; 4-6.

*Diagnosis* — Pear-shaped outer test ornamented by reticulations and spines; cyst only with a weak reticulation. Cyst free in the outer test.

*Description* — Single empty tests and tests with a cyst are observed. Both can be distinguished only by crushing the specimen.

The pear-shaped outer test is ornamented by widely spaced reticulations with simple spines on the edges of the polygons. It is perforated by irregularly arranged small pores (pl. 2, figs 2-3). A short, indistinct neck with a simple round aperture is developed. Sometimes a cyst consisting of two chambers is present inside the outer test, demonstrating a large main chamber and a significantly smaller secondary one, together building an elongated test. The unequal chambers of the cyst are separated by a smooth wall and connected by a small central hole. The oral opening of the cyst is very large. The cyst is ornamented by weak cancellations corresponding with features of the outer test, but

**PLATE 1**

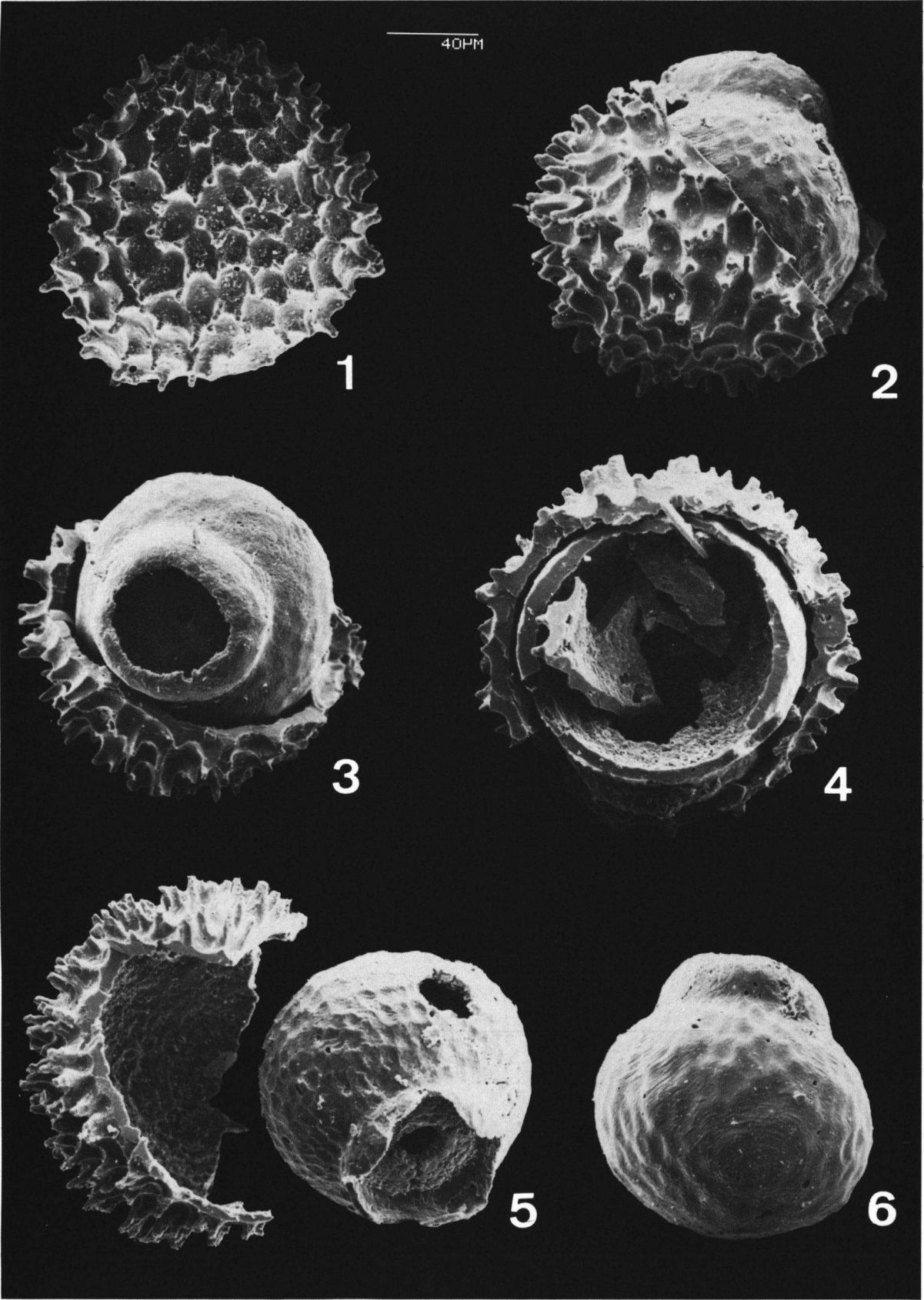
*Bolboforma voeringensis* n. sp.

