

40. THE OCCURRENCE OF BOLBOFORMA, A PROBABLE ALGAL CYST, IN THE ANTARCTIC MIOCENE OF DSDP LEG 35

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INTRODUCTION

Site 325 was drilled on the continental rise of the Bellingshausen Sea (65°2.79'S; 73°40.40'W) during DSDP Leg 35, the third cruise into Antarctic waters. A single hole was drilled in 3745 meters of water which penetrated 718 meters of sediment. Terrigenous sediments of gray and greenish clay, silty claystone, silts, and sandstones characterize the early Miocene to Pleistocene deposits. The hole bottomed in lithified sandstones and conglomerates.

The Pleistocene to late Miocene sediments yielded primarily well-preserved siliceous fossils; however, a sparse fauna of planktonic foraminifera, characteristic of high latitudes, was found in the uppermost Pliocene-Pleistocene part of the hole. A fauna of arenaceous benthonic foraminifera accompanied by a few calcareous specimens occurs beginning in Core 7 (moving downhole), at about 520 meters subbottom. One sample (325-10-1, 94-96 cm) at 709.5 meters contains the planktonic foraminiferal species *Globorotalia zealandica incognita* indicating that it is in the foraminiferal Zone N 6 to N 7 (early Miocene).

Within this section containing calcareous fossils, individuals of the fossil group *Bolboforma* were found at 615.3 meters (325-8-2, 133-135 cm). The genus *Bolboforma* has been described from the Oligocene and Miocene of northern Germany (Daniels and Spiegler, 1974) and the systematic position of this taxon is discussed below. The occurrence of *Bolboforma* at Site 325 in the early Miocene sediments, as determined by planktonic foraminifera, is in agreement with its occurrence in northern Germany. *Bolboforma* appears to be a fossil group with significant stratigraphic value.

The depositional environment of this part of the section at Site 325 was middle to lower bathyal. The dominance of more primitive genera of arenaceous foraminifera and the occurrence of deep water calcareous benthonic species indicate water depths of 2-3000 meters. *Bolboforma* is believed to be of planktonic origin.

LITHOLOGIC AND PALEONTOLOGIC COMPOSITION OF THE SEDIMENTS

Bolboforma was found only in Sample 325-8-2, 133-135 cm in the DSDP material. Lithologically the sample is a light gray silty claystone with burrow structures. The washed residue contained a rich fauna of arenaceous benthonic foraminifera, some calcareous benthonic foraminifera, as well as a few planktonic forms. These foraminifera were accompanied by numerous radiolarians and, in the 63 to 177 μm fraction, by several different species of *Bolboforma*. In the fine fraction (44-63

μm) there were only detrital minerals, radiolarians, and a few small foraminifera. *Bolboforma* was not found in the fraction finer than 63 μm , and it was also lacking in most of the coarser fraction.

The following species of arenaceous foraminifera were found in the sample: *Ammobaculites agglutinans*, *Ammolagena clavata*, *Bathysiphon* sp., *Bolivinospis* cf. *cubensis*, *Cribrostomoides crassimargo*, *C. subglobosus*, *Cyclammina incisa*, *Eggerella bradyi*, *E. propinqua*, *Haplophragmoides carinatus*, *H. quadratus*, *H. cf. scitulum*, *Martinotiella communis*, *Psammosphaera fusca*, *Pseudobolivina antarctica*, *Recurvoides contortus*, *Reophax* spp., *R. nodulosus*, *R. pilulifer*, *R. sabulosus*, ?*Reophax difflugiformis*, *Rhabdammina abyssorum*, *R. linearis*, *Rhizammina algaeformis*, *Saccamina placenta*.

