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DISSOLUTION OF MOLLUSCAN CALCITE BY THE ATTACHED FORAMINIFER *VASIGLOBULINA*, NEW GENUS (VASIGLOBULININAE, NEW SUBFAMILY)

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CONTENTS

I. Abstract

The new foraminiferal genus *Vasiglobulina* comprises polymorphine species which possess an apertural system of hollow tubules radiating outward from the distal end of the final chamber lumen to the exterior surface of the test. The type species, *Vasiglobulina alabamensis* (Cushman and McGlamery), occurs in Gulf Coast sedimentary rocks which were deposited under shallow marine conditions during the upper Eocene to lower Miocene Epochs. It is ornamented by exterior spines which penetrate mollusc fragments, establishing a unique mode of permanent epifaunal attachment. These unusual morphological features furnish the bases for significant paleoecological and functional inferences.

Five previously described species from Gulf Coast and European Tertiary localities are assigned to *Vasiglobulina,* establishing its known geologic range as upper Eocene to Pliocene.

II. Introduction

Benthonic Foraminifera are attached to the substratum in a variety of ways. They may be vagile grazers that temporarily at-

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tach themselves by pseudopodia (Arnold, 1964) or sessile forms permanently bound by anastomosing pseudopodial strands to loose sediment (Nyholm, 1952). Other forms are attached pseudopodially to living seaweeds (Bock, 1968), corals (Emiliani, 1951), molluscs (Todd, 1965), other organisms (Nyholm, 1961), and various inanimate objects. Permanent attachment by means of an encrusting cement is well known in living forms such as *Cibicides* (Nyholm, 1961), *Nubecularia,* and *Calcituba,* and in fossil forms such as *Webbinella* (Loeblich and Tappan, 1957). Some fossil forms, such as *Planorbulinella,* may be recognized as having been attached in the living state by the presence of a flattened or irregularly contorted test that reflects the contour of the substratum. Pokorný (1963) reports that certain species of the Buliminidae attach themselves by terminal spines. Some species live in the empty tests of other foraminifera or in worm tubes (Nyholm, 1953). A few are believed to be parasitic on other foraminifera (Le Calvez, 1947), and at least one species is epizoic on a bivalve (Todd, 1965).

The present work describes a new mode of attachment among the foraminifera (Polymorphinidae) which involves partial or complete penetration of molluscan shell fragments by acicular spines protruding from the exterior surface of the foraminiferal test. Such a peculiar means of attachment has not been documented in the foraminiferal literature, although some polymorphine species have been reported attached to calcareous fragments and quartz grains by extensions of the test (*e.g.*, Cushman, 1922a; Fuchs, 1967). Some significant additions to to the numerous known functional responses of foraminiferal pseudopodia are inferred from this manner of permanent attachment.

Forms with this unusual attachment also possess a singular modification of the usual polymorphinid aperture which consists of radiating slits. This unique aperture is a system of hollow tubules radiating from the distal end of the final chamber lumen to the exterior surface of the test.

In order to place this group of species within the taxonomic framework established by Loeblich and Tappan (1964), the new genus *Vasiglobulina* is erected. It is placed within the Nodosariacea, family Polymorphinidae, by modifying the definition of a radiate aperture given by Loeblich and Tappan (1964). It now becomes an "Opening associated with numerous diverging slits [or hollow tubules] . . . "* As no existing subfamily will accommodate the genus, the writer proposes the new subfamily, Vasiglobulininae.

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* Phrases in brackets are additions to the descriptions given by Loeblich and Tappan, 1964.

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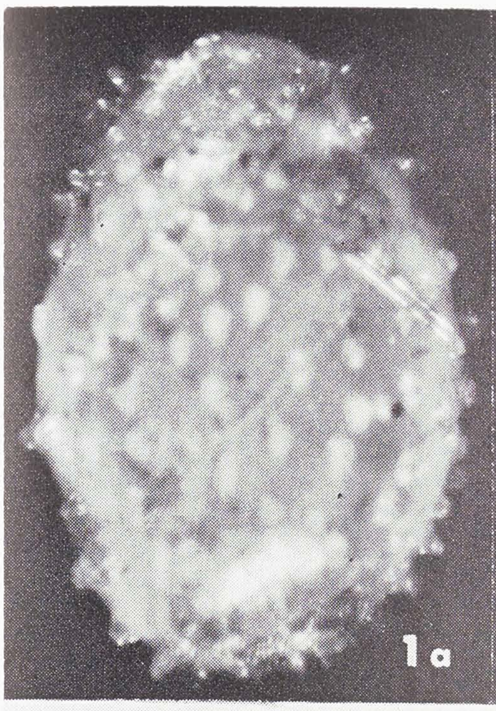
PLATE 1

Vasiglobulina alabamensis (Cushman and McGlamery). All specimens from the Oligocene Chickasawhay Formation near Millry, Alabama. Apertural ends are at the top.

Figures

1 Stereopair of 5-chambered holotype; note flattened test and distinct final suture crossing test diagonally. X 90
2 Apertural view of holotype; transmitted light. X 90
3 Paratype A; 4 chambers. X 90
4 Apertural view of holotype showing radiating tubules; focus below upper surface of apertural mound; transmitted light. X 420
5 Paratype B; 5 chambers; note smooth surface of reduced final chamber. X 90
6 Spine of paratype C showing distal thickening; note irregularly broken distal end. X 420
7 Paratype C showing well preserved long spines; 4 chambers. X 90
8 Spine of paratype C; note distal tapering. X 420
9 Spine of paratype C; note slight thickening of distal end and flat, evenly broken tip. X 420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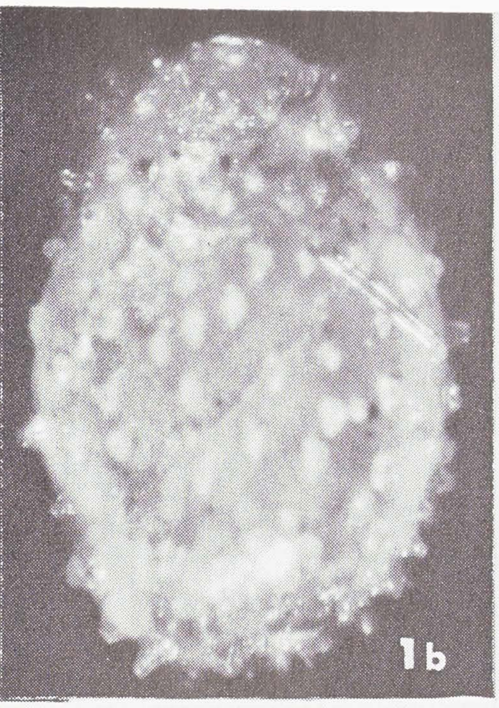
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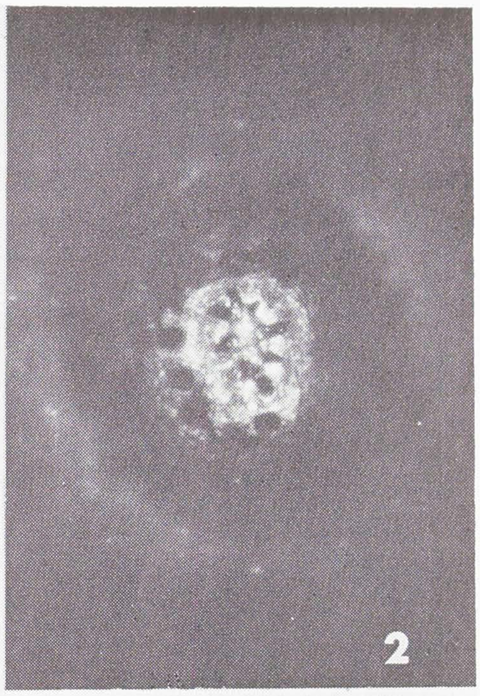
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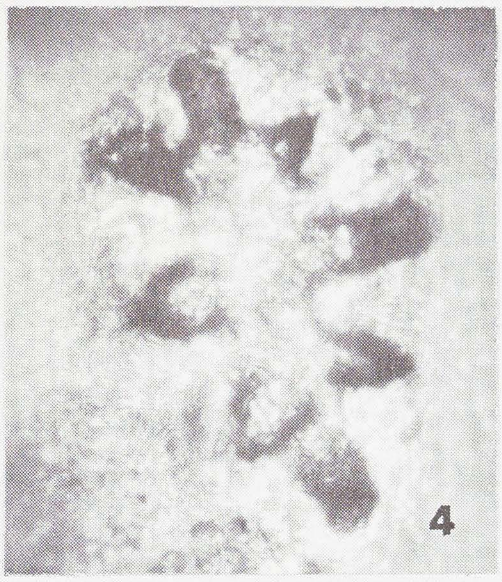
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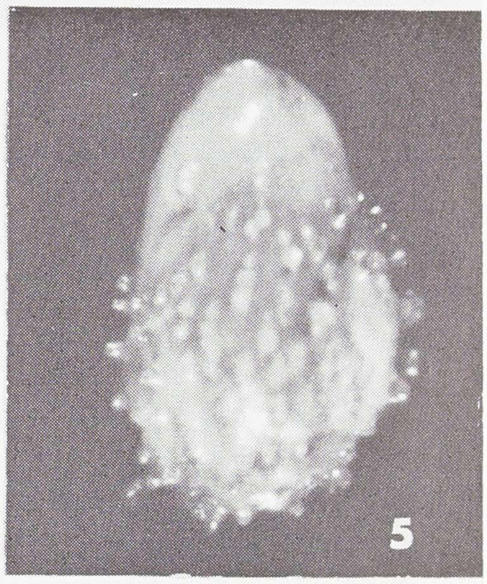
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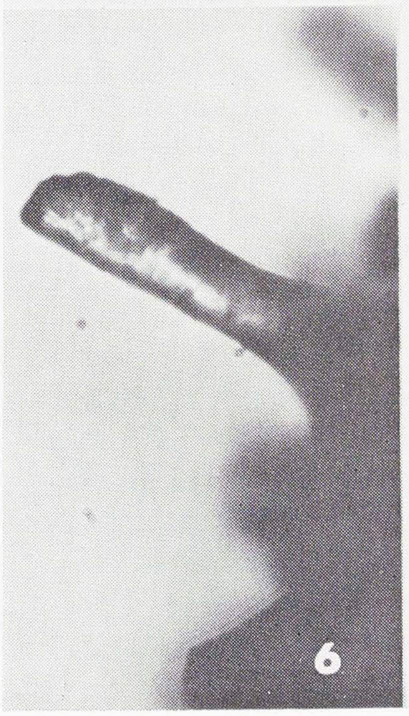
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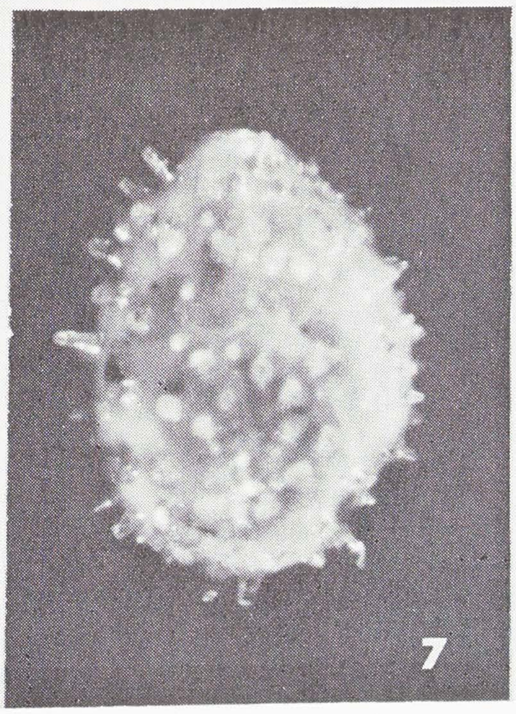
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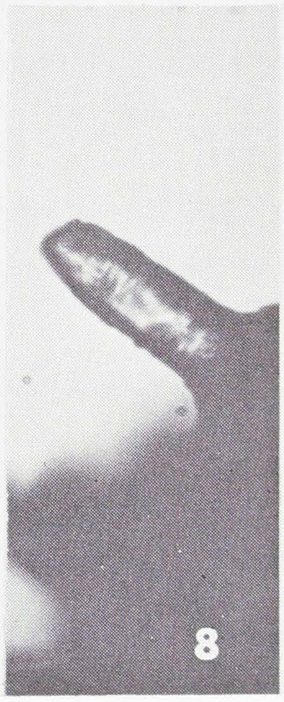
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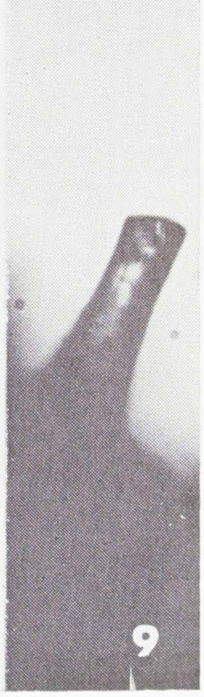
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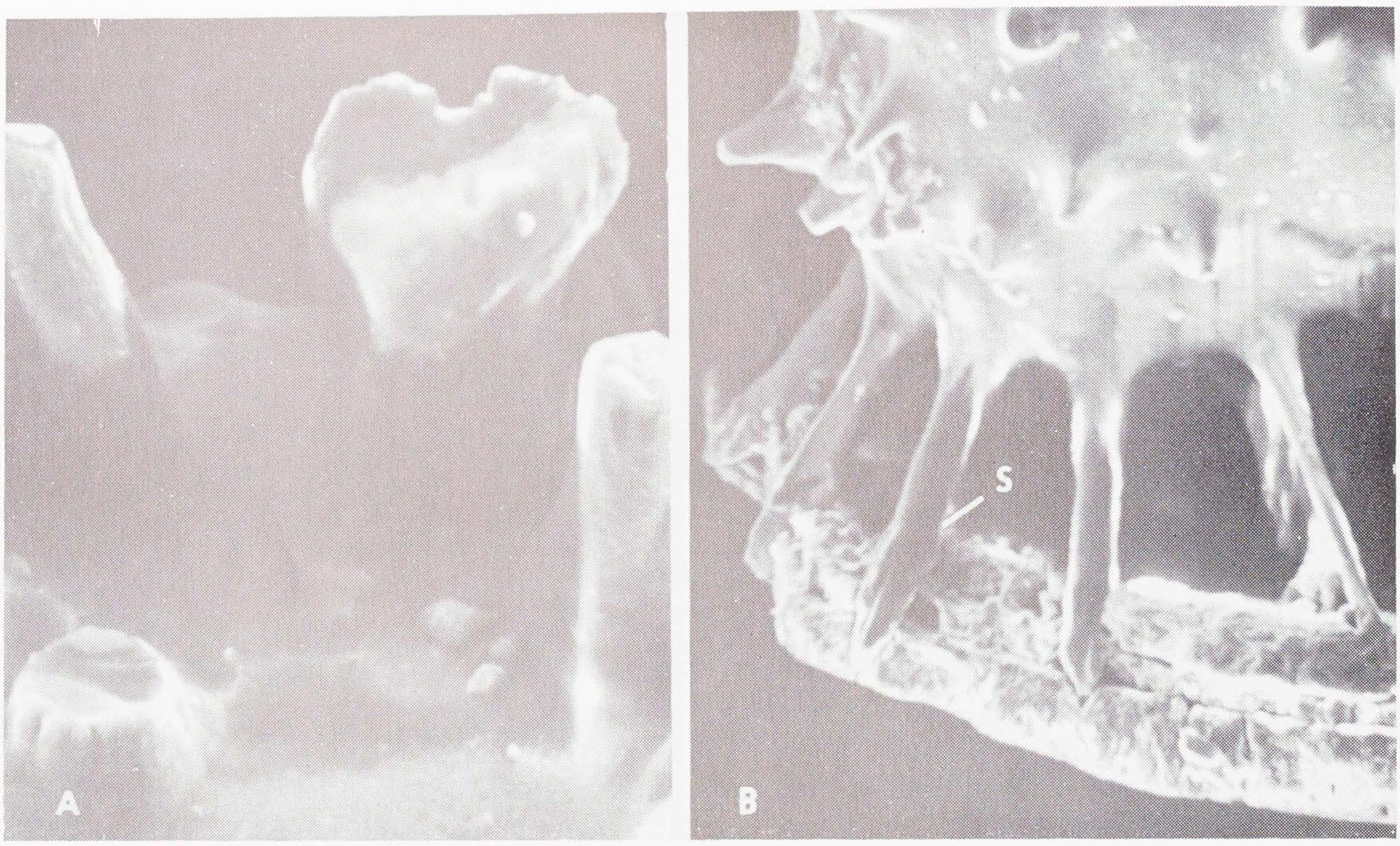
PLATE 1



TEXT FIGURE 1

Scanning electron photomicrographs of *Vasiglobulina alabamensis* spines. A. Note distal thickening of spine at upper right; note longitudinal grooves on broken spine base at lower left; X 1000. B. Spines of hypotype B penetrating mollusc fragment; note distal thickening of spine ("s") within the mollusc fragment and the longitudinal grooves near the tip; X 300.

III. SYSTEMATIC PALEONTOLOGY

Order FORAMINIFERIDA Eichwald, 1830

Suborder ROTALIINA Delage and Hérouard, 1896

Superfamily NODOSARIACEA, Ehrenberg, 1838

Family POLYMORPHINIDAE d'Orbigny, 1839

Test multilocular, chambers in spiral or sigmoidal coil about longitudinal axis of growth, or biserial, or uniserial, typically somewhat overlapping; [free or attached;]* apertures all develop in the same direction, terminal, radiate.

Subfamily VASIGLOBULININAE Poag, subf. n.

Test ovoid or pyriform, generally attached by spines; aperture a system of hollow tubules radiating outward from the distal end of the final chamber lumen to the exterior surface of the test.

Genus VASIGLOBULINA Poag, gen. n.