Fig. 1: outer test.

Figs 2-5: showing encapsulated tests, inner test free.

Fig. 6: cyst.

All specimens from the same sample: ODP Leg 104, Site 642B, 18-1-144 = 148.96 m; *acostaensis*-zone, Late Miocene.



without spines. No real pores are visible in the cyst (pl. 2, fig. 1). The openings in the cyst and the aperture of the outer test are aligned.

*Dimensions* — Outer test: diameter 130-150  $\mu\text{m}$ ; length 140-180  $\mu\text{m}$ ; cyst: diameter c. 120  $\mu\text{m}$ , length c. 130  $\mu\text{m}$ .

*Comparisons* — Round tests with the same ornamentation are named *Bolboforma badenensis* Szczechura, 1982.

*Occurrence* — Norwegian Sea, Site 642 B, 642 C.

*Age* — Early Late Miocene, *acostaensis*-Zone.

***Bolboforma capsula* n. sp.**

Pl. 2, figs 4-6; pl. 3, figs 1-4

1986 *Bolboforma* sp. - Poag & Karowe, p. 164, fig. 2F.

*Holotype* — Pl. 2, fig. 6.

*Type locality* — DSDP Leg. 94, Site 608, Kings Trough, North Atlantic.

*Type horizon* — Late Miocene, *acostaensis*-Zone.

*Syntypes* — Pl. 2, figs 4-5; pl. 3, figs 1-4.

*Diagnosis* — Spheroid outer test ornamented with some vertically arranged knobs; cyst smooth or with reduced, irregular knobs. Cyst firmly attached to the base of the outer test.

*Description* — Single empty tests and tests with a cyst are observed. The outer test is ornamented with thick knobs, loosely arranged in 8 to 10 vertical rows. An indistinctly separated round neck bears a simple circular opening. The cyst is firmly attached to the inside of the outer test. It is single-chambered and relatively smooth. A round aperture without a neck is aligned with the aperture of the outer test.

*Dimensions* — Outer test: diameter 160-190  $\mu\text{m}$ ; cyst: diameter 120-160  $\mu\text{m}$ .

*Comparisons* — Smooth *Bolboforma*, previously named *Bolboforma laevis* von Daniels & Spiegler, 1974, may be the inner tests of *Bolboforma capsula*. *Bolboforma laevis* is a small aboral flattened thinner form. Poag & Karowe (1968, p. 164, figs 2 C-D) showed smooth-surfaced *Bolboforma* with the typical form of free cysts. Their potential outer tests are unknown.

*Occurrence* — North Atlantic, DSDP Sites 608 and 106 B.

*Age* — Middle to Late Miocene.

PLATE 2

*Bolboforma voeringensis* n. sp.

Fig. 1: broken inner and outer test.

Figs 2-3: broken outer test with pores.

