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# Notes on the wall structure of the Globigerinacea

## ABSTRACT

Electron microscope, phase contrast, and dark-field illumination analyses of various Globigerinacea indicate that septal walls of specimens in both axial and horizontal sections are microgranular hyaline in character. The primary outer wall of Cretaceous Globigerinacea is microgranular hyaline, whereas Cenozoic Globigerinacea may have outer walls which are entirely microgranular hyaline, both radial hyaline and microgranular hyaline, or, rarely, entirely radial hyaline. Mesopelagic forms of *Globorotalia truncatulinoides* (d'Orbigny), for example, possess an outer wall divided into 1) a radial hyaline "calcite crust" composed of euhedral calcite prisms oriented with their C-axes normal to the surface of the test and 2) an inner laminated layer composed of heterogeneous microgranules of hyaline calcite.

## INTRODUCTION

In 1964, the senior author observed that the septal walls of *Globorotalia* s.s. appeared to be microgranular hyaline in character, being composed of minute granules of hyaline calcite. His observations were made optically through the examination of septal wall faces (e.g., plate 3, figure 2) in axial section. Since 1964, microgranular hyaline septal walls have been observed in axial sections of a number of Cretaceous and Cenozoic Globigerinacea, such as *Globotruncana*, *Rotalipora*, and *Globigerina*. Curiously enough, the walls of such forms appeared either cryptocrystalline or vaguely microgranular when viewed with polarized or non-polarized light in horizontal section. Inasmuch as it might be argued that the microgranules observed in axial section merely represent the ends of elongate radial hyaline microprisms oriented with their C-axes normal to a given septal wall face, the investigators set out to examine septal wall structure in horizontal section with the electron microscope, phase contrast, and dark-field illumination. At the same time numerous observations were made on the microstructure of the outer wall of *Globorotalia* s.s. and various other Globigerinaceae, producing interesting but totally unexpected results.

## METHODS OF STUDY

### Electron microscope analysis

Two species of *Globorotalia* s.s., *G. truncatulinoides* (d'Orbigny) and *G. crassaformis* (Galloway and Wissler), were selected for electron microscope analysis. Both of these species possess planoconvex tests and thus lend themselves readily to the preparation of horizontal sections.

Preparation of specimens for electron microscopy was carried out in the following steps:

- 1) Foraminiferal specimens were cleaned ultrasonically and with hydrogen peroxide to remove all or as much matrix as possible. Those which appeared completely matrix-free when wetted were selected for study.
- 2) Specimens were placed with their spiral (flat) sides down in the cavities of an embedding mold.
- 3) Equal amounts of epoxy resin (Aradite 6005) and a hardener (dodecenylsuccinic anhydride (DDSA)) were mixed and "degassed" in a vacuum oven at 75°C for 45 minutes.
- 4) A catalyst (*n*-benzyl dimethylamine (BDMA)) was added at the rate of one drop per ml. to the above mixture, the mixture being further "degassed" for a period of two hours without heat. Initially, excess air

bubbles were removed by a partial and periodic decrease (release) of pressure while under vacuum. When the epoxy was properly "degassed", the mixture was poured into the cavities of the mold containing the foraminiferal specimens.

5) After curing the epoxy for 24 hours at 60°C under vacuum, individual disks containing specimens were removed from the mold and allowed to cool.

6) Disks containing foraminiferal specimens were polished with a Sampson polishing machine utilizing 6-micron diamond polishing compound for rough polishing and 0.25-micron diamond polishing compound for fine polishing. Specimens were ground until the spiral roofs of tests were completely removed.

7) The sectioned foraminifera were etched using 0.01N HCl for 2 to 3 seconds.

8) Replicating tape coated and softened with acetone was superimposed over that portion of a given disk containing a specimen. The best results were obtained by applying considerable pressure on the replicating tape directly over the specimen. This prevented the formation of air bubbles. The specimen was examined under a stereoscopic microscope to make sure that no air bubbles were present.

9) The acetate peel after being stripped from the plastic disk was shadowed with uranium and coated with carbon using standard replicating techniques (see Krinsley and Bé, 1965; Hall, 1957, pp. 329–352).