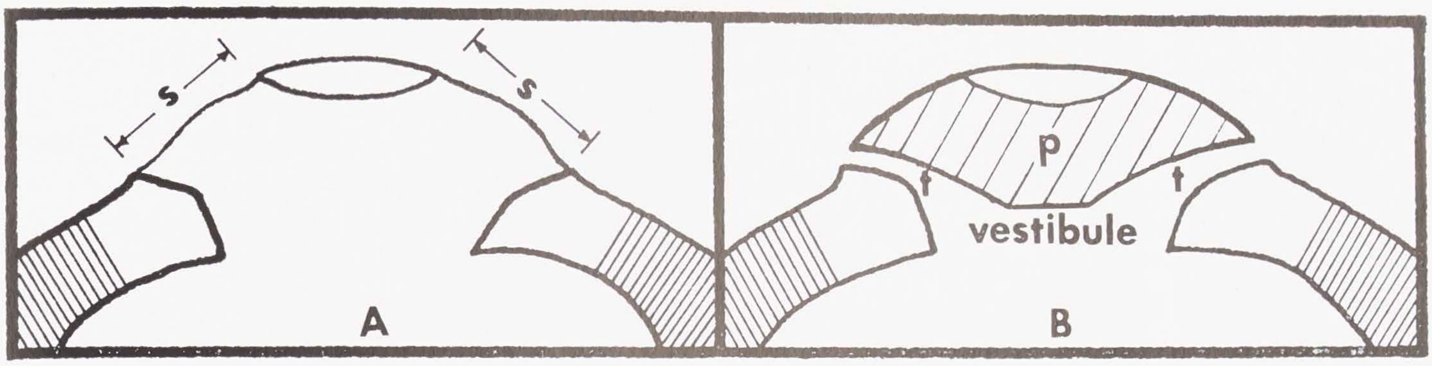
Test primarily attached by spines, calcareous, hyaline, with finely perforate monolamellar walls of optically radial calcite; chambers few, embracing, rapidly increasing in size as added; chambers added to spiral coil at approximately 144° intervals; wall generally spinose; aperture a system of hollow tubules radiating outward from a common vestibule at the distal end of the final chamber lumen to the exterior surface of the test.

Type species: *Globulina alabamensis* Cushman and McGlamery, 1939.

Etymology: From Latin *vas,* meaning duct and *Globulina,* a related foraminiferal genus; the name refers to the tubular aperture.

Material: *Vasiglobulina alabamensis* (Cushman and McGlamery), 1939

1) Paynes Hammock Formation on Chickasawhay River near Waynesboro, Mississippi—2 specimens
2) Chickasawhay Formation
   a) Taylor Mill Creek near Waynesboro, Mississippi—84 specimens
   b) Millry, Alabama—11 specimens
3) Byram Formation at type locality, Byram, Mississippi—1 specimen
4) Mint Spring Marl at Mint Spring Bayou, Mississippi—3 specimens



TEXT FIGURE 2

Diagrammatic illustration of transition from slit-like polymorphinid aperture to tubular vasiglobulinid aperture; A = polymorphinid aperture; s = slit openings; B = vasiglobulinid aperture; p = plug of calcite filling most of apertural cavity and blocking distal portions of elongate slits; t = tubular passages radiating from vestibule to exterior surface of test.

5) Red Bluff Clay
  a) Hiwannee, Mississippi—7 specimens
  b) Little Stave Creek, Alabama—2 specimens

Vasiglobulina tuberculata (d'Orbigny), 1846
  1) *Amphistegina* Marl near Vienna, Austria—2 specimens
  2) Pliocene near Piacenza, Italy—2 specimens probably conspecific

Vasiglobulina striata (Egger), 1857
  1) Miocene near Ortenburg, L. Bavaria—1 specimen
  2) Pliocene near Piacenza, Italy—6 specimens

Vasiglobulina variata (Jones, Parker, and Brady), 1866
  1) Coralline Crag, Sutton, Suffolk, England—3 specimens

Vasiglobulina punctata (d'Orbigny), 1846
  1) Coralline Crag, Sutton, Suffolk, England—13 specimens
  2) Pliocene near Piacenza, Italy—8 specimens
  3) Stampien at Jeurre, France—4 specimens

Smooth forms belonging to "*Globulina gibba*" group:
  1) Pliocene near Piacenza, Italy—3 specimens
  2) Pliocene near Cecina, Italy—2 specimens
  3) Chickasawhay Formation—7 specimens

Remarks: The radiating tubular apertural system is present in all the strongly spinose polymorphine forms observed. Several smooth specimens from the Pliocene near Piacenza, and Cecina, Italy, and in the Chickasawhay samples from Taylor Mill Creek, Mississippi, also have such an aperture (pl. 10, figs. 7, 9, 10, 12). The morphology of these smooth forms is otherwise that of the "*Globulina gibba*" group.

IV. DESCRIPTIVE MORPHOLOGY

The type species of *Vasiglobulina* is *Vasiglobulina alabamensis* (Cushman and McGlamery), a foraminifer of moderate size with an ovoid or pyriform shape. The base is generally broadly rounded, the apertural end is tapered, and the outline is circular to flatly ovate in transverse section (pl. 1, figs. 1,3,5,7; pl. 8, figs. 1-10). The finely perforate wall (pl. 3, fig. 3; pl. 5, fig. 7) is constructed of calcite crystals with their C-axes predominantly radially oriented, as indicated by the dark extinction figure produced under crossed nicols (pl. 3, fig. 5).

Spines

Most of the outer surface is ornamented by randomly placed spines, of large diameter, variable length, and generally bluntly broken (text figure 1A; pl. 1, figs. 6,8,9; pl. 4, figs. 1-12). The several attached specimens that have been observed display short or long spines, some of which partially or completely penetrate the molluscan fragments to which they attach (text fig. 1B; pl. 2, figs. 1-8; pl. 3, figs. 6,7,8). The spines pass through the mollusc shells without disturbing the normal molluscan calcite lamellae except to produce dissolution cavities into which the spines are inserted (text fig. 1B; pl. 2, fig. 5; pl. 5, fig. 1). This is in contrast to the anomalous mounds of calcite on the shells of living molluscs caused by the epizoic *Rosalina carnivora* (Todd, 1965).

markedly depressed (pl. 8, fig. 6). In most specimens the final intercameral suture is well above the base of the test (pl. 8, figs. 2,6), but in some 4-chambered forms it approaches the base more closely (pl. 9, figs. 1,2). The intercameral septa are rarely preserved in either juvenile or mature specimens, a phenomenon also observed in several fossil species of "*Globulina*" (Le Calvez, 1950). They apparently have been resorbed during growth creating a monothalamous condition (pl. 5, fig. 2). Varying degrees of resorption have been recorded in living genera, including *Elphidium* (Jepps, 1956), *Patellina, Discorbis,* and *Cymbalopora* (Myers, 1943), and *Cibicides* (Nyholm, 1961).

Aperture

The aperture is situated at the distal end of the final chamber, which is generally less spinose than the rest of the test surface (pl. 2, fig. 6). It consists of a system of hollow cylindrical tubules that radiate outward from a common vestibule at the distal end of the final chamber lumen (pl. 5; figs. 3,4; pl. 6, figs. 1-9; pl. 7, figs. 6-9; pl. 9, fig. 7). These tubules are widest at the inner ends, narrowing as they extend outward and upward toward the surface (pl. 5, figs. 3,4; pl. 9, fig. 7). On the outer test surface they open as small circular foramina, often in the center of low conical elevations (pl. 7, figs. 2-5). These elevations are part of a protruding cylindrical neck or low hummocky mass of thick, non-perforate calcite (pl. 2, fig. 1; pl. 5, fig. 3; pl. 7, figs. 2,4; pl. 8, figs. 1-10). The basic pattern is a symmetrical radiation of tubules (pl. 6, figs. 1-9), but they may be irregularly placed (pl. 7, fig. 1; pl. 9, fig. 8), and some may extend subparallel to the long axis of the test.

The radiate tubular apertural system of *Vasiglobulina* appears to have developed in the Late Cretaceous or early Paleogene Period from the polymorphinid system of radiating slits, which arose in the Triassic Period (Loeblich and Tappan, 1964). The oldest specimen of *Vasiglobulina* examined by the writer is of upper Eocene age. Some species probably referable to the genus have been reported from Eocene rocks by Cushman and Ozawa (1930; *V. verrucosa*), Bandy (1949; *V. alabamensis* ?), and Deboo (1965; *V. alabamensis* ?). *Globulina lacrima ericia* of Cushman and Ozawa (1930) may be a Cretaceous representative.

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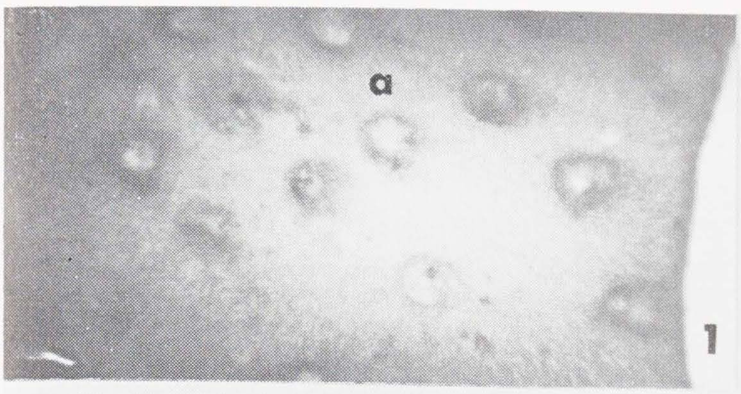
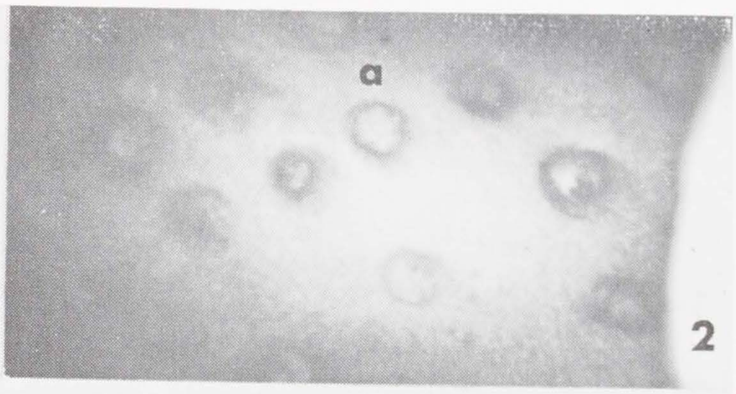
PLATE 3

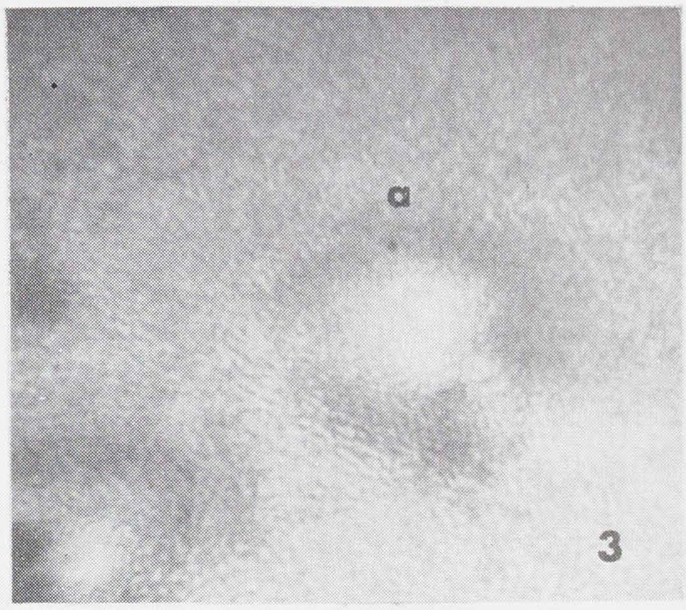
Vasiglobulina alabamensis (Cushman and McGlamery). All specimens from the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi. Figures 1-5 all same specimen.

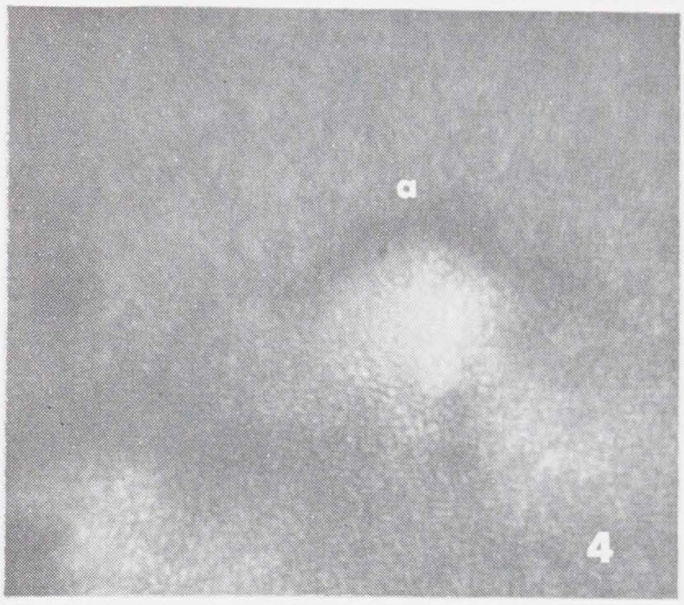
Figures

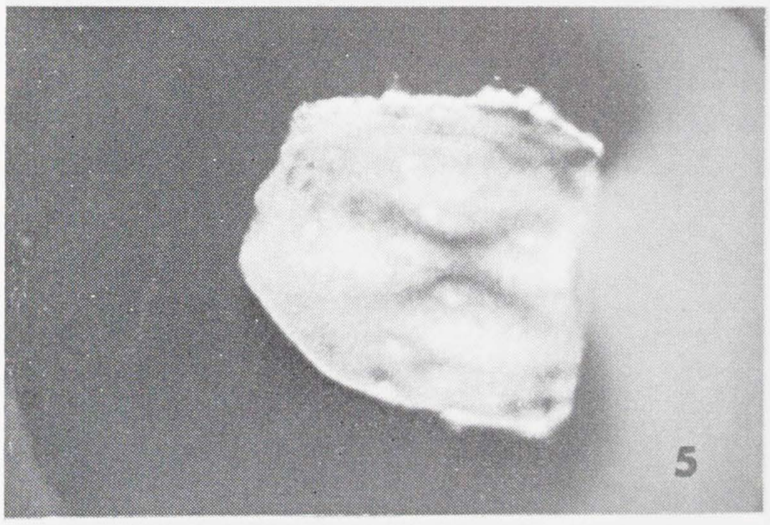
1 Interior surface of test wall; focus on surface. Note absence of structure in spines; glycerine mount, transmitted light. X 200
2 Interior surface of test wall; focus below surface. Note absence of structure in spines. X 200
3 Interior surface of test wall; focus on surface. Note continuity of pore pattern across spine base "a." X 860
4 Interior surface of test wall under crossed nicols. Note spines do not extinguish with the rest of test wall. X 860
5 Interior wall of test fragment under crossed nicols. Note dark extinction figure produced by radially arranged calcite crystals; bright spots are spine bases. X 100
6 Mollusc fragment. Dark angular spots are spine stubs of *Vasiglobulina alabamensis.* X 180
7 Hypotype B viewed from underside of mollusc fragment, showing spines (dark angular spots) completely penetrating the mollusc shell. X 90
8 Enlargement of figure 7. Note angularity of spines in transverse section. X 180

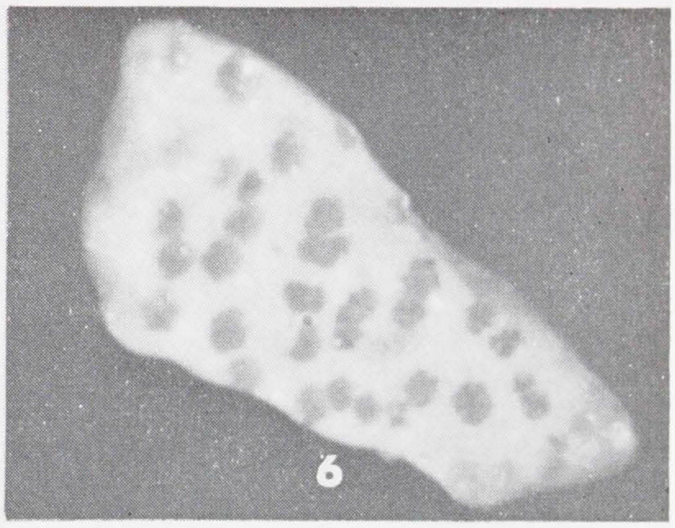












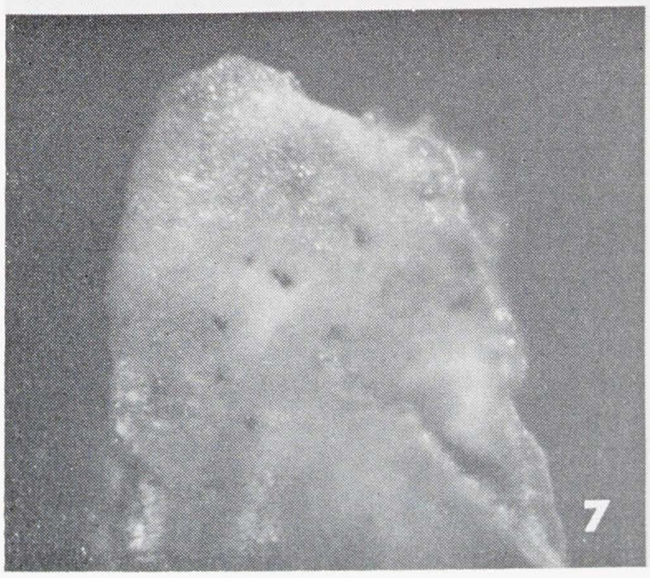


PLATE 3

The polymorphinid aperture consists of a distal cavity in the lumen of the final chamber, from which elongate radiating slits extend to the test surface and open between calcareous plates. These plates generally converge at the distal end of the final chamber, where they either join or leave a narrow apical gap. Transition to the vasiglobuline type of aperture can be accomplished by adding a calcite plug that fills most of the apertural cavity, blocking the distal portions of the slits and, thus, leaving only hollow tubules branching off a central vestibule (text fig. 2). Le Calvez (1950) describes a cylindrical canal in the neck of *Globulina gravida* (Terquem), which may represent a depature toward the vasiglobuline condition.

V. MORPHOLOGICAL VARIATION

The Polymorphinidae are notorious for the wide range of morphological variation at the species level. The plasticity of test shape and the frequent occurrence of fistulose apertural growths are the most common manifestations of this flexibility. *Vasiglobulina alabamensis* is no exception to this pattern; it displays numerous variations in test shape, spinosity, and apertual characteristics.