The calcareous foraminifera were less abundant and included: *Cibicidoides pseudoungerianus*, *Dentalina havanensis*, *Fissurina orbignyana*, *Gyroidina planulata*, *Lagena* spp., *Laticarinina pauperata*, *Lenticulina convergens*, *Nonion* sp., *Nonionella* sp., *Pyro murrhina*, *Quinqueloculina* sp., *Qu. collumosa*. A few specimens of planktonic foraminifera, including *Globigerina* sp., *Globorotalia* ex gr. *peripheroronda* were also found. The preservation of the material was good. The calcareous foraminifera showed almost no traces of dissolution and the radiolarians were recrystallized into quartz, but were not replaced by calcite.

SYSTEMATIC POSITION OF BOLBOFORMA

In their original description, Daniels and Spiegler (1974) said that the genus *Bolboforma* probably belonged to a group of test-forming protozoans. The authors discussed the affinities between this genus and Testacea, Tintinnina, and the calcareous algae. Consequently, it is possible that *Bolboforma* and the Calci-sphaerulidae belong to related fossil groups. In contrast to *Bolboforma*, all Protozoa which form calcareous tests construct the chamber walls with tiny crystals, or platelets. The wall structure in foraminifera is formed by a more or less regular arrangement of these small elements (Hemleben, 1969). In radiate, calcareous foraminifera, the wall comprises several different lamellae and is thickened by the addition of secreted carbonate layers (Hansen and Reiss, 1971; Bé and Hemleben, 1969). The foraminiferal genus most closely related to *Bolboforma* is *Lagena*. *Lagena* belongs to the *Rotaliina*, a group characterized by a perforated wall and which commonly exhibits a radial wall structure.

The wall of *Bolboforma* consists of a single layer of calcite which is optically a single crystal, without any traces of growth lines or separated elements (Plate 2,

Figures 5, 6); perforations are also lacking. The sectioned specimens show only the cleavage planes of calcite. Recrystallization probably did not occur as there is no evidence of a connection between the wall and the test infilling. The wall structure is the same regardless of whether the infilling is sediment or secondary calcite. The only growth pattern is seen at the surface of the wall which is scaly or granulated (Plate 2, Figures 4, 7, 8). The ornamentation of *Bolboforma* is variable, exhibiting numerous modifications ranging from sharp ridges to spines to knobs and/or smooth surfaces. There is, however, no difference in the wall structure. The wall and all the processes and ornamentations are formed by the same single calcite crystal.

These structures show that the test of *Bolboforma* is formed by a different process than forms the walls of protozoans. Consequently, a comparison with similar tests of algae is made. Algae which live in a single-chambered test are mostly planktonic fresh water forms. The Chrysomonadineae have organic and siliceous walls and some species of the Phacotaceae (Chlorophyceae) have organic tests incrustated by calcium carbonate. These tests, however, normally consist of two valves. Another group of flagellates living in tests are the Euglenophyceae; however, in this group the wall is formed by organic material and all tests formed by flagellates are very small—normally less than 20 μm .

Comparable forms are only the cysts of protozoans or algae. Encystments occur in different groups either as a regular stage in the ontogenetic cycle or as a resting stage as a protective function against changes in the environment. As far as is known, only organic cysts are formed as resting stages of protozoans. There are two groups among the algae which form anorganic encystments, Dinophyceae and Chrysophyceae. Although the Dinophyceae or dinoflagellates normally form organic cysts a few species of Peridiniaceae and the fossil family Calciodinelliaceae produce calcareous encystments. These cysts are characterized by girdle and tabulation, and an organic inner membrane (Wall and Dale, 1968; Wall et al., 1970). No organic inner membrane was found in *Bolboforma* after processing by acids.

Siliceous and calcareous encystments occur in the Chrysomonadales. In this group the Archaeomonadaceae occur in marine sediments and have siliceous cysts which are very similar in outline to *Bolboforma*. However, they measure only 5-30 μm in diameter. The Recent group, Ochromonadaceae, which lives in fresh water, also produces similar siliceous forms.