10) The small portion of the acetate peel containing the specimen was trimmed away and placed in a Petri dish filled with acetone. With the solution of the acetate peel the carbon film separates and can be placed on a 150-mesh to 200-mesh grid for examination with the electron microscope. If the carbon film folds or crinkles, thus disposing itself unequally on the grid, it can be flattened out by returning it to a second Petri dish containing a mixture of acetone and water. When properly flattened, the film can again be returned to the grid.

#### Dark-field illumination and phase contrast analyses

Sectioned specimens for dark-field illumination analysis were prepared either with or without cover slips and were photographed using a Zeiss photomicroscope equipped with a dry dark-field condenser. Specimens for phase contrast analysis were prepared without cover slips and were photographed with a Zeiss Photomicroscope equipped with a phase contrast consisting of a bright-field condenser and an oil emersion lens.

#### ANALYSIS OF THE WALL STRUCTURE OF THE GLOBIGERINACEA

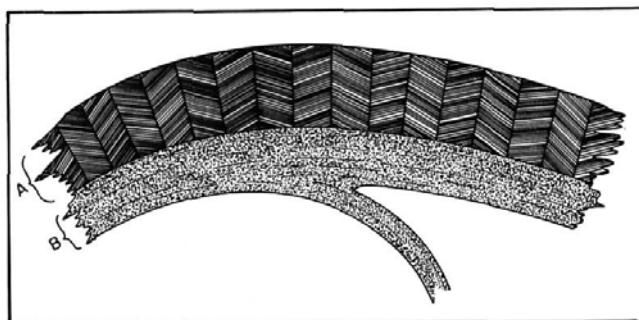
##### Wall structure of *Globorotalia s.s.*

##### 1) Microstructure of the septal wall.

Electron microscope analyses of the septal wall of *Globorotalia s.s.*, utilizing double-stage carbon replicas made from horizontal sections, definitely indicate that septal walls are microgranular hyaline in character, being composed of minute, irregularly shaped grains of calcite averaging about 0.5 microns in size (see plate 1, figures 1–3; plate 2, figure 1). The microgranular character of the septal wall of *Globorotalia s.s.* has likewise been confirmed by phase contrast and dark-field analyses of horizontally sectioned specimens (plate 4, figure 4; plate 5, figure 4; plate 7, figure 2).

Lipps (1966, p. 1262), with insufficient evidence to support all of his conclusions, stated: "The planktonic foraminifera, superfamily Globigerinacea, have bilamellar walls whose lamellae are composed of radially arranged calcite crystals, the C-axis of each crystal being perpendicular to the test surface. No true Globigerinacea have a granular crystalline wall, although it has been reported erroneously in the septa of some species (Pessagno, 1964). Photographs (Pessagno, 1964, plate 4, figures 9, 10) showing the presumed granular microstructure were taken in unpolarized light perpendicular to the chamber surface, so that the equidimensional ends of the radial crystals appear as granules." It is worth pointing out that Lipps (*ibid.*, plate 155, figures 1–8) failed to document radial hyaline septal wall structure in any of his illustrations. Furthermore, the senior author has never seen such structure documented for the Globigerinacea in the micropaleontological literature. The only structures which traverse a septal wall normal to its face are occasional widely spaced small pores (see plate 3, figure 1).

Although the present study definitely refutes the assumption that the septal walls of *Globorotalia s.s.* are composed of radially arranged, "equidimensional" calcite crystals, it has not established whether individual calcite granules are oriented crystallographically with their C-axes in any preferred direction. The microgranules are far too minute to isolate using standard petrographic techniques. With crossed nicols one can observe a weak wave of extinction passing along a septum as the stage of the petrographic microscope is rotated. This probably means that the septal wall is composed of microgranules which are oriented crystallographically in the same direction. However, it is also possible that 70% of the microgranules may share the same crystallographic orientation, whereas



TEXT-FIGURE 1

Schematic diagram showing the structure of the outer wall of a mesopelagic specimen of *Globorotalia* s.s. as seen in horizontal section. A, radial hyaline "calcite crust" composed of euhedral calcite prisms oriented with their C-axes normal to the test surface; B, microgranular hyaline laminated inner portion of outer wall.

the remaining 30% may be oriented at random. A definitive solution to this problem awaits the analysis of septal wall as well as outer wall structure with electron diffraction or x-ray diffraction techniques.