Test Shape

Most 4-chambered specimens are pyriform, with rounded initial ends and tapered apertural ends (pl. 8, figs. 4,10). They are generally longer than broad, but in some, breadth may almost equal length (pl. 9, fig. 2). In longitudinal view, most are bilaterally symmetrical (pl. 8, figs. 4,7,10), but some are asymmetrical, protruding markedly at one side (pl. 9, figs. 1,2). A few specimens are sharply tapered initially and broadly rounded aperturally (pl. 8, fig. 5); infrequently, both ends taper (pl. 9, fig. 5).

Spinosity

In general, the spines are arranged on the surface of the test with no clear relationship to one another except that the apertural region is relatively smooth. Individual specimens, however, may display lineation of some spines (pl. 8, fig. 2; pl. 9, fig. 2), and in some, even the apertural region is spinose (pl. 7, fig. 8; pl. 9, fig. 5). Density of spines varies considerably among speci-

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PLATE 4

Vasiglobulina alabamensis (Cushman and McGlamery)

Figures

1 Hypotype D, U.S.N.M. No. 687809; topotype from the Chickasawhay Formation near Millry, Alabama, showing well preserved spines; lettered spines are enlarged in figures 2-10; note apparent lack of internal structure. X 90

2,3 Spine "a." Note tapering and irregularly broken tip. 2, X 430; 3, X 860

4 Spine "b." X 430

5,6 Spine "c." Note hourglass shape and irregularly broken tip. 5, X 430; 6, X 860

7 Spine "c" under crossed nicols; note broad color bands denoted by horizontal white lines. X 860

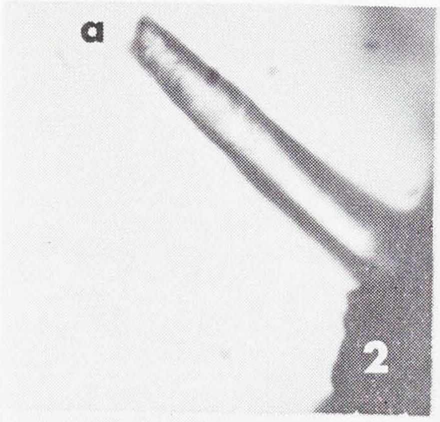
8 Spine "d." X 430

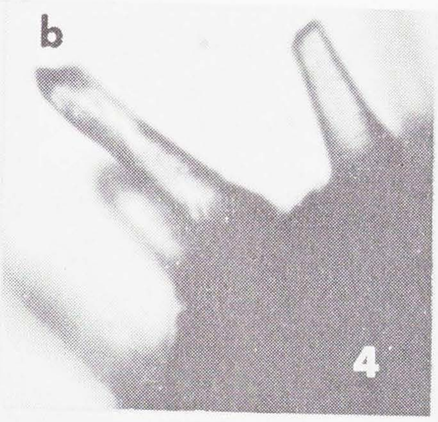
9,10 Spine "e." Note distal thickening and flatly broken tip. 9, X 430; 10, X 860

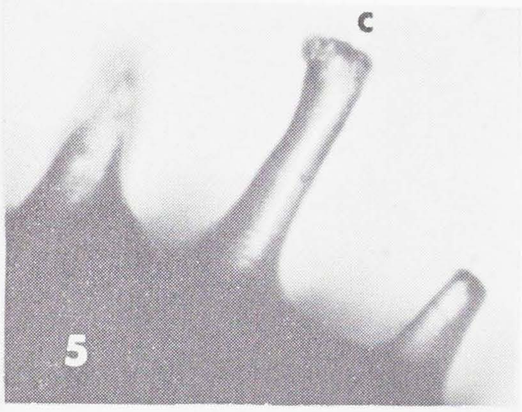
11 Hypotype from the Red Bluff Clay at Hiwannee, Mississippi. Note distal thickening and digitation and the alignment of the flat broken surfaces indicating site of previous attachment; spine "f" enlarged in figure 12. X 430

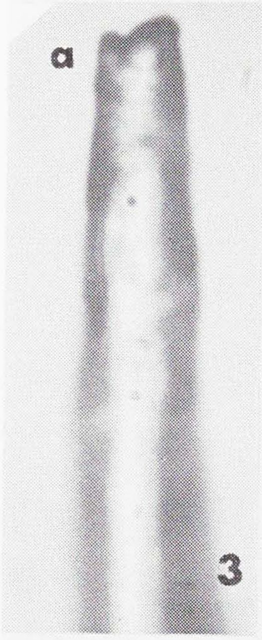
12 Enlargement of spine "f," figure 11. X 860

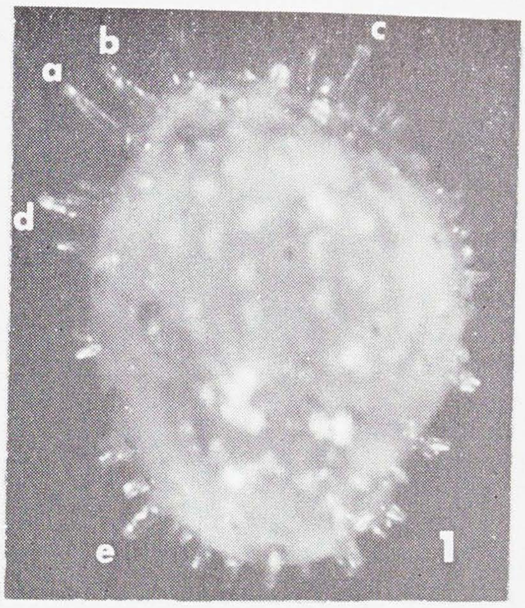
13,14 Spines of specimen from the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi; transverse sections under crossed nicols. Note absence of extinction, angularity of outline, lack of internal structure, and peripheral indentations resulting from longitudinal grooves on exterior of spines. X 860

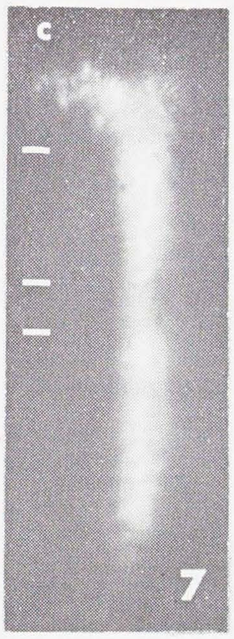


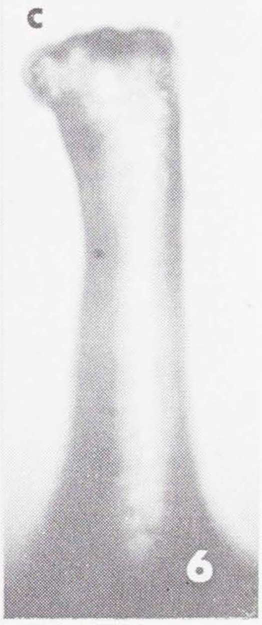


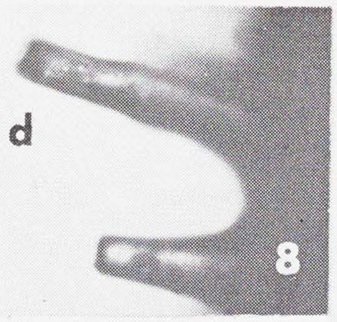


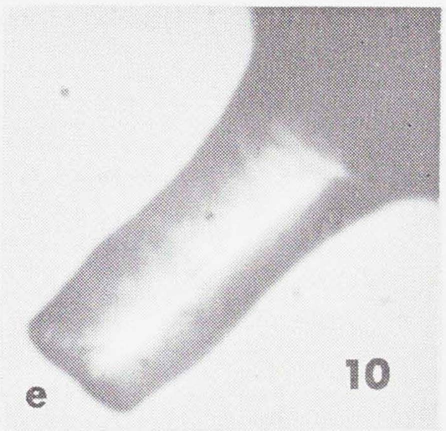


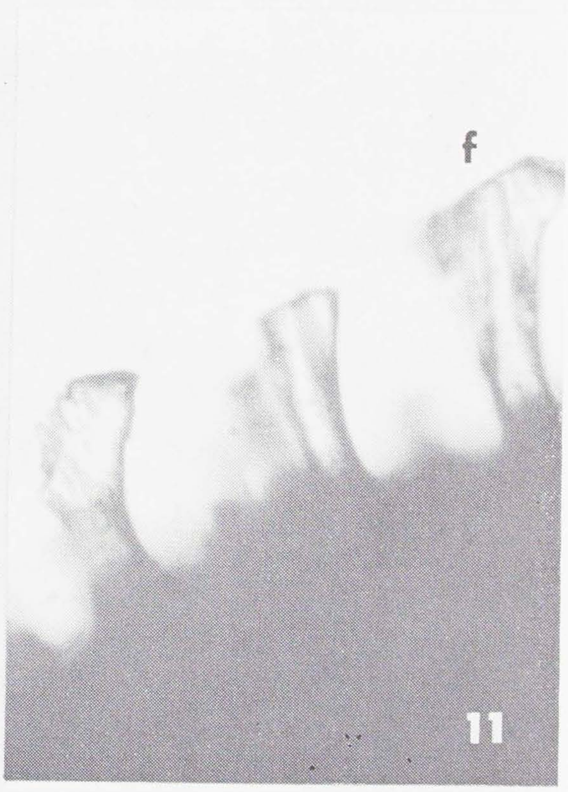


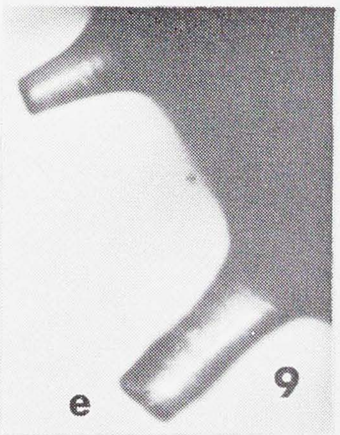


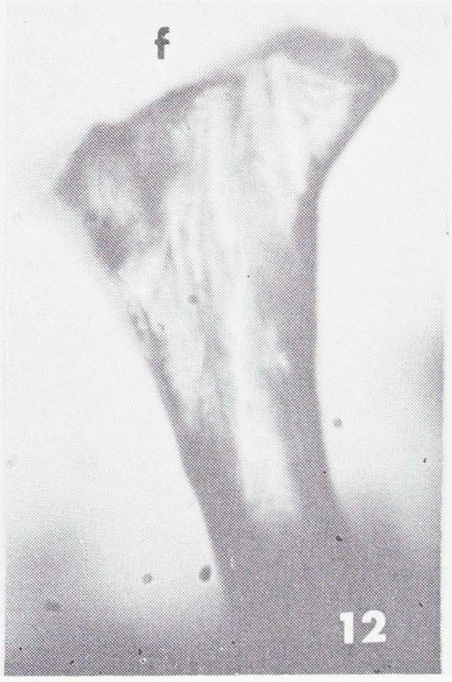


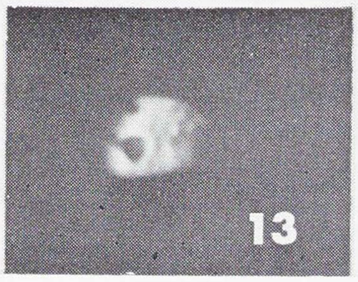












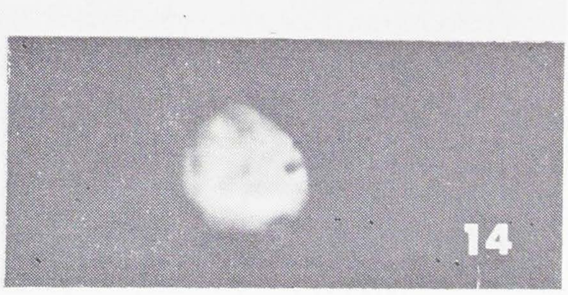


PLATE 4

mens and on individuals (pl. 8, figs. 1-10); they may be arranged in thick patches (pl. 8, fig. 6), or widely scattered (pl. 8, figs. 5,8). The shape in transverse section varies from circular to ovate to angular (pl. 3, figs. 1-8; pl. 4, figs. 13,14). Most project perpendicularly to the outer test surface (pl. 4, figs. 9,11), but others may project at different angles (pl. 4, fig. 4). Spine diameter is variable; one specimen may have predominantly thick spines (pl. 8, fig. 2), and another of similar size and number of chambers may have predominantly thin ones (pl. 8, fig. 4). Spines of various diameters are often present on a single specimen (pl. 8, fig. 3). Some spines are hourglass-shaped in longitudinal outline (pl. 2, fig. 2; pl. 4, fig. 6), but most taper to their preserved extremities (pl. 4, figs. 2,4). Some display longitudinal grooves (text fig. 1A,B) or digitation (pl. 4, figs. 11,12) at their distal extremities. Some spines display longitudinal grooves that can be seen only at high magnification (text fig. 1A,B). The presence of these grooves is reflected by peripheral indentations of the spines when viewed in transverse section (pl. 4, figs. 13,14).

Aperture

In observed specimens, the number of tubules constituting the aperture varies from a minimum of 7 (pl. 6, figs. 1-7) to a maximum of 19 (pl. 9, fig. 8). These tubules generally radiate subsymmetrically (pl. 6, figs. 1-7), but may also be conspicuously asymmetrical (pl. 7, fig. 1; pl. 9, fig. 8). The height and size of the exterior apertural mound is variable. It may extend as a distinct neck-like protuberance (pl. 8, fig. 1; pl. 9, fig. 7) or may be nearly flush with the rounded test surface (pl. 8, fig. 6). It may be symmetrically lobate, with each pore opening in the center of a conical elevation (pl. 6, fig. 5; pl. 7, figs 2-5), or may be a thickened irregular mass of nodose and spinose calcite (pl. 9, fig. 5).

VI. FUNCTIONAL MORPHOLOGY

Shape of Test

The ovoid or pyriform shape of the test of *Vasiglobulina alabamensis* suggests orientation of the long axis parallel to the sea bottom and to the dominant current direction in order to provide a more stable hydrodynamic configuration. This, together with

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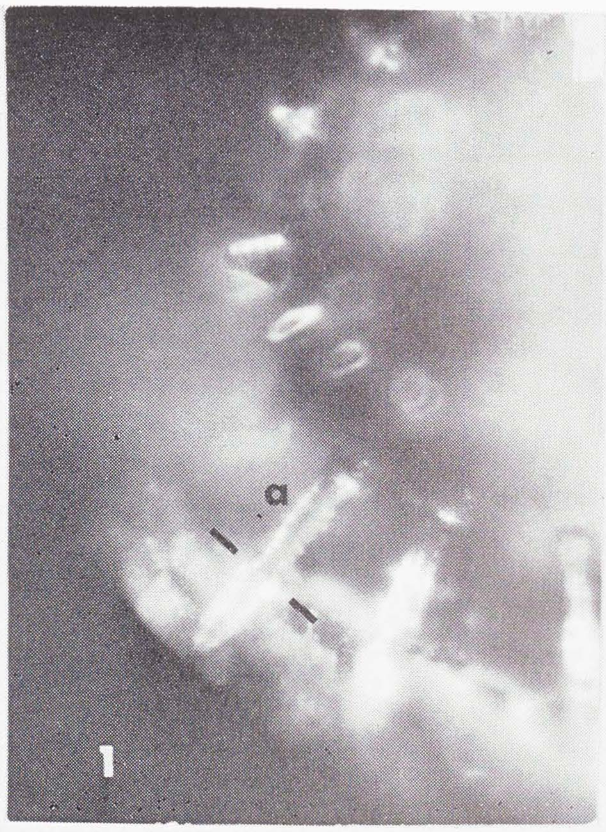
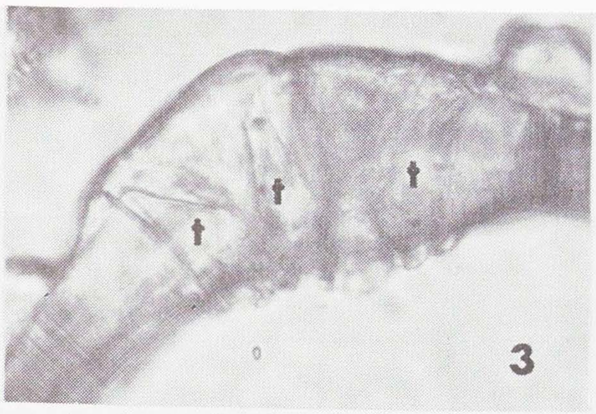
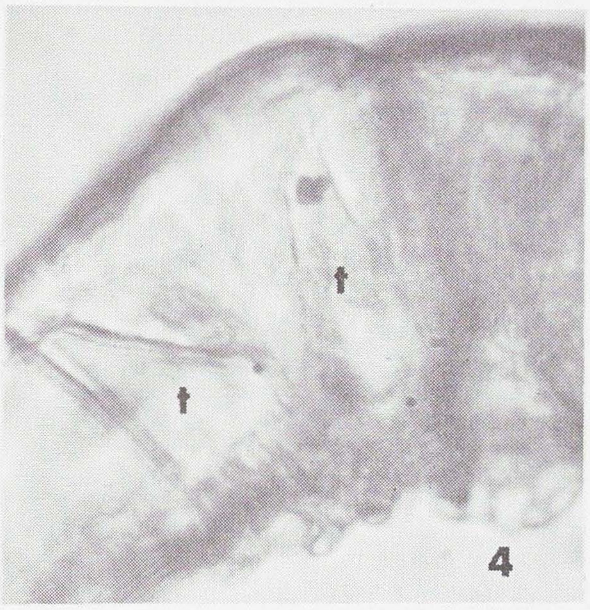
PLATE 5

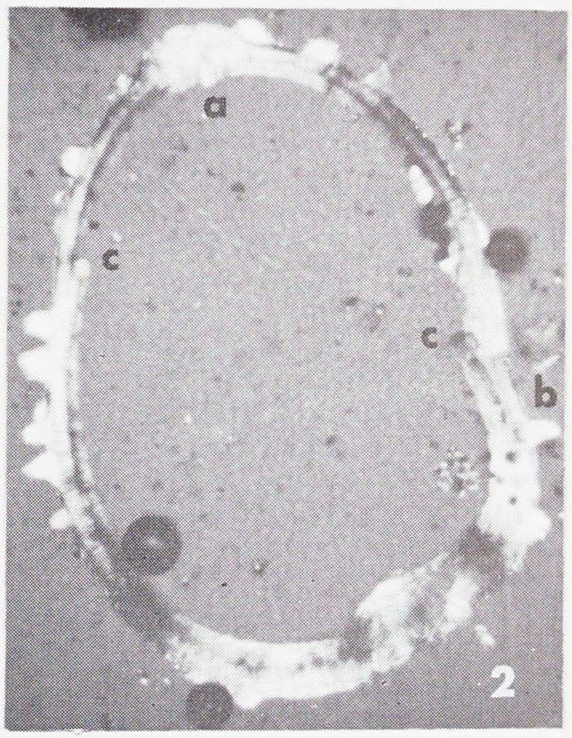
Vasiglobulina alabamensis (Cushman and McGlamery). All specimens from the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi.