The Coccolithineae, which also belong to the Chrysomonadales, have calcifications in the motile and nonmotile phase (Parke and Adams, 1960). These tests and cysts formed by these organisms each consist of a large number of small elements.

The fossil group Calcisphaerulidae, which probably belongs to the cyst-forming algae, possesses walls composed of small calcite crystals. Individuals of this group are normally smaller (50-60 μm) but range up to 200 μm .

It was possible to identify the genus, *Bolboforma*, in the Leg 35 material, as a cystal stage of an unknown fossil group. The neck-like aperture is closed by a calcite membrane (Plate 2, Figure 1), which seals the test at a

level below the beginning of the collar-like neck. This was observed to be a common feature on a large number of specimens which we viewed in transmitted light. The membrane has the same structure as the surrounding wall, and its surface shows the similar granulation. In comparison to the above-mentioned encystments, it seems to be advisable to classify *Bolboforma* as belonging to a hitherto unknown group of planktonic Chrysomonadales.

SYSTEMATIC DESCRIPTION

Bolboforma clodiusi Daniels and Spiegler (Plate 1, Figures 4-6; Plate 2, Figure 3)

1922 *Lagenia hystrix* Reuss—Clodius, p. 109.

1974 *Bolboforma clodiusi* n. sp.—Daniels and Spiegler, p. 63, pl. 7, fig. 4-6.

The onion-shaped test, for which the genus *Bolboforma* receives its name, is strongly flattened on the aboral side in *Bolboforma clodiusi*. The surface is covered by rounded to angular, short, stout spines. A short neck, bordered by an apertural lip protrudes from the sub-globular test. The shape of this neck is extremely variable and may be a simple rounded tube which is somewhat inflated near the base to triangular in cross-section (Plate 2, Figure 3). In contrast to the original description of the species, the population investigated here is believed to be related to *B. spinosa*, as some specimens have rounded spines and flattened bases which also have indications of spines. The circular diameter of test is 170 μm , and the height of the ovoid, without the neck, averages 125 μm . Individuals of the species are fairly common in the material studied. The stratigraphic distribution of *B. clodiusi* in northern Germany is from the Hemmor Stage to the "late" Miocene; the Hemmor Stage is early Miocene (Burdigalian after Anderson, 1961 and nannoplankton Zones NN 4 to ?NN 5 after Martini and Müller, 1973).

Bolboforma spinosa Daniels and Spiegler (Plate 1, Figures 1-3; Plate 2, Figures 2, 5, 6, 8, 9)

1974 *Bolboforma spinosa* n. sp.—Daniels and Spiegler, p. 67, pl. 9, fig. 3, 4.

Bolboforma spinosa has a globular, well-rounded test, covered by short, rounded spines. The investigated specimens are similar to the holotype, but do not have the numerous blunt spines as seen in the figured paratype. All intermediate stages between the globular *B. spinosa* and the flattened *B. clodiusi* were observed. There are also transitional forms to *B. cf. rotunda*, in which the spines are reduced in number and solidity. The apertural features are similar to those in *B. clodiusi* and the average test diameter is 160 μm . This species is the most common form in the investigated material and hundreds of specimens were found. The stratigraphic range given in the original description is late Oligocene (Chattian) to early Miocene (Vierlande Stage, corresponding to Aquitanian age after Anderson, 1961b).

Bolboforma laevis Daniels and Spiegler (Plate 1, Figure 12; Plate 2, Figures 1, 4)

1974 *Bolboforma laevis* n. sp.—Daniels and Spiegler, p. 64, pl. 7, fig. 7-9; pl. 10, fig. 6.

Bolboforma laevis has a compressed sphaeroidal test similar to *B. clodiusi*. The surface is smooth, with a slight granulation of small pustules, which is more distinct in the apertural region (Plate 2, Figures 1 and 4). Similar ornamentation was seen on the surface of the membrane enclosing the test of the cyst (Plate 2, Figure 1). The circular equatorial diameter of the test is between 120 and 145 μm and averages 135 μm ; the height of the test, without the neck, is between 90 and 115 μm and averages about 105 μm . Individuals of this species occurred less commonly than the other *Bolboforma*. The stratigraphic range in northern Germany is given as early Miocene (Hemmor Stage) to "late" Miocene.