## 2) Microstructure of the outer wall.

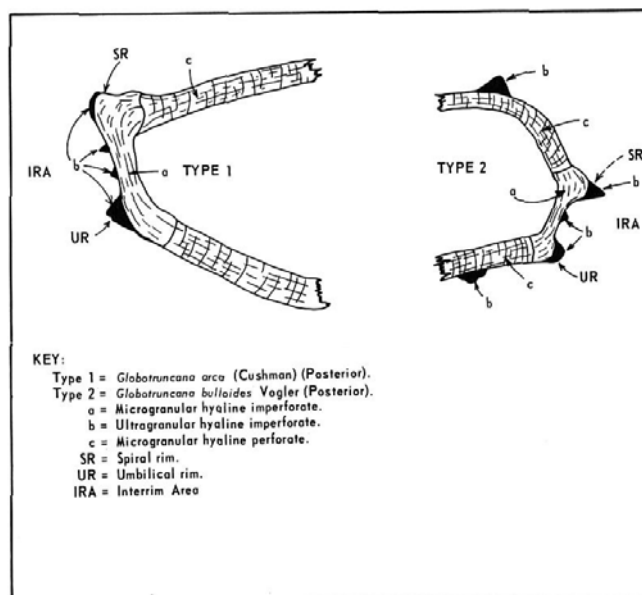
In 1963, Bé and Ericson made the interesting discovery that mesopelagic specimens of *Globorotalia truncatulinoides* (d'Orbigny) possess a thick "calcite crust" which is superimposed on all laminated portions of the test in the last whorl of chambers. Electron microscope analysis of the outer test wall of both mesopelagic and epipelagic forms indicates 1) that the "calcite crust" of mesopelagic forms is comprised of elongate, euhedral prisms of calcite oriented normal to the surface of the test wall (text-figure 1; plate 2, figure 2) and 2) that the laminated layer beneath the calcite crust of mesopelagic forms and comprising the entire primary outer wall of epipelagic forms is microgranular hyaline in character (text-figure 1; plate 2, figure 3).

Phase contrast and dark-field illumination analyses of the outer wall have yielded essentially the same results and substantiate the microgranular hyaline structure of the laminated layer (see plate 4, figure 4; plate 5, figure 5; plate 7, figures 1–2). The fibrous appearance which has been attributed to the laminated layer by many workers, including the senior author, is not due to the presence of radially aligned, elongate microprisms, but to the density of radially aligned pores.

## COMMENT ON THE WALL STRUCTURE OF OTHER GLOBIGERINACEA

### Upper Cretaceous Globigerinacea

Although Pessagno, in his recent (1967) monograph on Upper Cretaceous Globigerinacea, assumed that all Upper Cretaceous Globigerinacea possessed radial



TEXT-FIGURE 2

Basic types of keel structure among double-keeled species of *Globotruncana* s.s.

hyaline primary outer walls, a reanalysis of numerous thin sections has proven this assumption to be invalid. Upper Cretaceous Globigerinacea belonging to a number of different families appear to have both microgranular hyaline outer walls and septal walls (see plate 4, figure 2; plate 6, figures 1–5). The radially oriented structures seen in thin-sectioned specimens are pores, not elongate prisms of calcite. Secondary structures such as spines, beads, parts of keels, and rugosities are ultragranular hyaline (see text-figure 2 herein), whereas tegilla and portici tend to be microgranular hyaline in character, as noted by Pessagno (1967). Such observations do little more than confirm those made over eleven years ago by Bronnimann and Brown (1956, pp. 504–505).

### Cenozoic Globigerinacea

#### 1) *Orbulina universa* d'Orbigny

Thin-walled, assumedly epipelagic forms of *Orbulina universa* d'Orbigny appear to have test walls which consist solely of microgranular hyaline calcite (plate 5, figure 1). Thicker-walled mesopelagic forms have a radial hyaline (often initially ultragranular hyaline) outer layer and a microgranular hyaline inner layer (plate 5, figure 7). The examination of a number of thin sections appears to suggest that the radial hyaline (prismatic) layer grows at the expense of the inner microgranular hyaline layer via recrystallization. If such is the case, one might expect some mesopelagic individuals to have completely radial hyaline test walls (see Lipps, 1966, plate 155, figure 5).