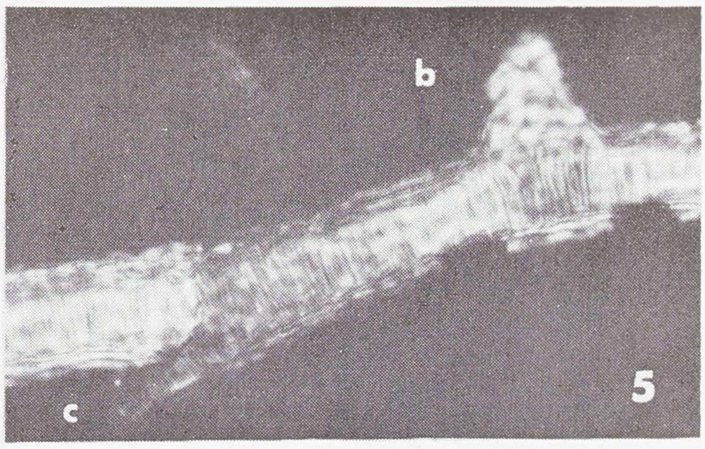
Figure	
1	Attached hypotype A showing spines penetrating edge of mollusc fragment; black line indicates interior surface of mollusc. Note slight thickening of spine "a" as it passes into the shell. X 200
2	Longitudinal section of specimen under crossed nicols. "a" = apertural region; "b" = spine enlarged in figures 5-7; "c" = remnants of internal septum separating final two chambers. X 100
3,4	Apertural section of figure 2. Upper ends of hollow tubules "t" extend below plane of section, narrowing upward; note absence of perforate wall structure in apertural mound. Perforations can be seen in wall at lower left of figure 3. Figure 3, X 430; 4, X 860
5,6	Portion of wall of figure 2 showing spine structure completely penetrating lamellae of juvenile test wall; note septal remnant "c." 5, X 430, crossed nicols; 6, X 430, plane polarized light.
7	Spine "b" of figures 2,5,6. Note spine structure present through entire wall; perforate wall structure absent in spine (apparent pores in lower portion of spine are below the plane of section); minute pores of wall curve outward away from spine base. X 860

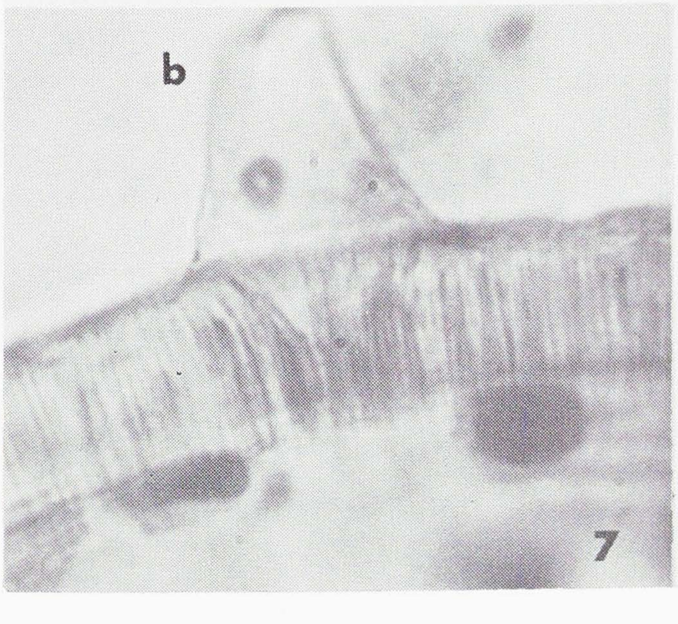












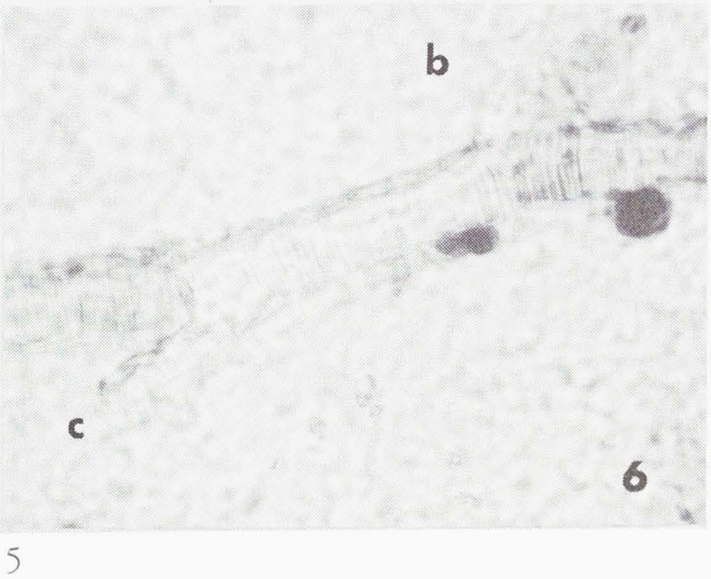
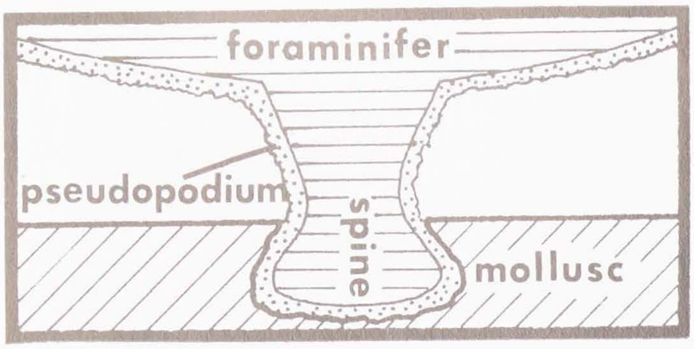


PLATE 5



TEXT FIGURE 3

Exaggerated diagrammatic section showing penetration of mollusc fragment by pseudopodium and hourglass-shaped spine. Thickened distal end prevents loss of attachment.

the need for such firm attachment, indicates that the species is part of the epifauna, not the infauna.

Size of Aperture

Narrowing of the apertural openings from elongated slits, as in many other polymorphinids, to the minute, circular foramina of *Vasiglobulina* may be a response analagous to the development of a tooth structure in some miliolids and buliminids. Arnold (1964) has suggested several possible advantages that may be derived from such constricted apertural openings. Some of his suggestions are applicable to *Vasiglobulina.*

1) The constriction may serve as a check valve to prevent premature extrusion of nucleated protoplasm; prevent entry of large predators, food particles, or debris; or, prevent proximal migration of large vacuoles.

2) It may facilitate segmentation of multinucleate protoplasm during schizogony.

3) It may change the velocity of protoplasmic flow and complicate circulation, lengthening the exposure of food particles to extrathalamous digestion. Pseudopodial digestion of larger food particles may logically be expected in *Vasiglobulina,* since the apertural openings are small relative to such food material as larger diatoms. Extrathalamous digestion has been reported in living forms such as *Elphidium* (Jepps, 1942).

Spines

The attaching spines are permanently wedged within the dissolution cavities in the mollusc fragments by varying degrees of distal thickening (text fig. 1B). A conspicuous hourglass shape is produced in those spines that thicken most (text fig. 3; pl. 2, fig. 2), but this shape is not apparent in those spines that thicken only slightly (pl. 2, fig. 3).

The non-attaching spines may serve to brace the waving pseudopodia against cur-

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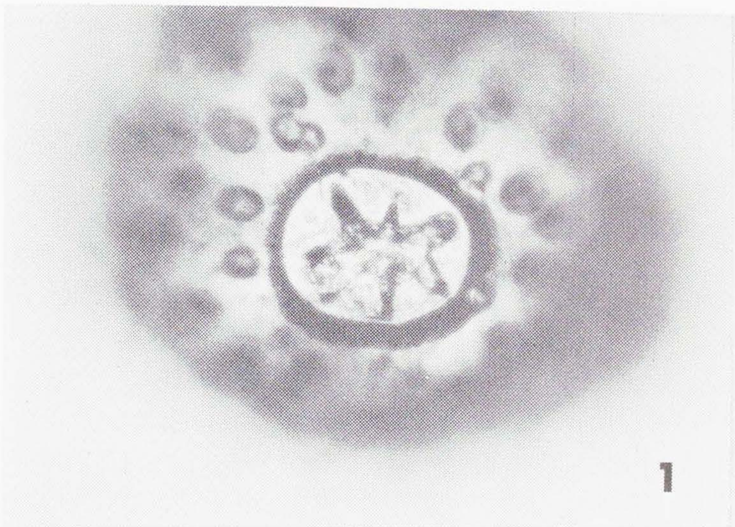
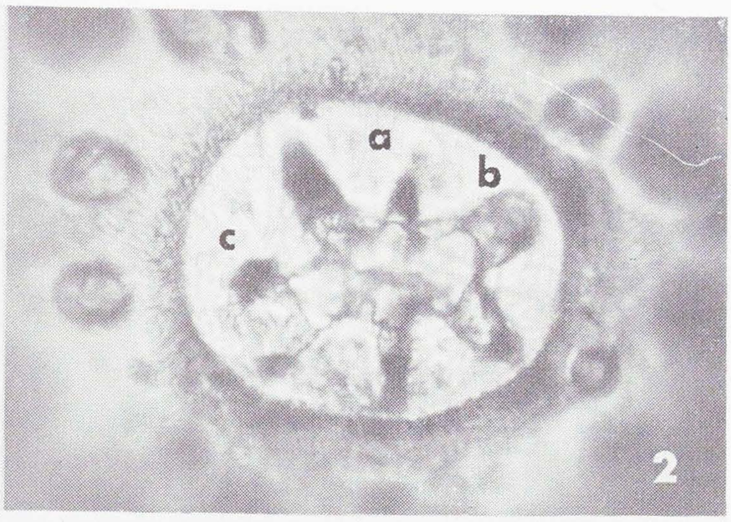
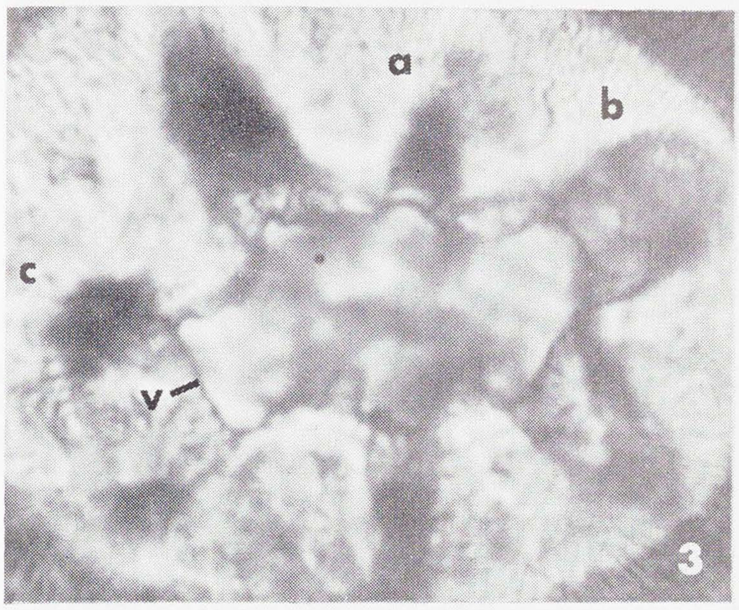
PLATE 6

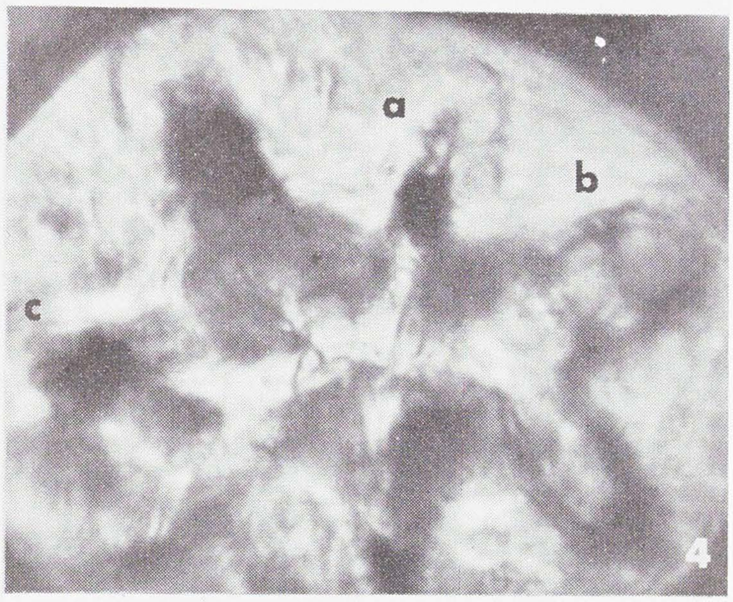
Vasiglobulina alabamensis (Cushman and McGlamery) from the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi. All figures are of the same specimen; transmitted light, glycerin mount.

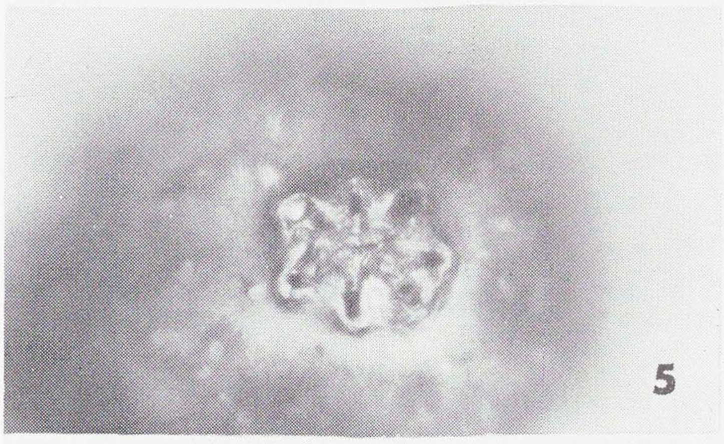
Figure	
1,2	Interior view of aperture showing tubules radiating downward below plane of paper; small dark spots are spine bases; glycerin forms dark ring around radiating tubules. 1, X 200; 2, X 420
3	Interior view of aperture; focus on interior rim of vestibule into which all tubules open interiorly; tubules "a" and "b" are shown in lower focus in figure 4. "v" = edge of vestibule (irregular ovate outline). X 860
4	Interior view of aperture; focus lower than in figure 3 (below rim of vestibule and closer to exterior surface below plane of paper; note narrowing of tubules "a" and "b" as they approach exterior surface. X 860
5-7	Exterior apertural view; note reversed position of tubules as indicated by "b" and "c"; tubule "c" shows normal configuration of external foramina; tip of tubule "b" is broken, resulting in enlarged exterior foramen; dark material in tubules is green food coloring. Note lobate outline of apertural mound in 5 and 6. 5, X 200; 6, X 420; 7, X 860
8	Detail of tubule "b" showing broken tip. X 860
9	Detail of tubule "c" showing normal tip. X 860

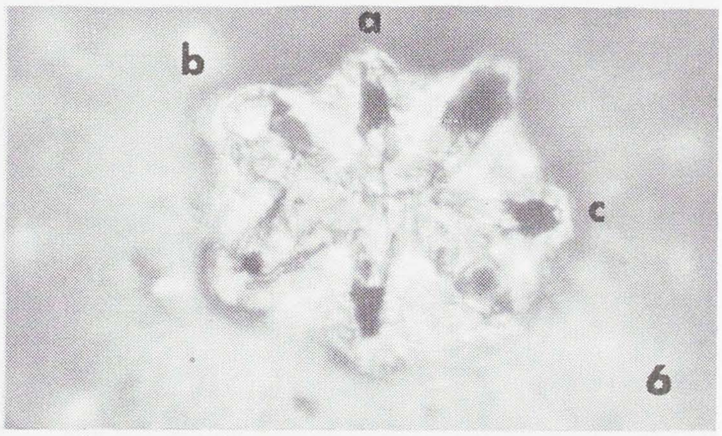


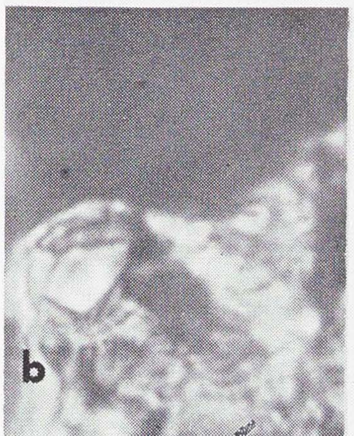












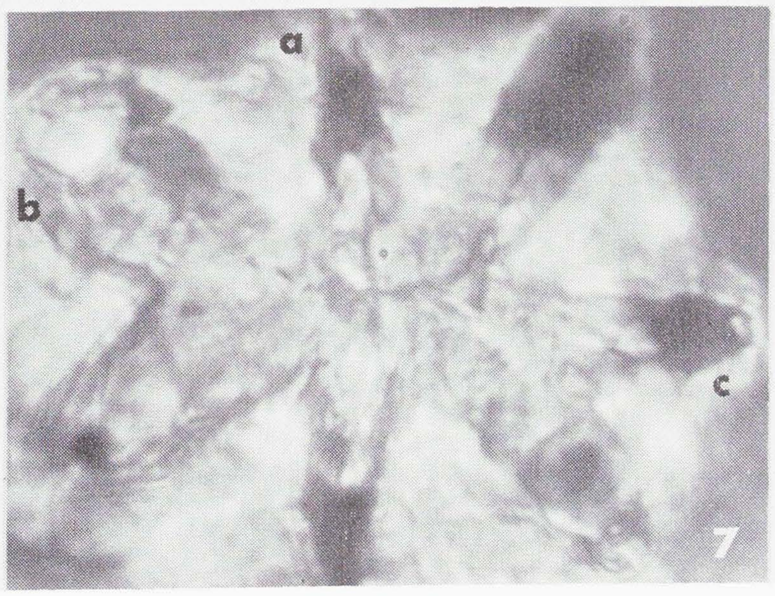


PLATE 6

rents in the inferred epifaunal environment. This would increase efficiency in active food gathering by enhancing their directed motion toward food particles. They may also augment passive food capture by serving as a framework for the outstretched network of pseudopodial strands.