Bolboforma cf. rotunda Daniels and Spiegler (Plate 1, Figures 10, 11; Plate 2, Figure 7)

Specimens with rounded, globular tests in the Leg 35 material are similar in outline to *B. rotunda*. The surface, however, is distinctly different, lacking the broad, rounded knobs. The surface of the observed specimens is smooth with small knobs, resembling the reduced

spine bases of *B. spinosa*. All transitions to the spinose forms are present. The species averages 140 μm in diameter. It occurs fairly frequently in the studied material. The stratigraphic range for *B. rotunda* is the same as for *B. spinosa* and is late Oligocene to early Miocene.

***Bolboforma* sp.**
(Plate 1, Figures 8, 9)

A few specimens of *Bolboforma* were observed which possess wing-like processes. The surface of the globular test is covered by short knobs or spines which is probably an abnormal development in individuals of *B. spinosa*. Protruding appendices were also seen in individuals of *B. irregularis*, kindly provided by C.H. v. Daniels. The diameter of the test without the processes is about 150 μm .

**CORRELATION OF LEG 35 MATERIAL
TO OTHER REGIONS**

The only known occurrences of *Bolboforma* are from the Oligocene-Miocene transgressions of the North Sea in the region of Hamburg in northern Germany (Daniels and Spiegler, 1974). Daniels and Spiegler also noted the earlier published accounts in which the genus had previously been described as *Lagena*. The striking change in faunal assemblages between the Vierlande and Hemmor stages, as described by these authors, is also accompanied by a different paleogeographical distribution of the faunas and is attributed to a sedimentary discordance as a result of renewed transgression between deposition of these two stages.

The material investigated from the early Miocene of the Antarctic area provides the missing link to these populations. The fauna is distinctly transitional in the composition of species and variety of forms. The spinose species *Bolboforma spinosa* and *B. clodiusi* both occur and are related by transitional forms. The smooth ovoid *B. laevis* is also accompanied by a globular species, here designated as *B. cf. rotunda*. The globular specimens are distinctly more common than the flattened ones.

That this population is stratigraphically transitional between that of the Vierlande and Hemmor stages is consistent with the age of *Bolboforma*-bearing sediments at Site 325 which were dated by means of planktonic foraminifera. In comparison, the inclusion of the nanoplankton Zone NN 4 as a part of the Hemmor Stage (Martini and Müller, 1973) indicates that the investigated sample is probably early Burdigalian or slightly older.

Bolboforma spiralis was observed in samples from the Palmer Ridge by Ms. L. Molinsky (personal communication). She also found this genus in samples from DSDP sites from the North Atlantic and from the Bay

of Biscay (Leg 12). The worldwide use of this fossil group as a biostratigraphic indicator seems possible.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to C.H. von Daniels (Hannover), who kindly made available material for comparison with new species of *Bolboforma* and for their helpful discussions of the investigated material. We wish to thank Ms. K. Perch-Nielsen and J.P. Beckmann (Geol. Dept. Zurich) and C.D.K. Cook (Bot. Garten, Zurich) for discussions on the systematical position of this fossil group, and Ms. L. Molinsky (Sudbury, Ontario) who contributed to the understanding of the distribution of *Bolboforma* from her unpublished data. K. Kelts (Zurich) kindly read the manuscript. The SEM micrographs and photoprints were prepared with high quality by H.E. Franz and U. Gerber from the ETH Geology Department. The investigations were supported by the Swiss National Science Foundation.