## 2) *Globoquadrina altispira* (Cushman and Jarvis)

Phase contrast and dark-field illumination analysis of thin-sectioned specimens of *Globoquadrina altispira* (Cushman and Jarvis) indicate 1) that septal walls are microgranular hyaline in character (plate 4, figures 1, 3; plate 5, figure 3), 2) that the revolving wall (outer wall) of earlier whorls is microgranular hyaline (plate 4, figures 1, 3), and 3) that the revolving wall (outer wall) of the last whorl is radial hyaline in character (plate 4, figure 1; plate 5, figure 3). It is conceivable that the prisms comprising the radial hyaline outer wall of the last whorl were formed in part as a result of the recrystallization of a microgranular hyaline primary outer wall.

## 3) *Globigerina rohri* Bolli

Sectioned specimens of *Globigerina rohri* Bolli examined with phase contrast show microgranular hyaline septal walls. Outer walls possess an inner microgranular hyaline layer and an outer radial hyaline "calcite crust" (plate 5, figure 2).

## 4) *Globigerina triloculinoides* Plummer

Phase contrast analysis of both the septal and outer walls of specimens of *Globigerina triloculinoides* Plummer shows microgranular hyaline structure (plate 5, figure 6). The sectioned forms may, however, represent only the epipelagic individuals.

Electron micrographs of the test surface of *Hantkenina* sp. shown to the writer by Berggren (Honjo and Berggren, in progress) clearly demonstrate the presence of a microgranular hyaline test wall. These results are particularly significant in that they were obtained directly through the use of a scanning electron microscope and not indirectly through the use of replicating techniques and the standard electron microscope.

## CONCLUSIONS

The present study of Globigerinacea wall structure suggests the following conclusions and working hypotheses:

1) Upper Cretaceous Globigerinacea possess microgranular hyaline outer walls, septal walls, tegilla and portici. Secondary structures such as short spines, beads, and portions of keels are ultragranular hyaline in character.

The lack of radial hyaline (prismatic) "calcite crusts" suggests that Upper Cretaceous Globigerinacea were entirely epipelagic in nature, since Bé and Ericson (1963, pp. 72-78) have demonstrated that among Recent specimens of *Globorotalia truncatulinoides* (d'Orbigny) only the mesopelagic forms living below a depth of nearly 500 meters possess a "calcite crust".

Severe ecological changes at the end of Mesozoic times or the beginning of Cenozoic times may have led the Globigerinacea to assume a mesopelagic as well as an epipelagic way of life during the Cenozoic.

2) True radial hyaline (prismatic) wall structure is characteristic of Cenozoic Globigerinacea that lived in deep water. Epipelagic individuals assumedly have microgranular hyaline septal walls and outer walls. Mesopelagic individuals have microgranular hyaline septal walls and either radial hyaline outer walls or outer walls which are both radial hyaline and microgranular hyaline. It is possible that the euhedral prisms of calcite comprising the "calcite crust" of forms like *G. truncatulinoides* (d'Orbigny) may serve as a protective coating to individuals living in the mesopelagic zone at depths of more than 500 meters (see Bé and Ericson, 1963, pp. 78-79). Conceivably, at such depths the solution of  $\text{CaCO}_3$  would be more rapid due to increased pressure and decreased pH. Park (1966, pp. 1540-1541, text-figure 1) showed that a pH minimum, having a range in pH values from 7.5 to 7.7 exists at depths between 200 and 1200 meters in the northeastern Pacific Ocean. It is here conceived that under such conditions larger crystals comprising the "calcite crust" might dissolve less readily than the minute granules comprising the laminated portion of the test.

## ACKNOWLEDGMENTS

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# PLATE 1

All figures are electron micrographs illustrating the microgranular hyaline character of the septal wall.

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| <p>1 <i>Globorotalia truncatulinoides</i> (d'Orbigny)<br/>Electron micrograph of septal wall made from two-stage replica of horizontal section. <math>\times 25,800</math>.</p> <p>2 <i>Globorotalia truncatulinoides</i> (d'Orbigny)<br/>Electron micrograph of septal wall made from two-stage replica of horizontal section. Different specimen from that shown in figure 1. Negative</p> | <p>(reverse) print of portion of septum shown in figure 3. <math>\times 8,748</math>.</p> <p>3 <i>Globorotalia truncatulinoides</i> (d'Orbigny)<br/>Electron micrograph of septal wall at point near juncture with outer wall. Two-stage replica of horizontal section. <math>\times 8,748</math>.</p> |
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# PLATE 2

All figures are electron micrographs.