Attached Condition

Arnold (1964) has described the retraction of pseudopodia of the foraminifer *Spiroloculina hyalina* in response to prolonged unfavorable conditions in its environment. Since this species adheres to to the substratum only by means of pseudopodia, the consequent loss of attachment or means of active locomotion leaves it at the mercy of external forces of displacement, even though it is able to remain practically dormant for long periods of time. Under similar circumstances, the permanent attachment of *Vasiglobulina alabamensis* would enable it to remain stationary even after withdrawing its pseudopodia, thus being protected from dislodgement until favorable conditions were restored. A similar advantage is gained by such attachment if pseudopodia are withdrawn after periods of feeding or during reproduction, as in *Allogromia laticollaris* (Arnold, 1953).

Time of Attachment

Vasiglobulina alabamensis attaches to the concave internal surface of mollusc fragments as well as to the convex outer surface. In specimens attached to the inner side, there is no mounding or irregular lamination of calcite to suggest interruption of normal nacre deposition by the mantle of the mollusc. Such interruption would be expected if attachment were accomplished while the mollusc lived (see Todd, 1965; Meglitsch, 1967). It is improbable that such a spinose form, which presumably would be highly irritating to its host, could survive within the shell of the living mollusc.

The time of attachment during the life cycle of the foraminifer can not be de-

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PLATE 7

Vasiglobulina alabamensis (Cushman and McGlamery) from the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi; all except figure 2 taken with transmitted light.

Figure

1 Interior apertural view showing asymmetry of tubular arrangement and large number of tubules; compare with specimen on plate 6; dark circles are air bubbles trapped in tubules (glycerin mount). X 420

2 Hypotype E, U.S.N.M. No. 687810. Lateral view showing apertural end of longitudinal axis tilted toward viewer (top of photograph); note symmetrical lobation of apertural mound. Reflected light. X 90

3 View identical to figure 2; transmitted light; exterior opening of one tubule is barely visible at "a." X 90

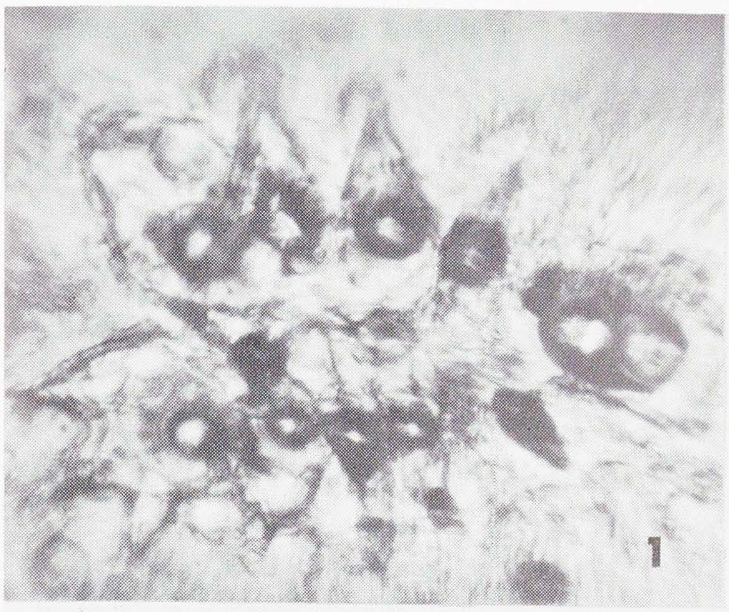
4,5 Lateral view of apertural mound; same specimen as figures 2,3; note conical elevations containing exterior foramina of tubules "a," "b," and "c"; note circularity of foramen "a." 4, X 420; 5, X 860

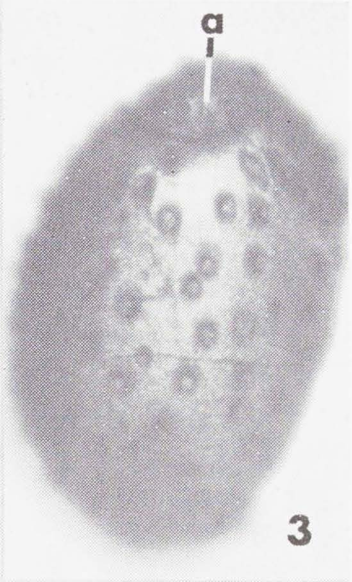
6 Longitudinal section through one side of apertural mound; section does not contain plane of the long axis, therefore, tubules appear as five circular openings in slightly oblique transverse section. X 100

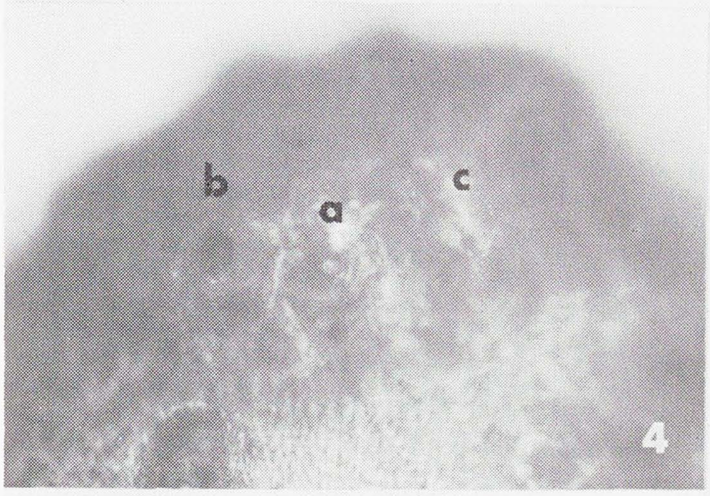
7 Longitudinal section as above; apertural mound; plane polarized light; note spine projecting from apertural mound; pore structure along interior surface of apertural mound is due to thickness of section, which preserves a portion of the curved wall of final chamber; three openings are filled with green food coloring. X 430

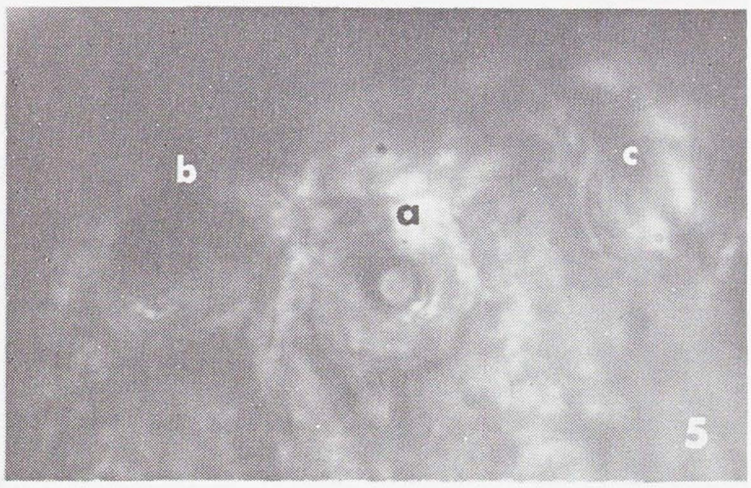
8 Longitudinal section as in figure 7; crossed nicols; one arm of black cross extinction figure seen on either side of apertural mound. X 430

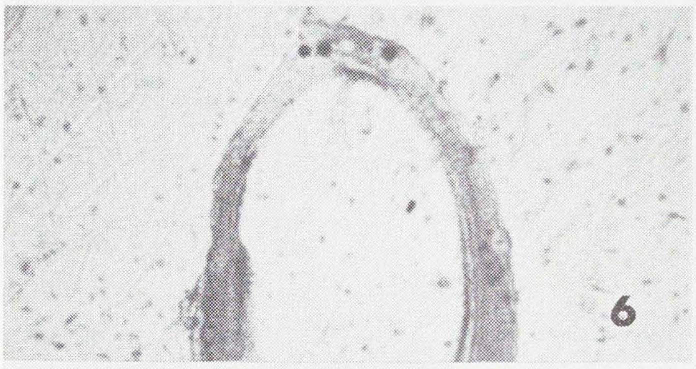
9 Longitudinal section of apertural mound; enlargement of figure 7. X 645

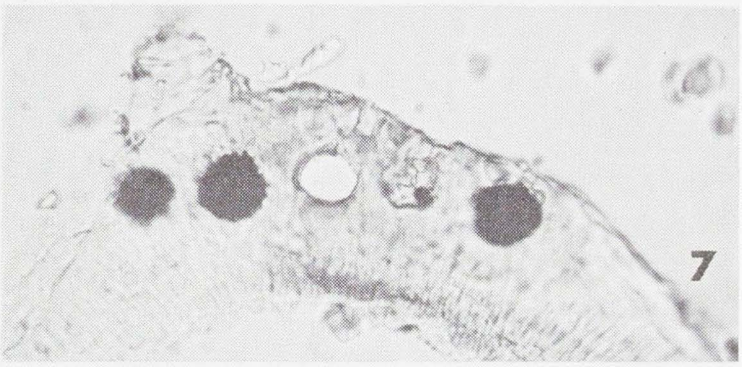












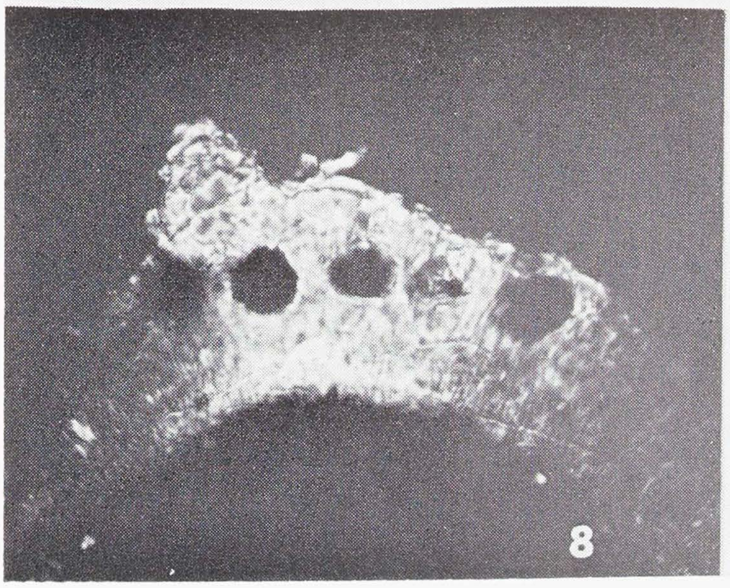


PLATE 7

termined from present data. No juveniles were observed either attached or bearing hourglass-shaped spines. The penetration of the juvenile layers of the test by some spines (pl. 5, figs. 5-7) indicates that *Vasiglobulina alabamensis* became spinose early in ontogeny, but this does not necessarily imply early attachment.

Dissolution of Exotic Calcite

It is conceivable that *Vasiglobulina alabamensis* may use the ability to dissolve exotic calcite for purposes other than attachment. Such a capacity would permit it to prey upon other small organisms that possess calcareous hard parts, such as foraminifers and ostracodes.

VII. PALEOECOLOGICAL IMPLICATIONS

Vasiglobulina alabamensis attached itself to molluscan fragments for anchorage in a shallow, moderate energy marine environment. Poag (1966) has suggested that Paynes Hammock beds in which this species was recorded were deposited in water depths of 40-120 feet, with bottom salinity of 34-36.5‰, and bottom temperature of 20-27° C. The Chickasawhay foraminiferal fauna is similar to the Paynes Hammock, requiring similar paleoecological conditions. The association of *Vasiglobulina alabamensis* with such attached forms or *Cibicides lobatulus, Webbinella fimbriata, Cycloloculina miocenica,* and *Planorbulinella larvata* (Poag, 1966) implies water turbulence. Attachment by dissolution of molluscan calcite would limit the selectivity of substrata for the species if attachment were obligatory to survival, as it could become viable only in the presence of sufficient molluscan fragments.

VIII. PSEUDOPODIAL FUNCTIONS

The pseudopodia of foraminifera are elongate, granuloreticulose extensions of protoplasm which perform with marvelous versatility a wide array of functions as vividly described by many authors, including Lister (1903), Heron-Allen (1915), Cushman (1920), Myers (1943), Jepps (1956), Nyholm (1961), Arnold (1964), Hedley (1964), Loeblich and Tappan (1964), Boltovskoy (1965), and Angell (1967). The most frequently cited pseudopodial functions are those concerned with the capture, ingestion, and digestion of food, the con-

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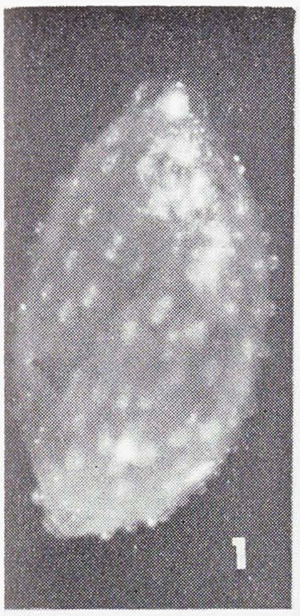
PLATE 8

Vasiglobulina alabamensis (Cushman and McGlamery); all specimens from the same sample of the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi. Note morphological variation, especially in prominence of apertural mound; size and shape of test; length, diameter, density, and location of spines. Apertures are toward top of page; all X 90.

Figure
1 Hypotype F, U.S.N.M. No. 687811; 4 chambers; note neck-like extension of apertural mound.
2 Hypotype G, U.S.N.M. No. 687812; 4 chambers; note alignment of spines and their large diameter compared to figure 4.
3 Hypotype H, U.S.N.M. No. 687813; 4 chambers.
4 Hypotype I, U.S.N.M. No. 687814; 4 chambers; note symmetrical pyriform shape and small diameter of spines.
5 Hypotype J, U.S.N.M. No. 687815; 4 chambers; note acuminate initial end and broadly rounded apertural end; spines are widely scattered.
6 Hypotype K, U.S.N.M. No. 687816; 5 chambers; note thick patches of spines; aperture is nearly flush with surface of test.
7 Hypotype L, U.S.N.M. No. 687817; 5 chambers; note bilateral symmetry.
8 Hypotype M, U.S.N.M. No. 687818; 5 chambers; note widely scattered spines.
9 Hypotype N, U.S.N.M. No. 687819; 4 chambers.
10 Hypotype O, U.S.N.M. No. 687820; 4 chambers; note symmetrical pyriform shape.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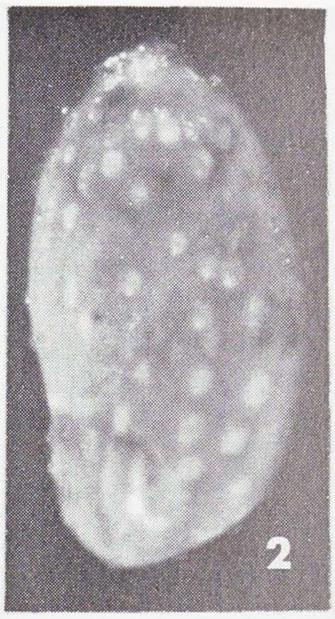
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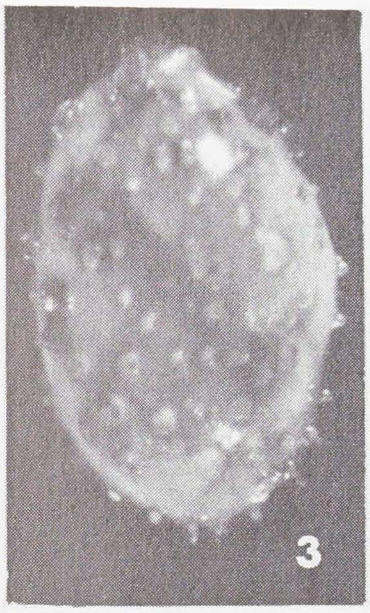
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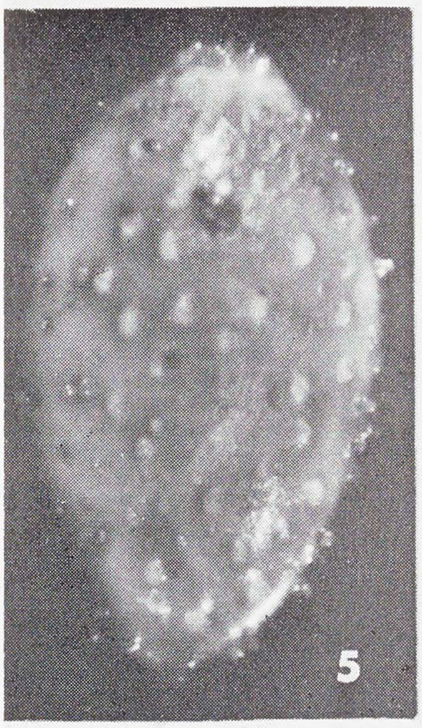
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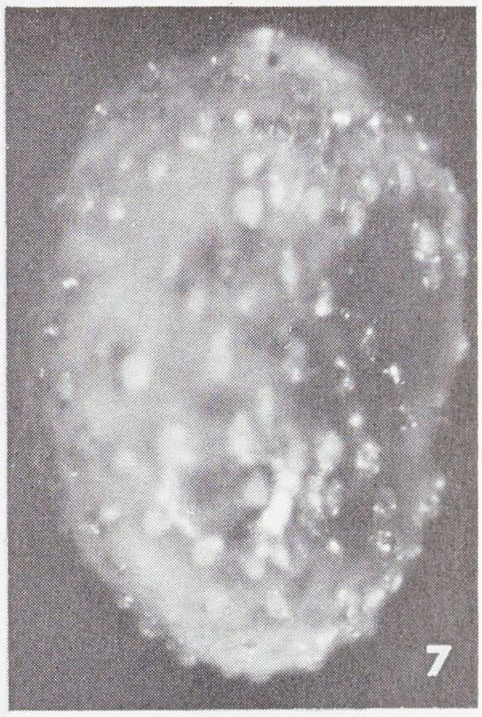
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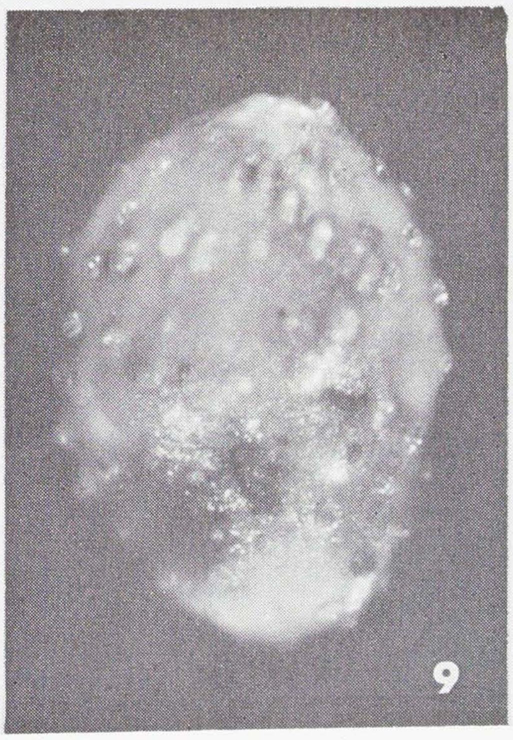
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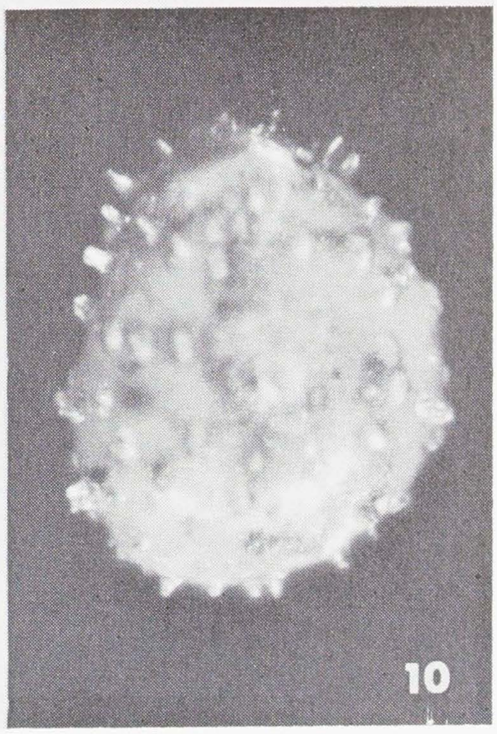
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PLATE 8