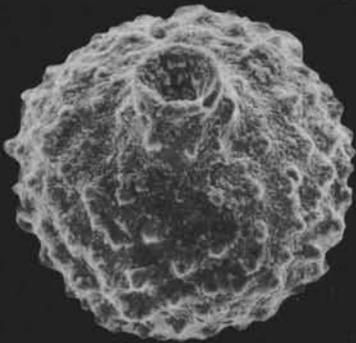
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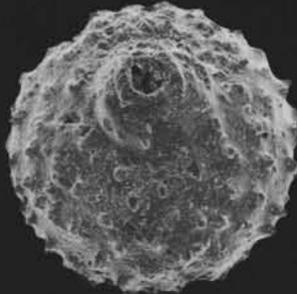
PLATE 1
(Magnification $\times 298$)

- Figures 1-3 *Bolboforma spinosa* Daniels and Spiegler.
1. NMB-C 31031.
2. NMB-C 31035.
3. NMB-C 31033.
- Figures 4-6 *Bolboforma clodiusi* Daniels and Spiegler.
4. NMB-C 31032.
5-6. NMB-C 31034.
- Figure 7 *Bolboforma spinosa*, sectioned specimen; interior of the test filled with secondary calcite. NMB-C 31046.
- Figures 8, 9 *Bolboforma* sp. NMB-C 31037.
- Figures 10, 11 *Bolboforma* cf. *rotunda* Daniels and Spiegler.
10. NMB-C 31041.
11. NMB-C 31042.
- Figure 12 *Bolboforma laevis* Daniels and Spiegler. NMB-C 31040.

PLATE 1



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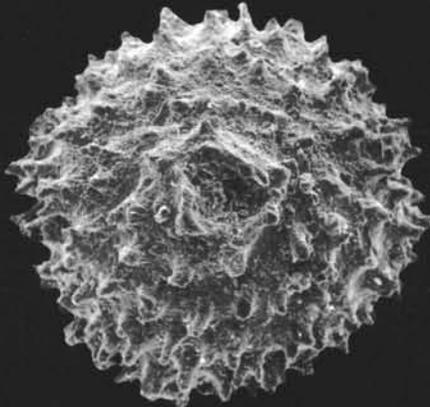
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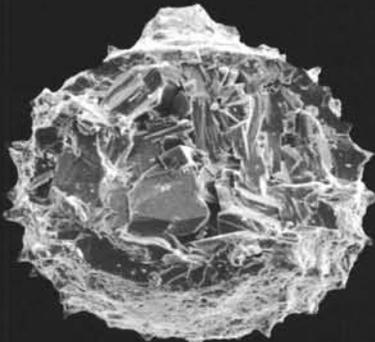
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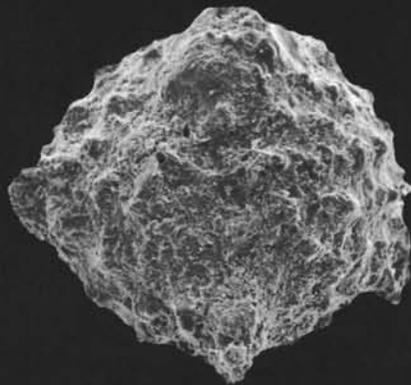
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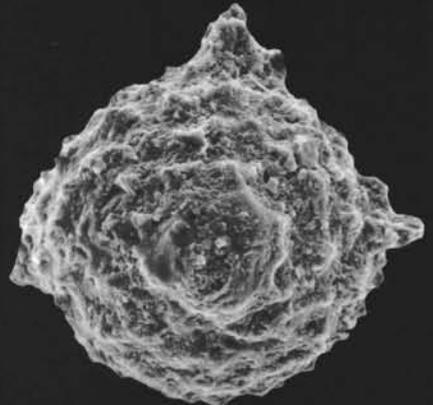
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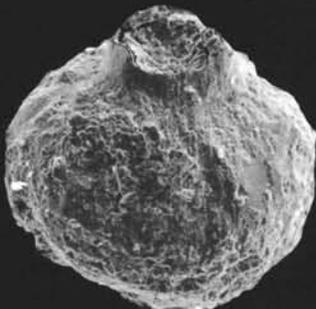
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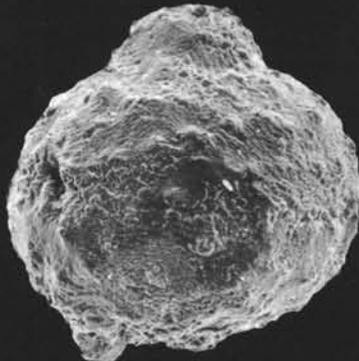
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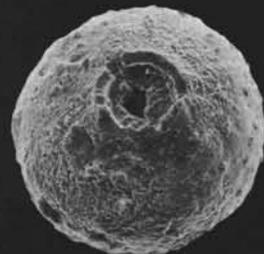
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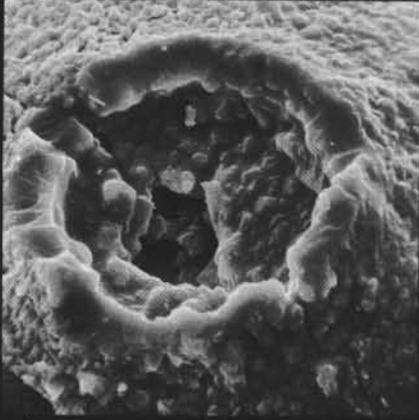