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| <p>1 <i>Globorotalia truncatulinoides</i> (d'Orbigny)<br/>Electron micrograph of septal wall made from two-stage replica of horizontal section. Negative (reverse) print of portion of same septum figured in plate 1, figure 1. Note microgranular character of test wall. <math>\times 17,100</math>.</p> <p>2 <i>Globorotalia truncatulinoides</i> (d'Orbigny)<br/>Electron micrograph of radial hyaline "calcite crust" composing outer portion of outer wall. Note</p> | <p>euhrdal prisms of calcite. Negative (reverse) print from two stage replica of horizontal section. <math>\times 3,100</math>.</p> <p>3 <i>Globorotalia truncatulinoides</i> (d'Orbigny)<br/>Electron micrograph of laminated layer of outer wall. Negative (reverse) print showing microgranular hyaline structure. Two-stage replica of horizontal section. <math>\times 5,535</math>.</p> |
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# PLATE 3

All figures are photomicrographs taken with unpolarized light.

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| <p>1 <i>Globorotalia crassaformis</i> (Galloway and Wissler)<br/>Outer wall and septal wall. Recent of Atlantic Ocean. A, laminated layer of outer wall; B, "calcite crust" of outer wall; C, pore in septal wall. <math>\times 410</math>.</p> | <p>2 <i>Globorotalia crassaformis</i> (Galloway and Wissler)<br/>Axial section illustrating microgranular appearance of face of septal wall. Recent of Atlantic Ocean. F, face of septal wall. <math>\times 700</math>.</p> |
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# PLATE 4

All figures are photomicrographs with dark-field illumination.

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| <p>1,3 <i>Globoquadrina altispira</i> (Cushman and Jarvis)<br/>Miocene of Jamaica. A, microgranular hyaline septal wall; B, more translucent radial hyaline (prismatic) outer wall of last whorl; C, microgranular hyaline septal wall of inner whorl. <math>\times 410</math>.</p> <p>2 <i>Globotruncana linneiana</i> (d'Orbigny)<br/>Late Campanian "Upper Taylor Marl", Upper Cretaceous of Texas. Note microgranular hyaline structure of test wall. <math>\times 163</math>.</p> | <p>4 <i>Globorotalia truncatulinoides</i> (d'Orbigny)<br/>A, laminated portion of outer wall; B, radial hyaline "calcite crust" portion of outer wall; a, side of outer wall; b, side of septal wall. Note microgranular appearance of septa and laminated layer of outer wall (final whorl and preceding whorl). Radial hyaline "calcite crust" portion of outer wall behaves differently with dark-field illumination and appears more translucent than laminated layer. Horizontal section. <math>\times 410</math>.</p> |
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## PLATE 5

All figures are photomicrographs with phase contrast.

- 1 *Orbulina universa* d'Orbigny  
Microgranular wall structure of epipelagic form. Recent of Atlantic Ocean.  $\times 1000$ .
- 2 *Globigerina rohri* Bolli  
Miocene of Jamaica. a, microgranular hyaline laminated layer; b, microgranular hyaline septal wall; c, radial hyaline (prismatic) layer. Horizontal section.  $\times 400$ .
- 3 *Globoquadrina altispira* (Cushman and Jarvis)  
Note radial hyaline outer wall composed of wedge-shaped prisms. Septal wall microgranular hyaline, more perforate near its juncture with outer wall. Horizontal section.  $\times 400$ .
- 4 *Globorotalia truncatulinoides* (d'Orbigny)  
Note microgranular hyaline septal wall. Horizontal section.  $\times 400$ .
- 5 *Globorotalia truncatulinoides* (d'Orbigny)  
Outer wall of mesopelagic individual showing microgranular hyaline laminated layer and radial hyaline "calcite crust". Horizontal section.  $\times 510$ .
- 6 *Globigerina triloculinoides* Plummer.  
Note completely microgranular septal and outer wall. Horizontal section.  $\times 400$ .
- 7 *Orbulina universa* d'Orbigny  
Recent of Atlantic Ocean. Note inner, distinctly microgranular, hyaline laminated layer and outer radial hyaline (prismatic) layer. Radial hyaline layer may have originated with formation of ultra-granular hyaline spines which grow in part inwardly by recrystallization at expense of microgranular hyaline laminated layer.  $\times 400$ .