struction of organic and inorganic layers of the test wall, the formation of protective cysts during chamber addition and reproduction, locomotion, and the temporary or semipermanent attachment to the substratum.

In most forms, pseudopodia extend from the primary aperture in a spreading reticulose mesh of slender tendrils. A thin layer of cytoplasm may also extend over the exterior of the test. In highly spinose planktonic forms, the pseudopodia extend along and between the radiating spines, the protoplasmic granules apparently streaming up and down the spine surfaces.

Temporary attachment by pseudopodia in benthonic species is generally accomplished by spreading the myriad extensions into the soft substratum. It may be achieved by relatively rigid pseudopodia, allowing erect posture of the test, as in *Hippocrepina*, or by more fragile pseudopodia which extend horizontally outward from the test, as in *Phainogullmia* (Nyholm, 1957).

Based on its peculiar mode of attachment, the writer infers that the pseudopodia of *Vasiglobulina alabamensis* enveloped the spines as in some planktonic species. In order to attach, they created narrow cavities in the molluscan fragments by dissolving the molluscan conchiolin and calcite. The latter phenomenon has been previously described only in *Rosalina carnivora* (Todd, 1965). It is logical to assume that this dissolved calcite was then redeposited as penetrating foraminiferal spines, to provide the most efficacious attachment known in the Foraminiferida. *Vasiglobulina alabamensis*

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PLATE 9

Vasiglobulina alabamensis (Cushman and McGlamery); apertural ends are at top of page.

Figure

1 Hypotype P, U.S.N.M. No. 687821; from the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi; 4 chambers. Note widely spaced spines and broadly rounded base which bulges outward at lower right. X 90

2 Hypotype Q, U.S.N.M. No. 687822; from the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi; 4 chambers. Note longitudinal lineation of spines and broad flattened base which bulges outward at lower right; final intercameral suture extends almost to base of test. X 90

3 Hypotype R, U.S.N.M. No. 687823; from the Mint Spring Marl Member of the Marianna Limestone at its type locality near Vicksburg, Mississippi; 4 chambers. Note symmetrical pyriform outline and even distribution of spines. X 90

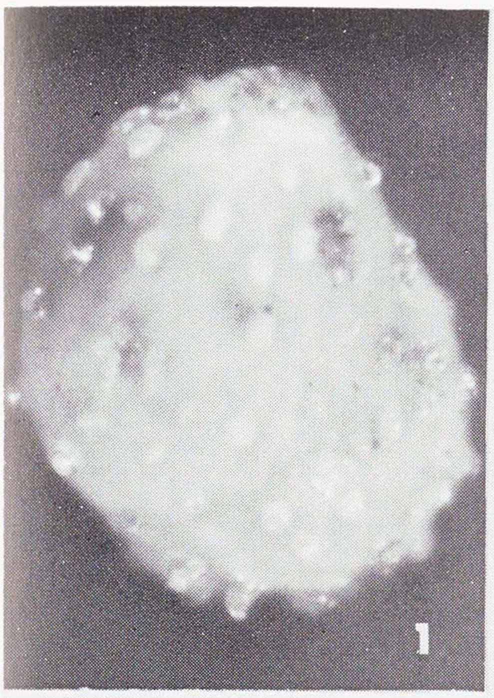
4 Hypotype S, U.S.N.M. No. 687824; attached specimen from the Red Bluff Clay at Hiwannee, Mississippi; Note angle of attachment relative to long axis of test. X 90

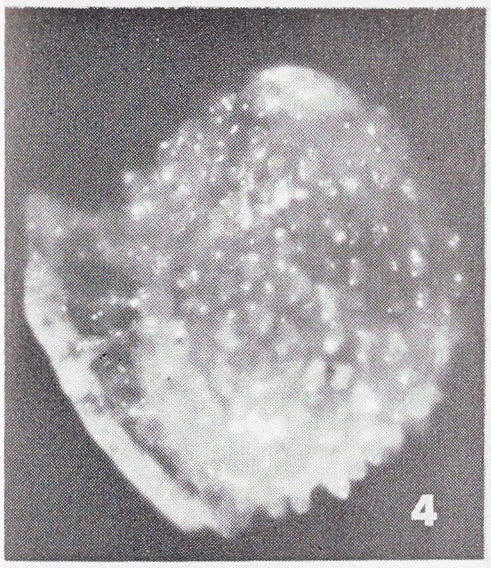
5 Hypotype T, U.S.N.M. No. 687825; from the Paynes Hammock Formation on the Chickasawhay River, near Waynesboro, Mississippi; number of chambers not discernible. Note thick clusters of spines, especially around apertural mound, and large size of test; both ends of test are acuminate. X 52.5

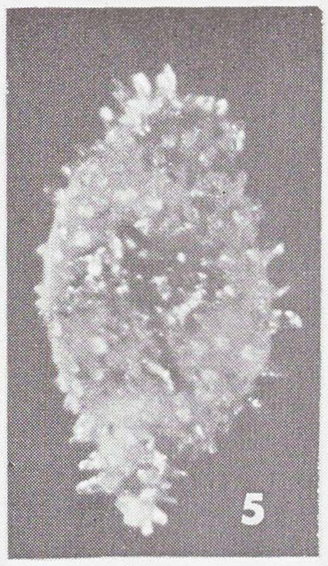
6 Stereopair of portion of specimen from the Red Bluff Clay at Hiwannee, Mississippi. Spines fuse into amorphous mass; one flares into a hollow, horn shaped structure. X 180

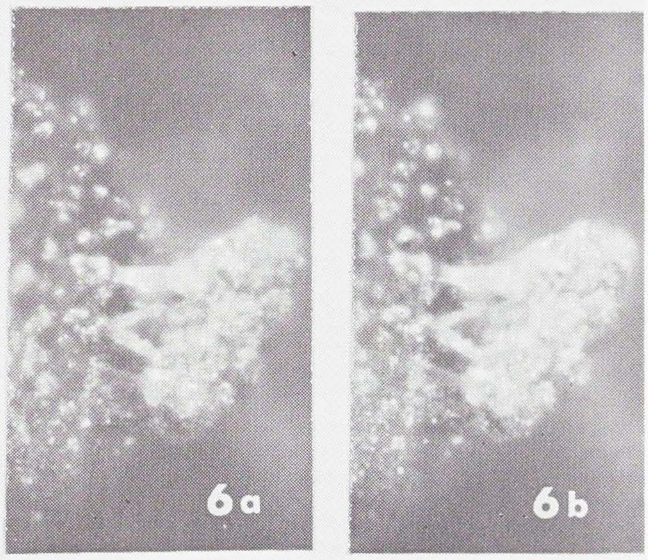
7 Apertural mound of entire specimen from the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi; lateral view. Note outline of radiating hollow tubules ("t") within mound; focus below surface of mound; transmitted light, glycerin mount. X 430

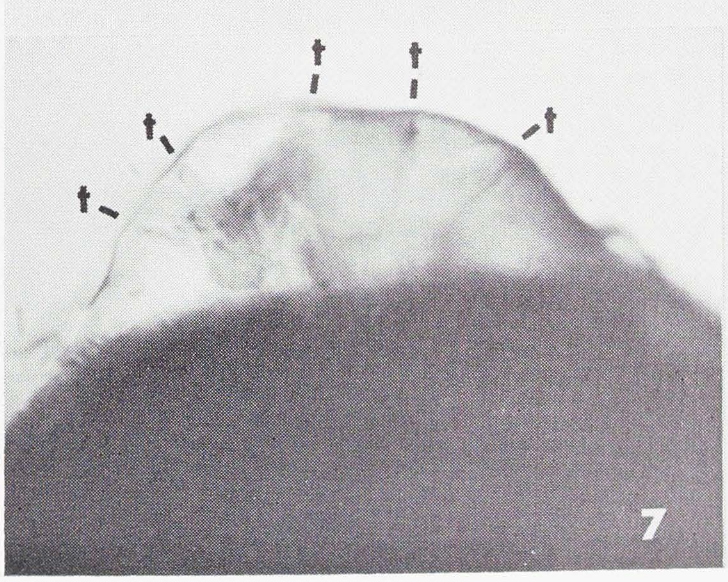
8 Exterior apertural view of specimen from the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi. Note large number (19) of asymmetrically arranged tubules; focus near exterior surface; reflected light. X 200











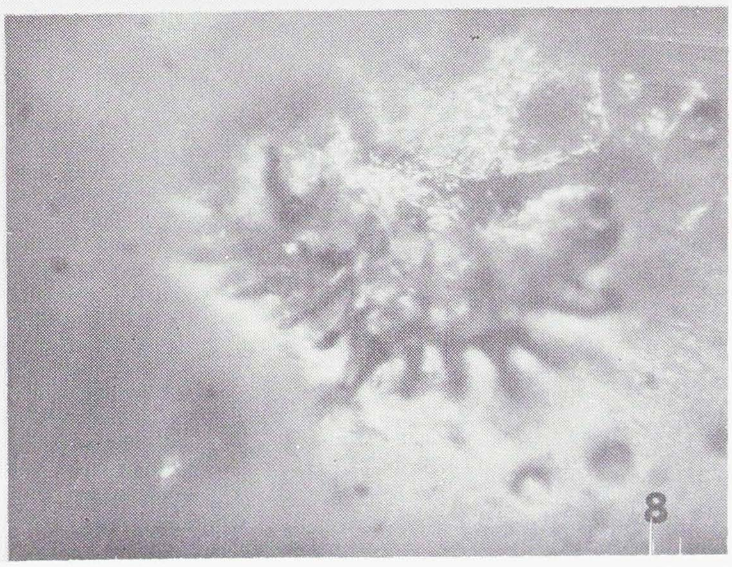


PLATE 9

provides new insight into some little known functions of foraminiferal pseudopodia.

IX. GEOLOGIC AND GEOGRAPHIC DISTRIBUTION

Gulf Coast

Vasiglobulina alabamensis was first reported in the Gulf Coast (as *Polymorphina spinosa* d'Orbigny) from the Mint Spring Marl Member of the Marianna Limestone at Mint Spring Bayou, near Vicksburg, Mississippi, and from the Glendon Limestone and calcareous marl members of the Byram Formation from various Mississippi and Alabama localities (Cushman, 1922b). Cushman referred to " . . . numerous short, projecting spines which seem to be hollow where broken." Howe (1934) reported what is apparently the same species as *Globulina spinosa* from the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi. In 1938, Cushman and McGlamery recorded a specimen provisionally as *Globulina inaequalis* Reuss var. *caribaea* d'Orbigny from the Chickasawhay Formation at Choctaw Bluff, Alabama. They noted " . . . an irregularly spinose specimen . . . whose spinose projections are very irregularly scattered, much more so than in Recent forms of the species." From these remarks and their illustrations, the writer infers that this is *Vasiglobulina alabamensis*. The taxon *Globulina alabamensis* was erected the following year (Cushman and McGlamery, 1939) based on a holotype and three paratypes from the Chickasawhay Formation near Millry, Alabama (see pl. 1, figs. 1-9). It was originally described as follows:

> "Test slightly longer than broad, both ends broadly rounded, periphery broadly rounded, thickness slightly less than the breadth; chambers few, only slightly inflated, increasing rapidly in size as added, last-formed chamber making up at least half the surface in the adult; sutures distinct, sigmoid in the adult, little if at all depressed, very slightly limbate; wall ornamented with numerous short spines, rather evenly scattered over the whole surface; aperture terminal, radiate."

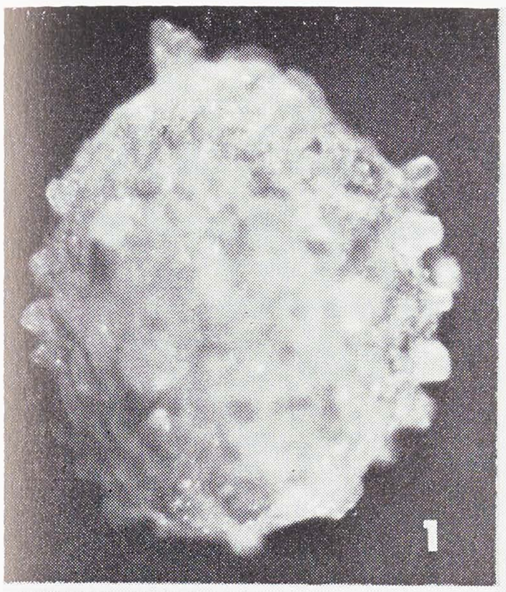
It has subsequently been recorded (Cushman and McGlamery, 1942) from the Chickasawhay Formation near Millry, Alabama, and apparently assigned to two different species (*Globulina alabamensis,* pl. 5, figs. 1-4; and *Globulina inaequalis cari-*