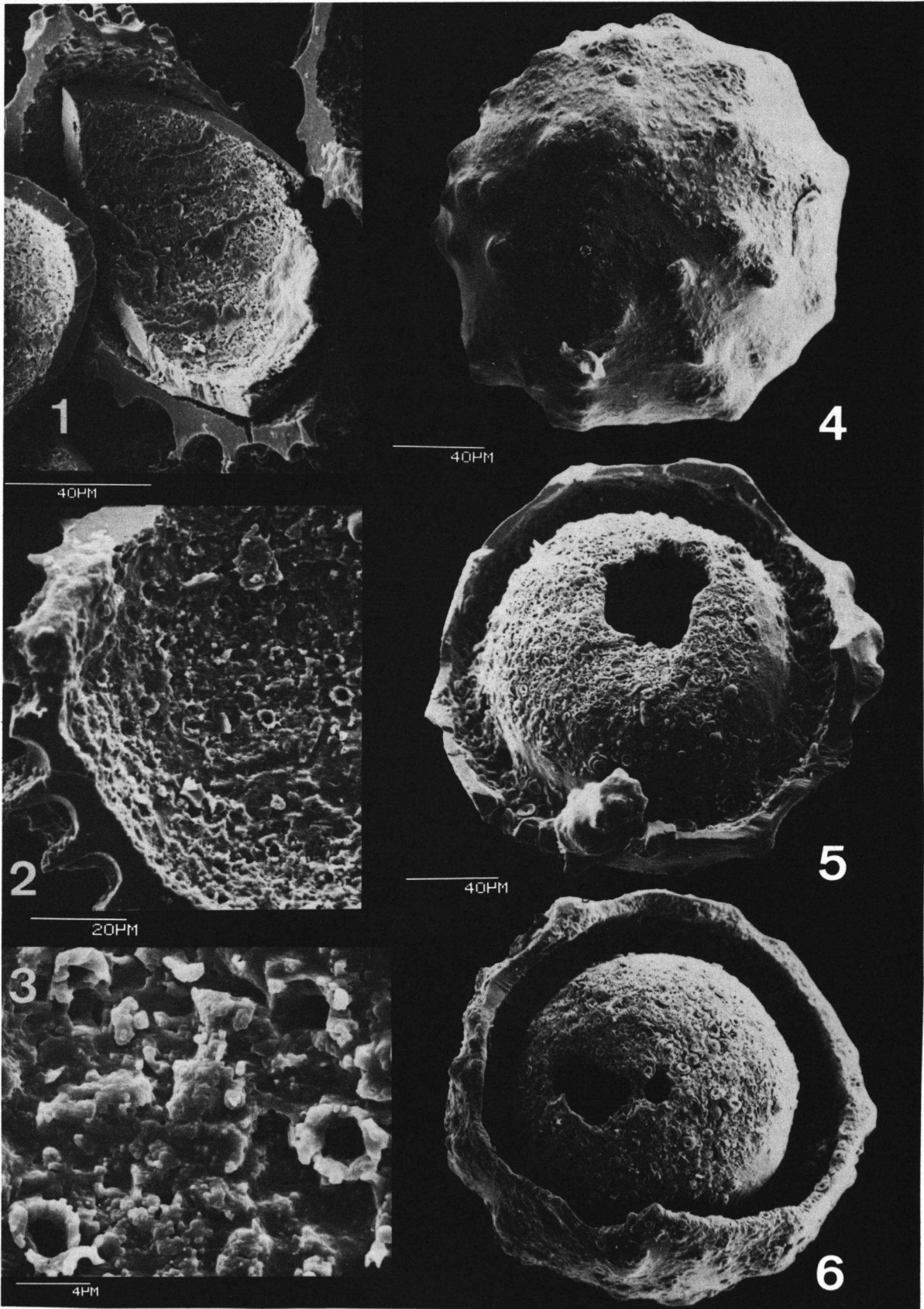
Same locality as pl. 1, figs 1-6.

*Bolboforma capsula* n. sp.

Fig. 4: outer test.

Figs 5-6: showing encapsulated test.

DSDP Leg 94, Site 608: 217.96 m; *acostaensis*-zone, Late Miocene.



***Bolboforma pseudohystrix* Müller & Spiegler, 1984**

Pl. 3, figs 5-6

1983 *Bolboforma clodiusi* Daniels & Spiegler. — King, p. 20, pl. 1, figs 9-10.

1984 *Bolboforma pseudohystrix* Müller & Spiegler, in Müller et al., p. 871, pl. 1, figs 9-13.

*Remarks* — In the same sample, ODP Leg 104, Site 642 C: 19-5-64 = 155.24 m empty tests of *Bolboforma pseudohystrix* and only one specimen like pl. 3, fig. 6 were observed. It is interpreted as a free cyst of *Bolboforma pseudohystrix*, analogous to *Bolboforma voeringensis* tests. The specimen also has the typical unequal two-chambered form of free cysts and a weak ornamentation, comparable to the ornamentation of *Bolboforma pseudohystrix*.

## CONCLUSIONS

It is important to distinguish between outer and inner tests of *Bolboforma* in order to fit the morphotypes together. We can now recognize the outer and the inner tests of *Bolboforma voeringensis*, *Bolboforma capsula* and probably of *Bolboforma pseudohystrix*, indicating that a weakly ornamented or a smooth test is often formed inside an outer test.

*Bolboforma* may represent an independant fossil group. The new family Bolboformaceae considered to be algae (Chrysophyta) is here defined.

The stratigraphically youngest species *Bolboforma costairregularis* (Toering & van Voorthuysen, 1973) continues into the Pliocene. We hope to detect *Bolboforma* in Recent material to confirm the true nature of this interesting fossilgroup.

## ACKNOWLEDGEMENTS

Sincere thanks are due to Dr S. Locker for extensive discussions and critical reading of the manuscript, to Dr S. Pfirman for correcting the English text and to my colleagues of the Geologisches Institut und Museum, Kiel, for their much appreciated assistance. Special acknowledgements are due to Mr W. Reimann for operating the SEM and to Dr D. Ackermann, Mineralogisches Institut, Kiel, for stoichiometric analysis.