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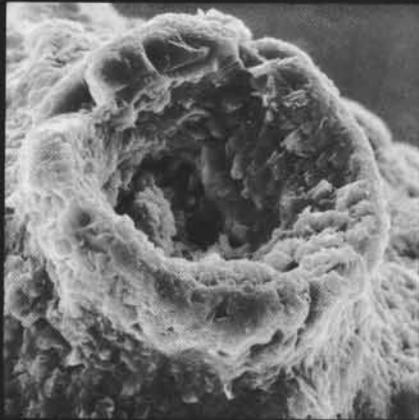
PLATE 2

- Figure 1 *Bolboforma laevis* (see Plate 1, Figure 12). Membrane closing the apertural opening of the cyst shows the same granulation as the surrounding wall. $\times 1190$.
- Figure 2 *Bolboforma spinosa* (see Plate 1, Figure 1). Relicts of the membrane are observed near the bottom of the apertural neck. $\times 1190$.
- Figure 3 *Bolboforma clodiusi* (see Plate 1, Figures 5, 6). Triangular shape of the apertural neck as one of the varieties occurring within one species. $\times 590$.
- Figure 4 *Bolboforma laevis* (see Plate 1, Figure 12). Wall surface in the apertural region covered with small pustules. $\times 1785$.
- Figure 5 *Bolboforma spinosa* (see Plate 1, Figure 7). The sectioned wall shows cleavages of calcite crystals; the interior of the test is filled with secondary calcite, without connection between wall and filling. $\times 1190$.
- Figure 6 *Bolboforma spinosa* (NMB-C 31044). The sectioned wall shows no structure; the test is filled with sediment. $\times 1190$.
- Figure 7 *Bolboforma cf. rotunda* (see Plate 1, Figure 11). Wall surface showing small scales of calcite and coarser rugosities, resembling reduced spines. $\times 1190$.
- Figure 8 *Bolboforma spinosa* (see Plate 1, Figure 3). Wall surface with blunt spines and small calcite scales, which are arranged in lines, growing from the spines as a center (see lower left spine). $\times 1190$.
- Figure 9 *Bolboforma spinosa* (see Plate 1, Figure 2). Form of spines varies within one specimen from knobs to tips; the small openings found in this single specimen are no pores but secondarily caused perforations. $\times 1190$.