→

PLATE 10

Figure

1 *Vasiglobulina tuberculata* (d'Orbigny); topotype from the *Amphistegina* Marl near Vienna, Austria. Note thick bluntly broken spines; a large one extends from the apertural mound. X 52.5
2 *Vasiglobulina punctata* (d'Orbigny); specimen from the Coralline Crag of Suffolk, England; note finely hispid exterior surface. X 90
3 *Vasiglobulina striata* (Egger); topotype from the Miocene near Ortenburg, L. Bavaria. Note weakly spinose costae. X 90
4 *Vasiglobulina tuberculata* (d'Orbigny); apertural view of figure 1. X 100
5 *Vasiglobulina punctata* (d'Orbigny); apertural view of figure 2. X 210
6 *Vasiglobulina striata* (Egger); apertural view of figure 3. X 210
7 "*Globulina*" sp.; smooth specimen from Piacenza, Italy. X 52.5
8 *Vasiglobulina* sp.; finely hispid specimen from Piacenza, Italy. X 52.5
9 "*Globulina*" sp.; smooth specimen from the Chickasawhay Formation near Millry, Alabama. X 52.5
10 "*Globulina*" sp.; apertural view of figure 7. X 210
11 *Vasiglobulina* sp.; apertural view of figure 8. X 210
12 "*Globulina*" sp.; apertural view of figure 9. X 210
13 *Vasiglobulina variata* (Jones, Parker, and Brady); topotype from the Coralline Crag of Suffolk, England; note sparse thick short spines. X 90
14 *Vasiglobulina tuberculata?* (d'Orbigny); specimen from the Pliocene near Piacenza, Italy; note thick rounded spine bases on exterior surface. X 90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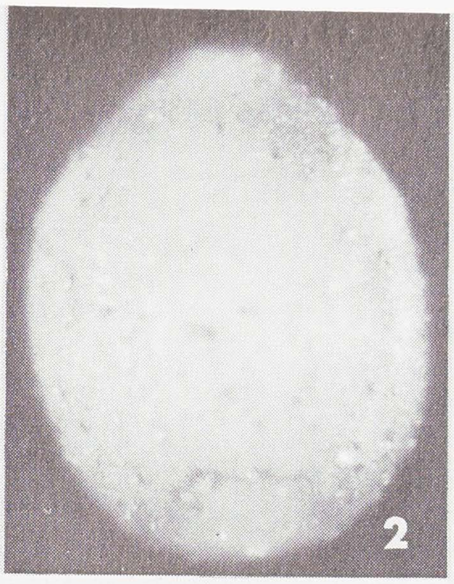
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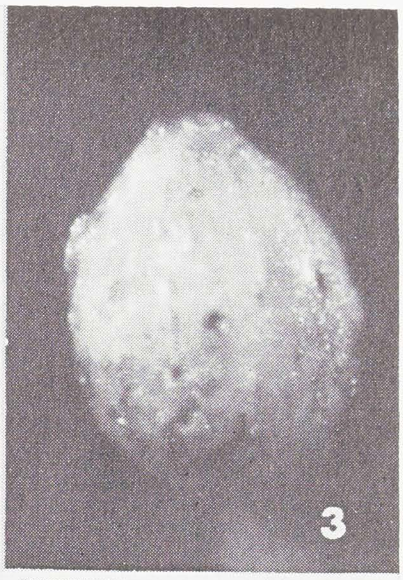
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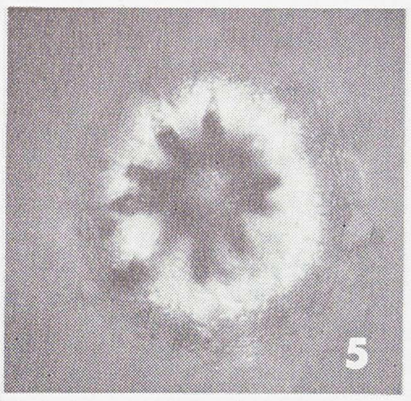
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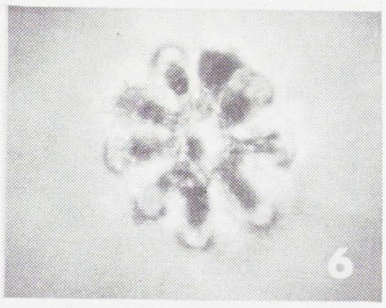
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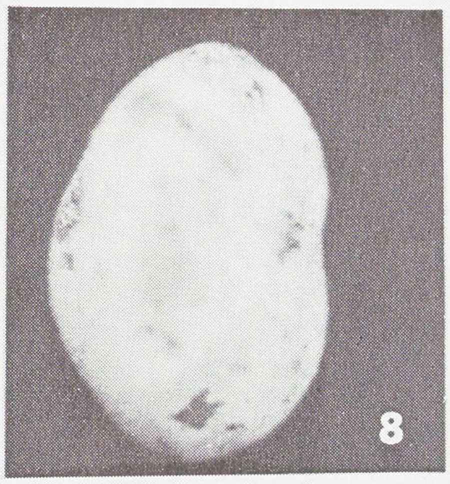
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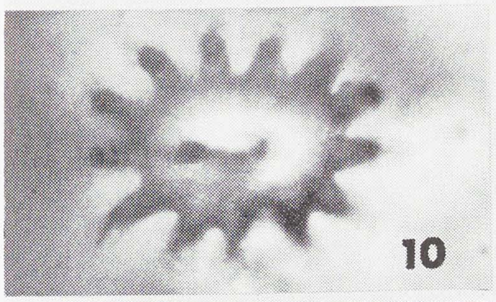
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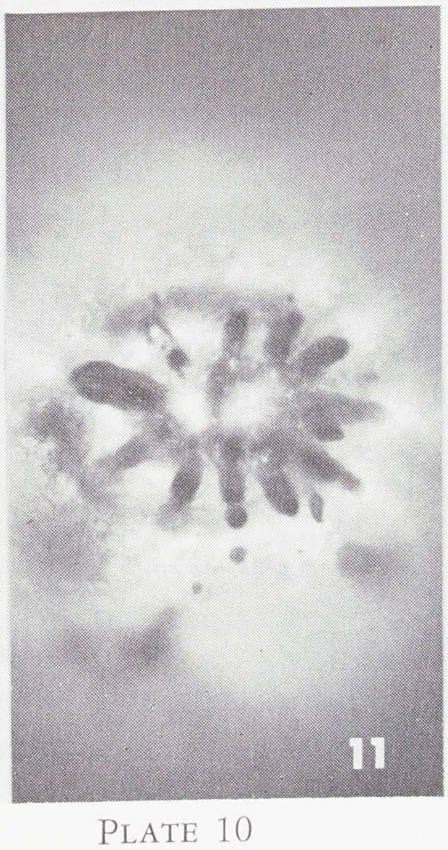
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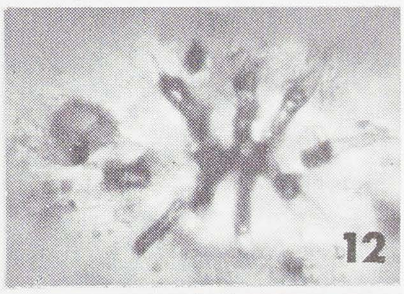
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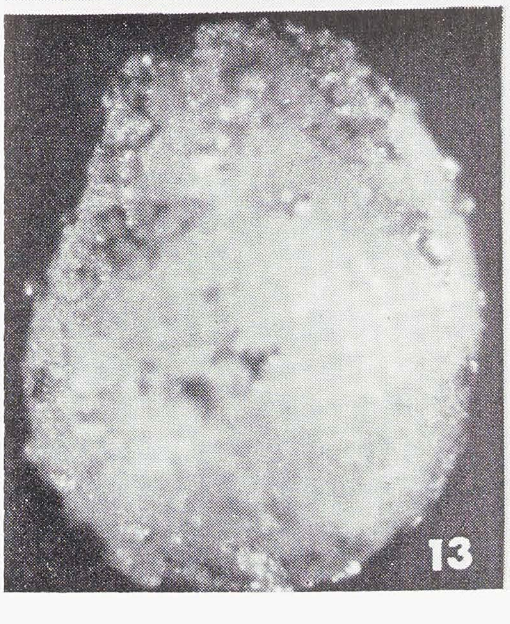
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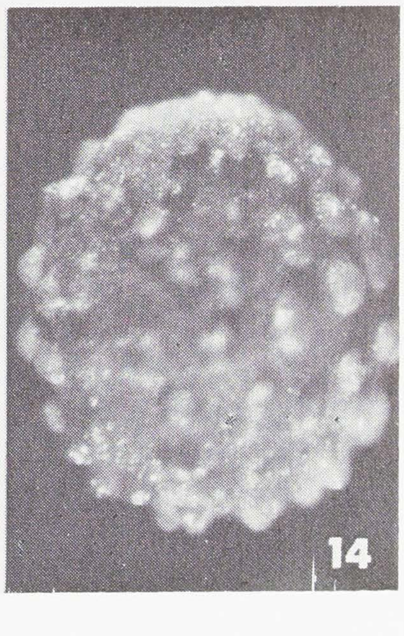
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Plate 10

Most spines taper as they elongate (pl. 4, figs. 2,3,4,8), but some have an hourglass shape that results from distal thickening within the mollusc shell (text fig. 3; pl. 1, figs. 6,9; pl. 2, fig. 2; pl. 4, figs. 5,6,11,12; pl. 5, fig. 1). All spines examined appear to be non-perforate calcite (pl. 4, figs. 2-14; pl. 5, fig. 7).

Under crossed nicols, the spines do not extinguish in transverse section (pl. 3, fig. 4; pl. 4, figs. 13,14). In longitudinal section, however, they extinguish almost completely or produce broad transverse bands of color (pl. 4, fig. 7). They are, therefore, in optical continuity, and may be single crystals or groups of similarly oriented crystals in which the C-axes are perpendicular to the long axis of the spine and to the C-axes of the crystals in the test wall proper. Wood (1949) and Lipps (1966) have described the spines of certain planktonic species as single crystals of calcite, but Towe and Cifelli (1967) have discussed the ambiguities involved in the concept of single crystals and have cautioned against the uncritical use of wall structural terms based on optical observations.

Some spines extend through all the calcite lamellae of the test wall, in the juvenile as well as adult portions of the test (pl. 5, figs. 5-7); others are formed from only the final lamella. Although layering is apparently lacking in the spines, the general configuration in longitudinal section (pl. 5, fig. 7) is similar to that of inflational pillars ascribed to the Rotaliidae by Smout (1954; *cf.* pl. 19, figs. 11,12).

A broken hourglass-shaped spine on unattached specimens indicates a point of previous attachment (pl. 4, figs. 1,5,6,11; pl. 9, fig. 6). Although the site of attachment may vary, it is most commonly along the flattened side of the test, subparallel to the axis of coiling (pl. 2, figs. 1,4,7; pl. 9, fig. 4).

Chamber Arrangement

The test generally comprises 4 to 5 visible chambers, which increase rapidly in size as added (pl. 8, figs. 1-10). The coiling pattern is spiral, with chambers added at intervals of approximately 144°. Each succeeding chamber extensively embraces one or more of those preceding it. The initial chamber is often difficult to observe because it is enveloped almost completely by the succeeding chambers. A reduced final chamber may be present (pl. 1, fig. 5), a variation apparently characteristic of many foraminiferal species. Intercameral sutures are narrow; those separating the first three or four chambers are flush with the surface or slightly depressed (pl. 8, fig. 4). The final intercameral suture, however, may be

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PLATE 2

Figures

Vasiglobulina alabamensis (Cushman and McGlamery). Attached specimens from the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi.

1 Stereopair of hypotype A, U.S.N.M. No. 687806. Note close attachment to interior surface of mollusc, and thickening of spine "c" after entering fragment; 4 chambers. X 90

2 Hourglass-shaped spine "f" of holotype C. X 180

3 Stereopair of hypotype B, U.S.N.M. No. 687807. Note length of slender attaching spines; note spine tips at "d" and "e" entering edge of mollusc. X 90

4 Hypotype B showing attachment to concave inner surface of mollusc fragment; 4 chambers; apertural end at bottom. X 52.5

5 Stereopair of basal view of hypotype B showing spines penetrating edge of mollusc fragment. X 90

6 Hypotype C, U.S.N.M. No. 687808. Note attachment to outer ornamented surface of *Pecten* fragment; 4 chambers; aperture at top. X 35

7 Stereopair of hypotype C showing hourglass-shaped spine at "f"; apertural end at bottom. X 52.5

8 Stereopair of hypotype C. Note hourglass-shaped spine "f." X 90

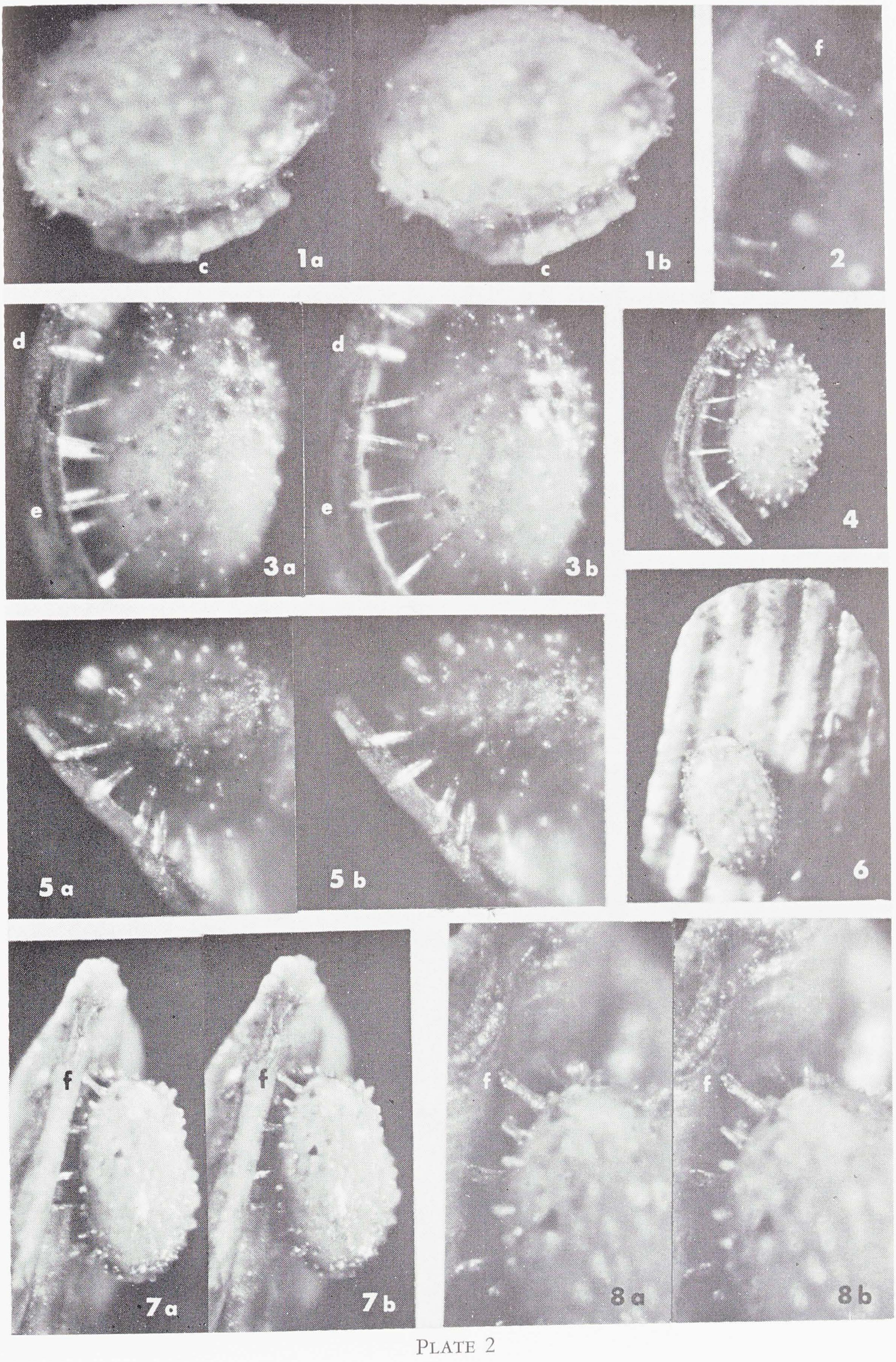

PLATE 2

markedly depressed (pl. 8, fig. 6). In most specimens the final intercameral suture is well above the base of the test (pl. 8, figs. 2,6), but in some 4-chambered forms it approaches the base more closely (pl. 9, figs. 1,2). The intercameral septa are rarely preserved in either juvenile or mature specimens, a phenomenon also observed in several fossil species of "*Globulina*" (Le Calvez, 1950). They apparently have been resorbed during growth creating a monothalamous condition (pl. 5, fig. 2). Varying degrees of resorption have been recorded in living genera, including *Elphidium* (Jepps, 1956), *Patellina, Discorbis,* and *Cymbalopora* (Myers, 1943), and *Cibicides* (Nyholm, 1961).

Aperture

The aperture is situated at the distal end of the final chamber, which is generally less spinose than the rest of the test surface (pl. 2, fig. 6). It consists of a system of hollow cylindrical tubules that radiate outward from a common vestibule at the distal end of the final chamber lumen (pl. 5; figs. 3,4; pl. 6, figs. 1-9; pl. 7, figs. 6-9; pl. 9, fig. 7). These tubules are widest at the inner ends, narrowing as they extend outward and upward toward the surface (pl. 5, figs. 3,4; pl. 9, fig. 7). On the outer test surface they open as small circular foramina, often in the center of low conical elevations (pl. 7, figs. 2-5). These elevations are part of a protruding cylindrical neck or low hummocky mass of thick, non-perforate calcite (pl. 2, fig. 1; pl. 5, fig. 3; pl. 7, figs. 2,4; pl. 8, figs. 1-10). The basic pattern is a symmetrical radiation of tubules (pl. 6, figs. 1-9), but they may be irregularly placed (pl. 7, fig. 1; pl. 9, fig. 8), and some may extend subparallel to the long axis of the test.

The radiate tubular apertural system of *Vasiglobulina* appears to have developed in the Late Cretaceous or early Paleogene Period from the polymorphinid system of radiating slits, which arose in the Triassic Period (Loeblich and Tappan, 1964). The oldest specimen of *Vasiglobulina* examined by the writer is of upper Eocene age. Some species probably referable to the genus have been reported from Eocene rocks by Cushman and Ozawa (1930; *V. verrucosa*), Bandy (1949; *V. alabamensis* ?), and Deboo (1965; *V. alabamensis* ?). *Globulina lacrima ericia* of Cushman and Ozawa (1930) may be a Cretaceous representative.

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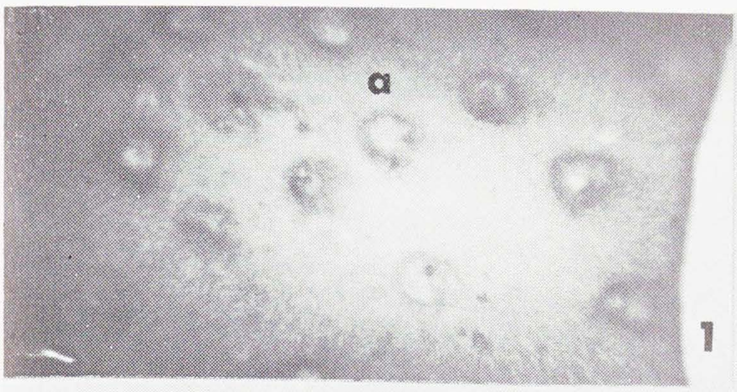
PLATE 3

Vasiglobulina alabamensis (Cushman and McGlamery). All specimens from the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi. Figures 1-5 all same specimen.