The type material is stored in the collection of the Geologisches Institut und Museum, Kiel; registration nrs 3531-3535.

## PLATE 3

*Bolboforma capsula* n. sp.

Fig. 1: broken inner and outer tests filled with coccoliths.

Fig. 2: broken inner and outer tests, structurally connected at the base.

Figs 3-4: isolated inner tests.

DSDP Leg 94, Site 608: 217.96 m; *acostaensis*-zone, Late Miocene.

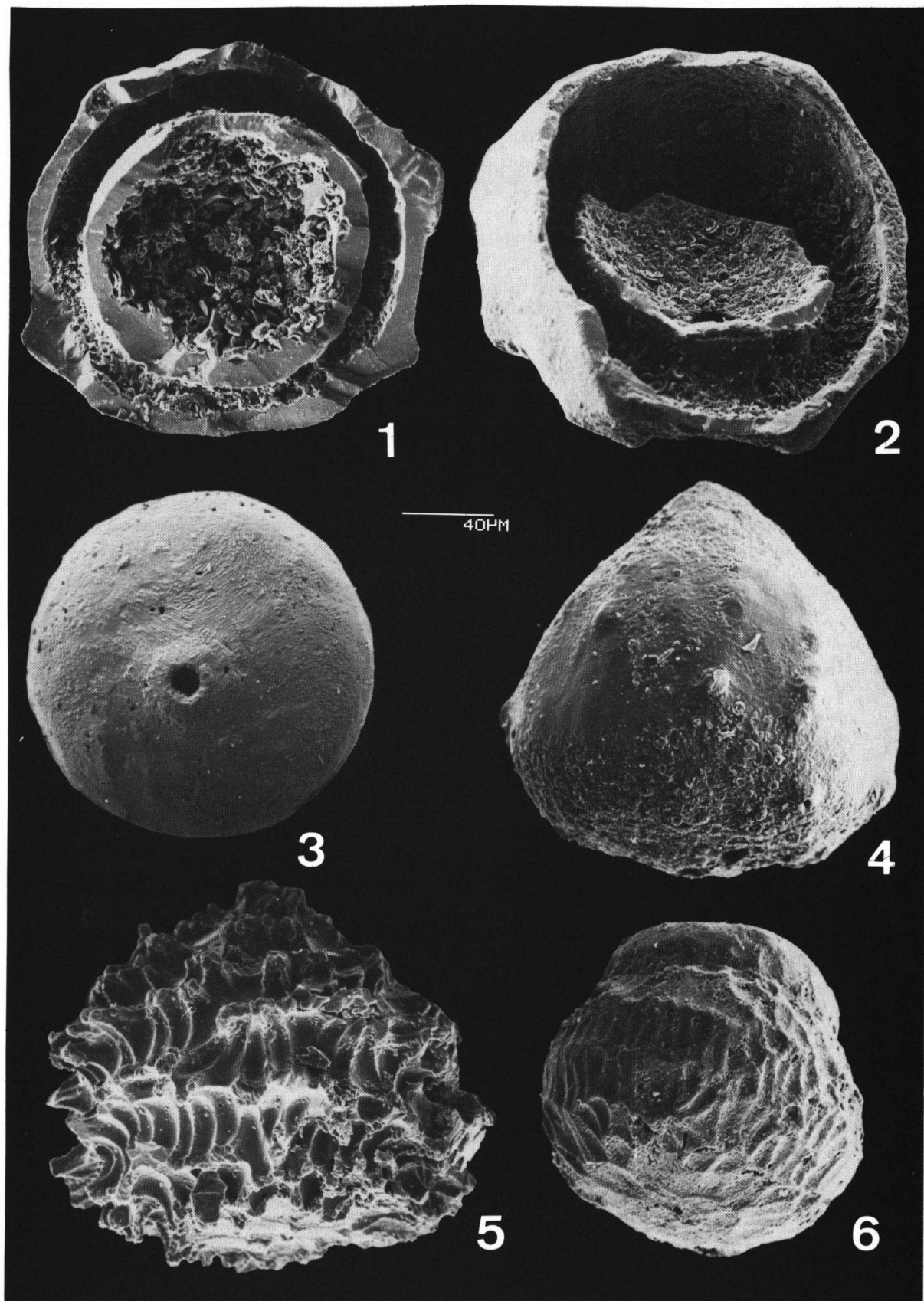
*Bolboforma pseudohystrix* Müller & Spiegler

Fig. 5: outer test.

Fig. 6: free cyst.

ODP Leg 642 C, 19-5-64 = 155.25 m; *acostaensis*-zone, Late Miocene.





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Manuscript received 20 March 1987, revised version accepted 31 March 1987.