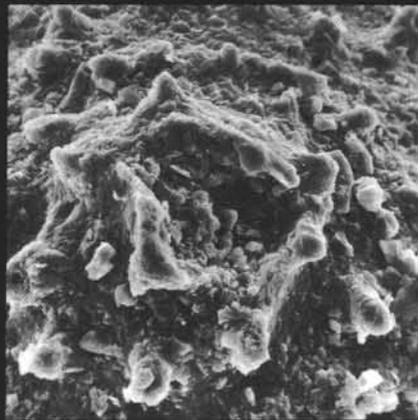
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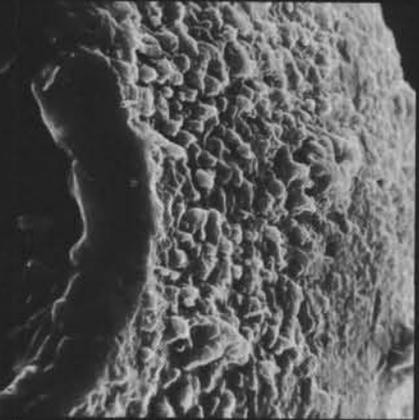
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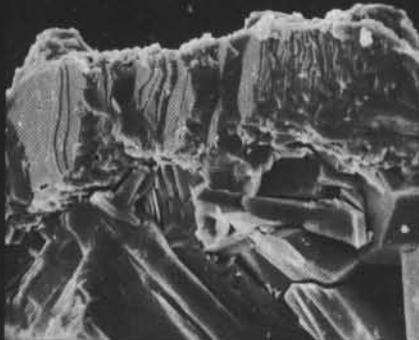
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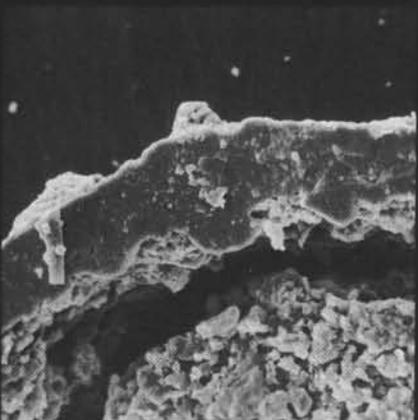
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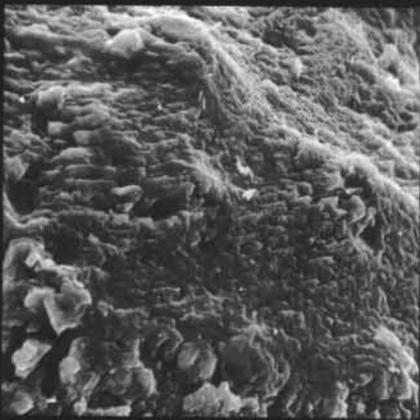
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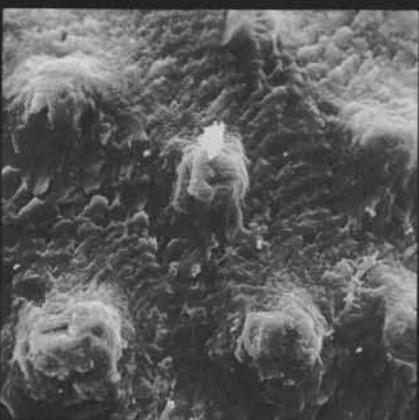
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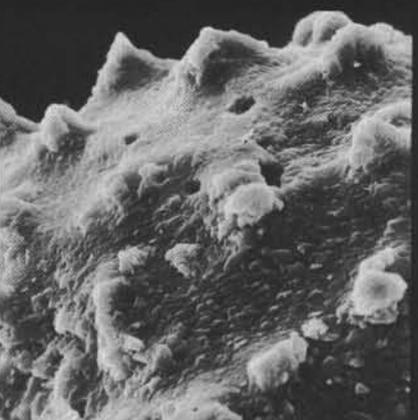
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