## PLATE 6

All figures are photomicrographs with dark-field illumination.

- 1 *Rotalipora cushmani* (Morrow)  
Axial section of specimen from upper Cenomanian part of Britton Formation (Eagle Ford Group) of Texas. Note microgranular hyaline structure of primary outer wall.  $\times 100$ .
- 2 *Globotruncana duwi* Nakkady  
Axial section (part) of specimen from the Maestrichtian Kemp Clay of Texas. Note microgranular hyaline structure of primary test wall. Darker (more translucent) spines and outer part of keel are ultra-granular hyaline in character. Radial structures in primary test wall are pore canals and do not represent radially aligned calcite prisms.  $\times 324$ .
- 3 *Loeblichella hessi* (Pessagno)  
Axial section of specimen from the upper Cenomanian portion of the Britton Formation (Eagle Ford Group) of Texas. Note microgranular hyaline wall structure.  $\times 165$ .
- 4 *Pseudotextularia difformis* (Kikione)  
Maestrichtian Kemp Clay of Texas. Note microgranular hyaline wall structure.  $\times 230$ .
- 5 *Globigerinelloides prairiehillensis* Pessagno  
Late Campanian "Upper Taylor Marl" of Texas. Note microgranular hyaline wall structure.  $\times 233$ .

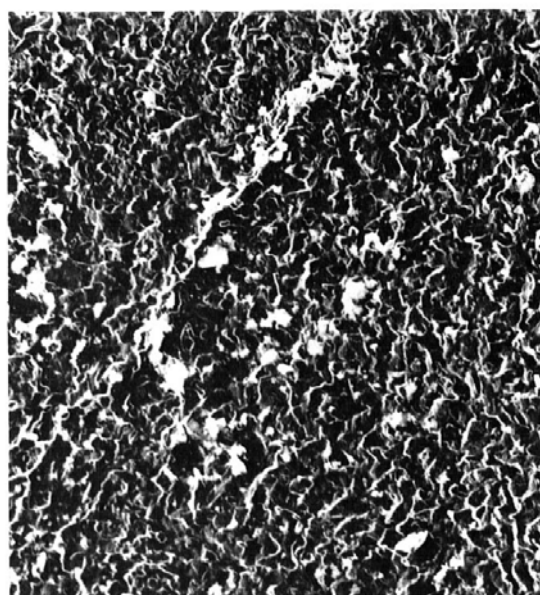
## PLATE 7

All figures are photomicrographs with dark-field illumination.

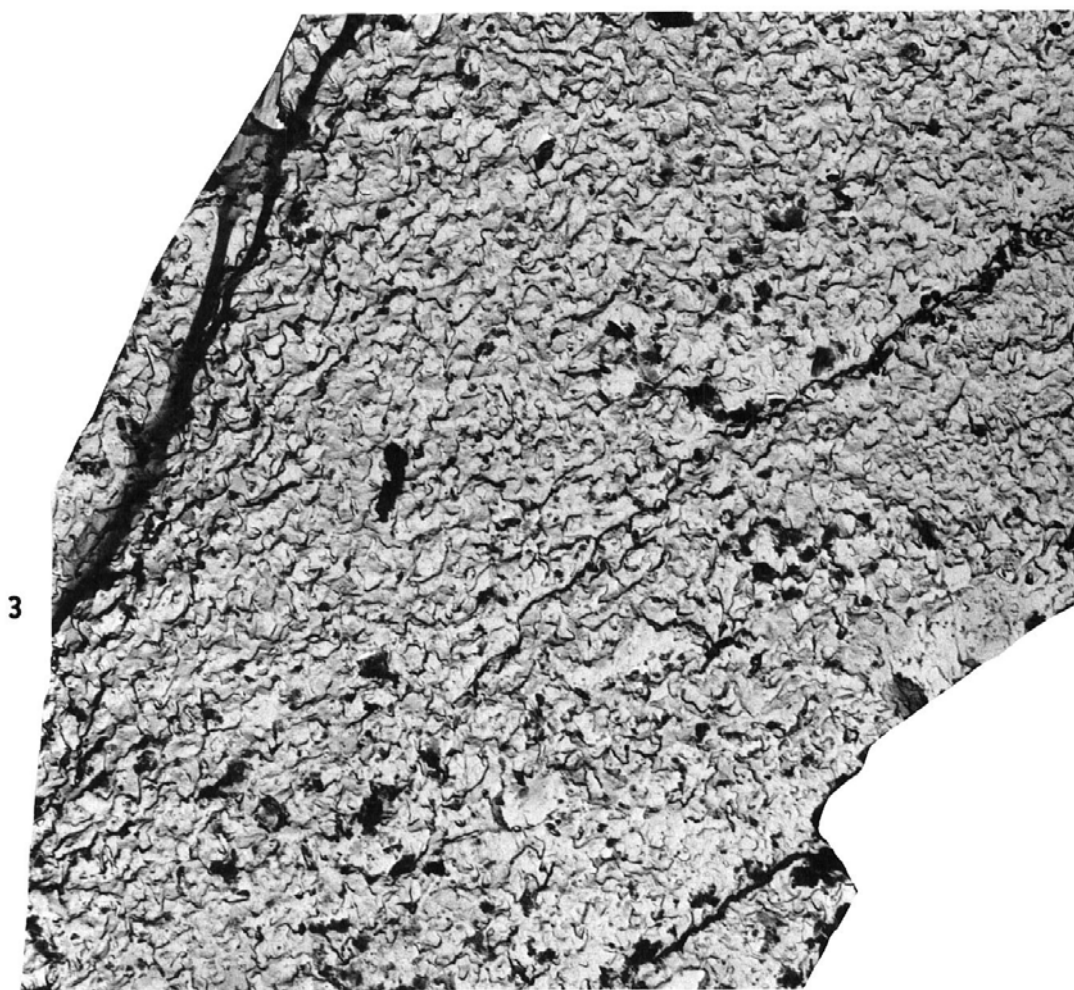
- 1 *Globorotalia truncatulinoides* (d'Orbigny)  
Axial section of a Recent epipelagic individual from the Mediterranean Sea. Note completely microgranular hyaline character of test wall.  $\times 235$ .
- 2 *Globorotalia truncatulinoides* (d'Orbigny)  
Horizontal section of a Recent mesopelagic individual from the Atlantic Ocean. A, microgranular hyaline laminated portion of outer wall; B, radial hyaline (prismatic) portion of outer wall; C, microgranular hyaline septa. Note more translucent character of radial hyaline "calcite crust" with dark-field illumination.  $\times 706$ .
- 3 *Globorotalia truncatulinoides* (d'Orbigny)  
Enlargement of portion of same epipelagic specimen shown in figure 1.  $\times 385$ .



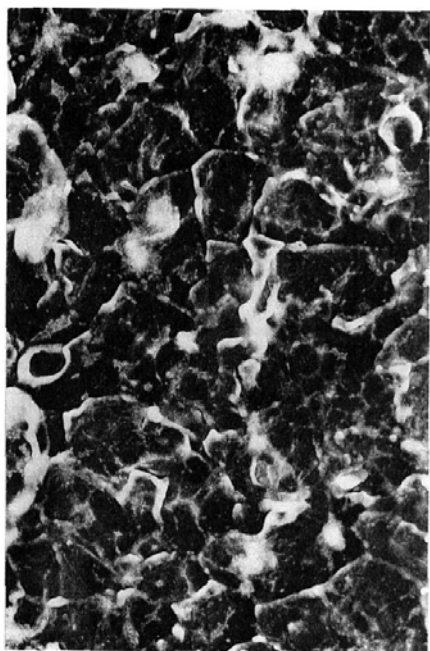
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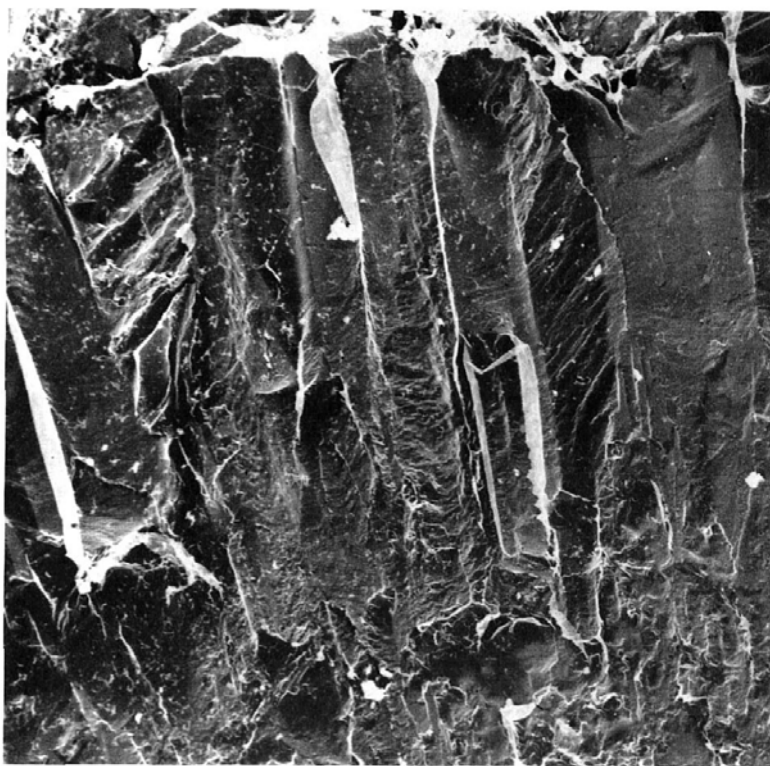
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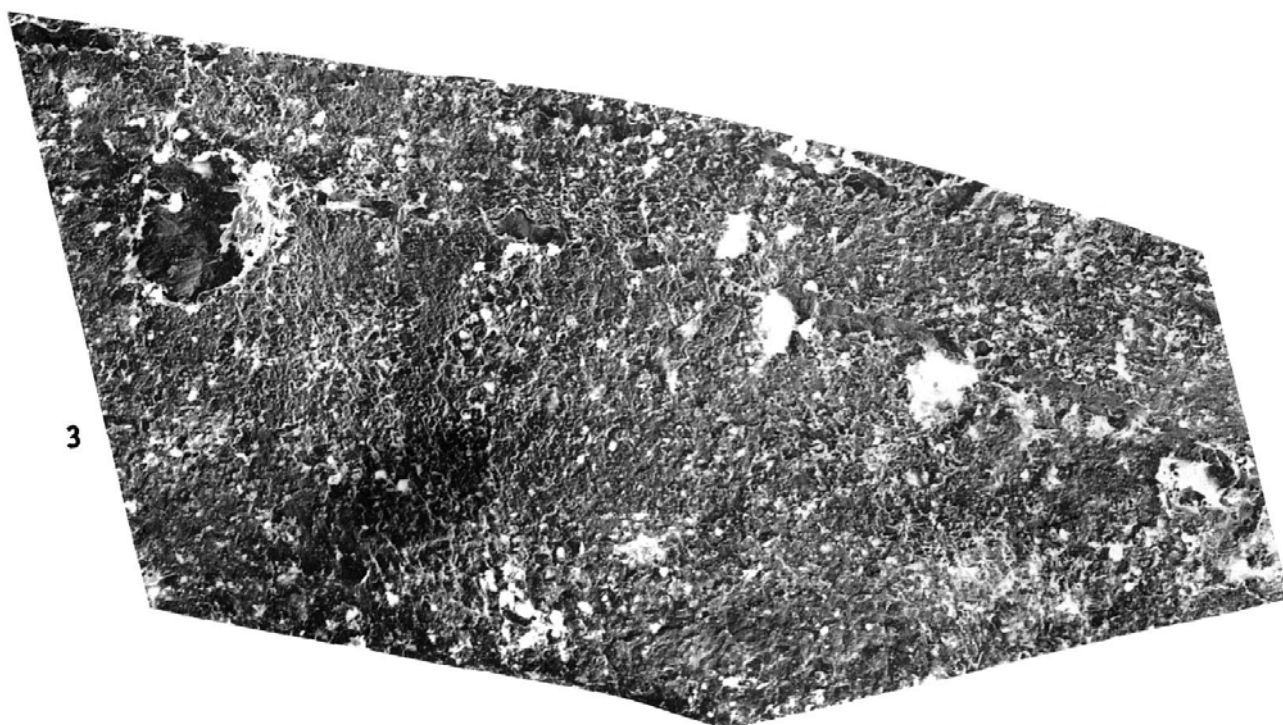
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