Figures
1 Interior surface of test wall; focus on surface. Note absence of structure in spines; glycerine mount, transmitted light. X 200
2 Interior surface of test wall; focus below surface. Note absence of structure in spines. X 200
3 Interior surface of test wall; focus on surface. Note continuity of pore pattern across spine base "a." X 860
4 Interior surface of test wall under crossed nicols. Note spines do not extinguish with the rest of test wall. X 860
5 Interior wall of test fragment under crossed nicols. Note dark extinction figure produced by radially arranged calcite crystals; bright spots are spine bases. X 100
6 Mollusc fragment. Dark angular spots are spine stubs of *Vasiglobulina alabamensis.* X 180
7 Hypotype B viewed from underside of mollusc fragment, showing spines (dark angular spots) completely penetrating the mollusc shell. X 90
8 Enlargement of figure 7. Note angularity of spines in transverse section. X 180



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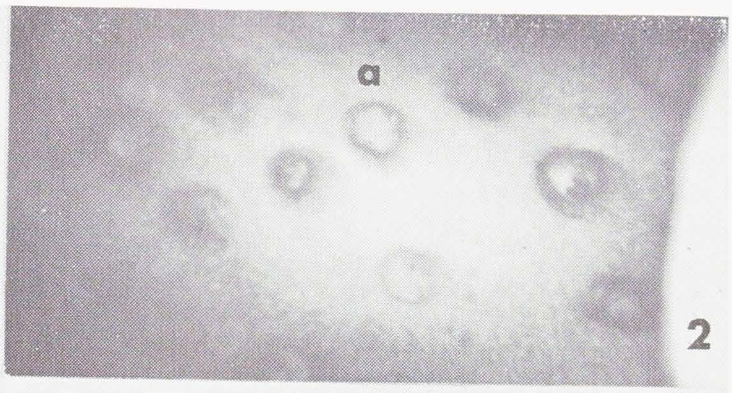

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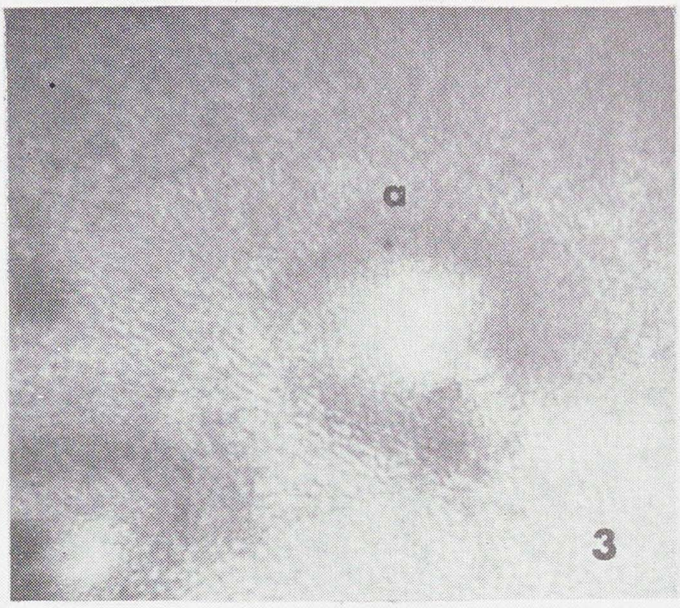

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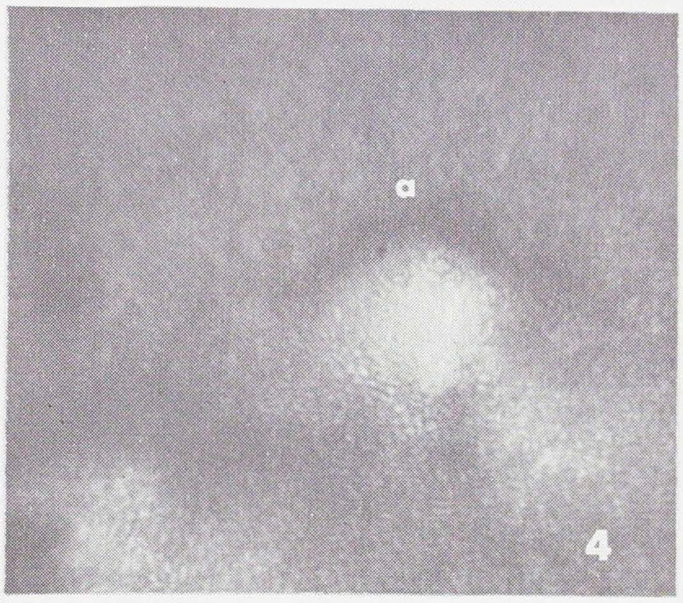

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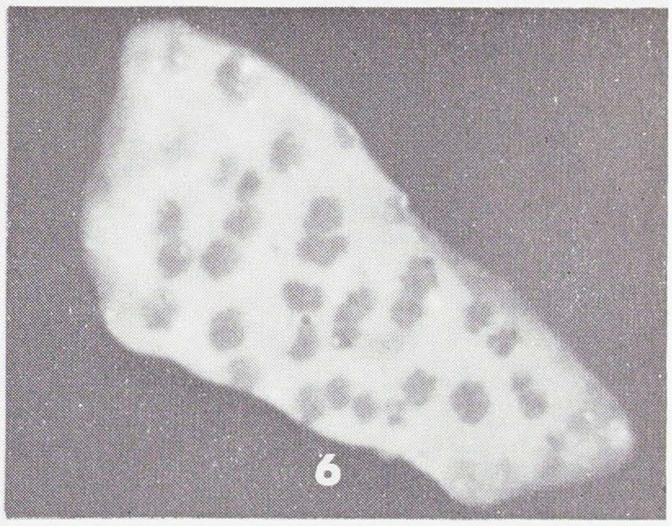

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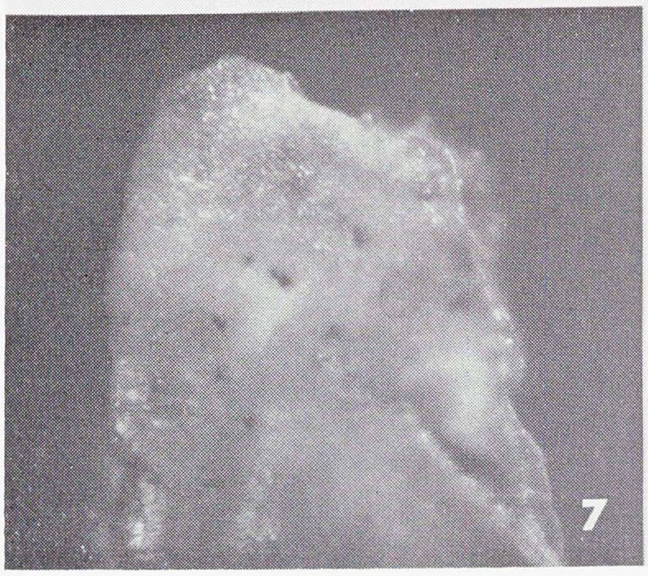

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PLATE 3

provides new insight into some little known functions of foraminiferal pseudopodia.

IX. GEOLOGIC AND GEOGRAPHIC DISTRIBUTION

Gulf Coast

Vasiglobulina alabamensis was first reported in the Gulf Coast (as *Polymorphina spinosa* d'Orbigny) from the Mint Spring Marl Member of the Marianna Limestone at Mint Spring Bayou, near Vicksburg, Mississippi, and from the Glendon Limestone and calcareous marl members of the Byram Formation from various Mississippi and Alabama localities (Cushman, 1922b). Cushman referred to " . . . numerous short, projecting spines which seem to be hollow where broken." Howe (1934) reported what is apparently the same species as *Globulina spinosa* from the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi. In 1938, Cushman and McGlamery recorded a specimen provisionally as *Globulina inaequalis* Reuss var. *caribaea* d'Orbigny from the Chickasawhay Formation at Choctaw Bluff, Alabama. They noted " . . . an irregularly spinose specimen . . . whose spinose projections are very irregularly scattered, much more so than in Recent forms of the species." From these remarks and their illustrations, the writer infers that this is *Vasiglobulina alabamensis*. The taxon *Globulina alabamensis* was erected the following year (Cushman and McGlamery, 1939) based on a holotype and three paratypes from the Chickasawhay Formation near Millry, Alabama (see pl. 1, figs. 1-9). It was originally described as follows:

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PLATE 10

Figure

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2 *Vasiglobulina punctata* (d'Orbigny); specimen from the Coralline Crag of Suffolk, England; note finely hispid exterior surface. X 90

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4 *Vasiglobulina tuberculata* (d'Orbigny); apertural view of figure 1. X 100

5 *Vasiglobulina punctata* (d'Orbigny); apertural view of figure 2. X 210

6 *Vasiglobulina striata* (Egger); apertural view of figure 3. X 210

7 "*Globulina*" sp.; smooth specimen from Piacenza, Italy. X 52.5

8 *Vasiglobulina* sp.; finely hispid specimen from Piacenza, Italy. X 52.5

9 "*Globulina*" sp.; smooth specimen from the Chickasawhay Formation near Millry, Alabama. X 52.5

10 "*Globulina*" sp.; apertural view of figure 7. X 210

11 *Vasiglobulina* sp.; apertural view of figure 8. X 210

12 "*Globulina*" sp.; apertural view of figure 9. X 210

13 *Vasiglobulina variata* (Jones, Parker, and Brady); topotype from the Coralline Crag of Suffolk, England; note sparse thick short spines. X 90

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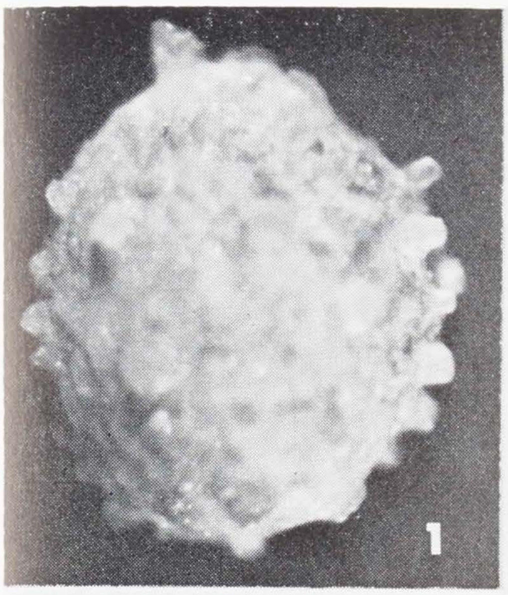
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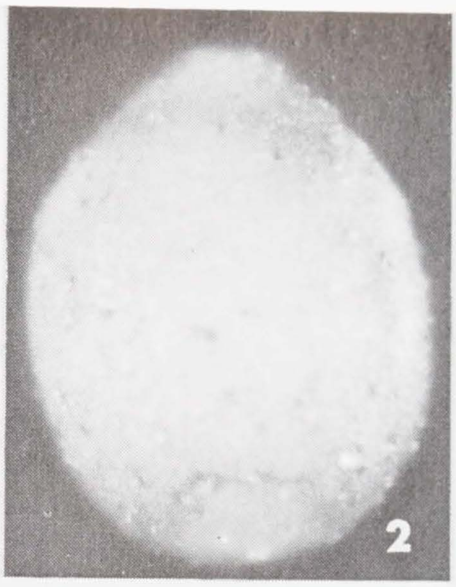
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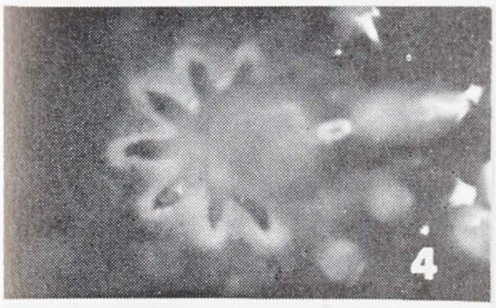
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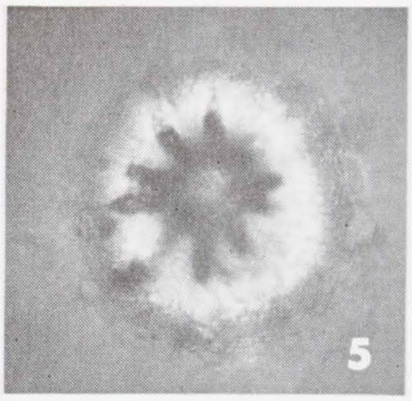
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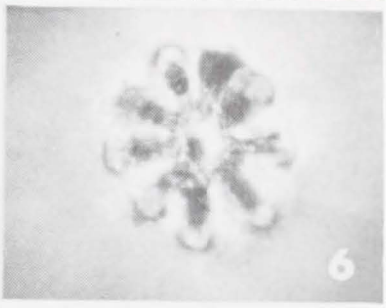
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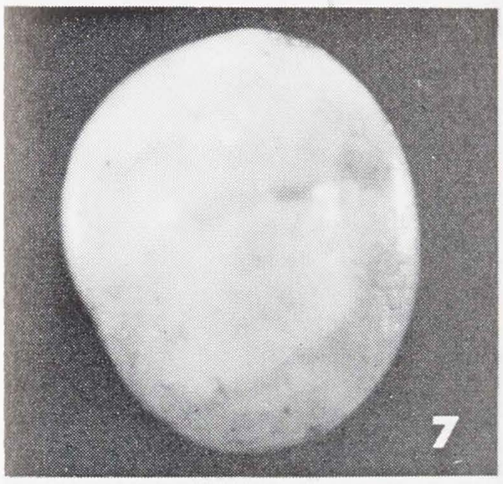
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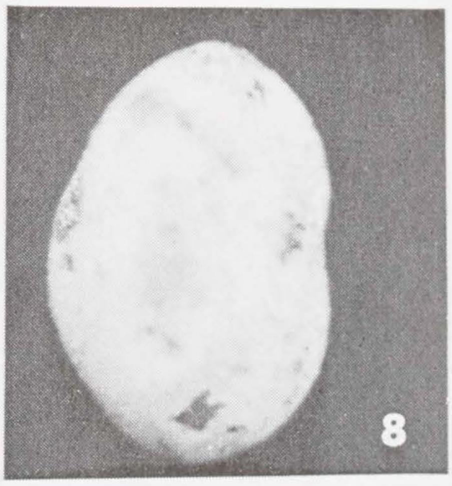
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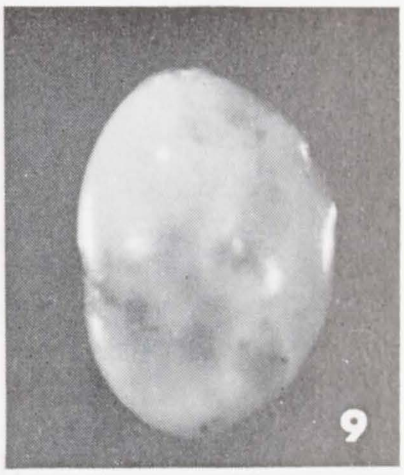
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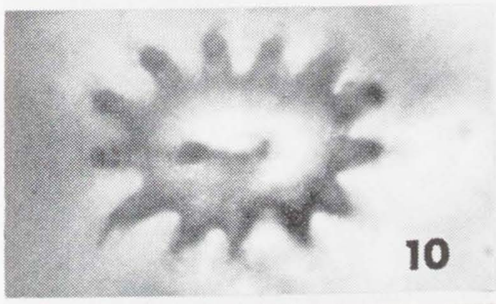
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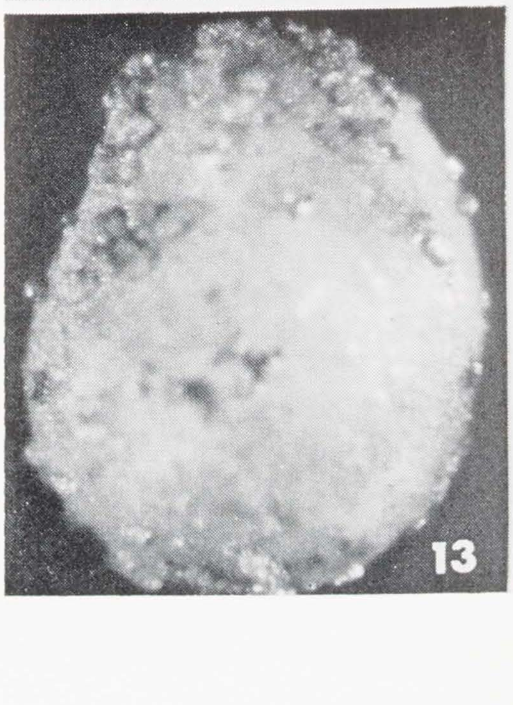
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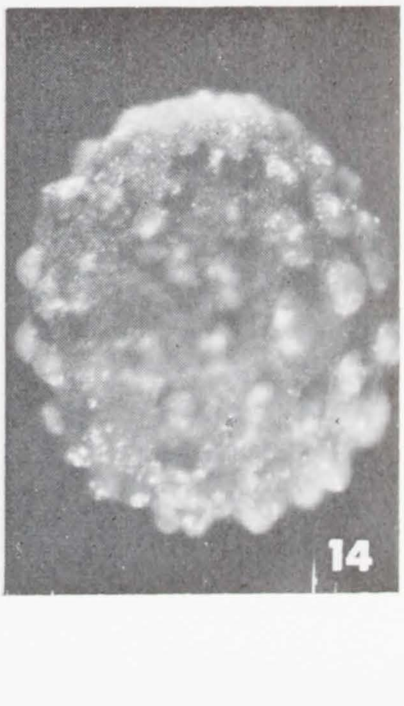
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PLATE 10

baea, pl. 4, fig. 36; not figs. 34,35). One specimen of the latter was reported attached to a mollusc fragment. It has been reported from the Byram Marl at Byram, Mississippi (Cushman and Todd, 1946); the Red Bluff Clay at Red Bluff, Mississippi (Cushman and Todd, 1948); the Red Bluff Clay at Little Stave Creek, Alabama (recorded as *Raphanulina tuberculata* by Bandy, 1949); the Mint Spring Marl Member of the Marianna Limestone at its type locality near Vicksburg, Mississippi (Todd, 1952); the Glendon Limestone Member and the typical marl member of the Byram Formation at various Mississippi localities, where its " . . . rather widely spaced, blunt, stalk-like projections rather than true spines . . . " were noted (Todd, 1952); the Red Bluff Clay at Hiwannee, Mississippi (Deboo, 1965); and, from the Paynes Hammock Formation on the Chickasawhay River, near Waynesboro, Mississippi (Poag, 1966).

The latter author assumed that the thick apertural mound illustrated on plate 2, figures 35 and 36 (Poag, 1966), was merely an anomalous, secondarily deposited calcite mass which obscured the radiate globuline aperture.

In addition to these reported occurrences, the writer has examined excellent specimens from the Red Bluff Clay at Hiwannee, Mississippi (pl. 9, fig. 4), and at Little Stave Creek, Alabama (locality 63 of Bandy, 1949); the Mint Spring Marl Member of the Marianna Limestone at its type locality near Vicksburg, Mississippi (pl. 9, fig. 3); the Byram Formation at its type locality, Byram, Mississippi; the Chickasawhay Formation at Taylor Mill Creek, near Waynesboro, Mississippi (pl. 8, figs. 1-10); and, from the the Chickasawhay Formation near Millry, Alabama (pl. 1, figs. 1-9; pl. 4, figs. 1-10, the holotype, paratypes, and topotypes).

Two species which may be synonymous with *Vasiglobulina alabamensis* have been reported from the Eocene Yazoo Clay. Bandy (1949) recorded *Raphanulina tuberculata* (d'Orbigny) from Little Stave Creek, Alabama. Deboo (1965) listed *Globulina inaequalis caribaea* Reuss from the Pachuta Marl Member at Shubuta Hill, Clarke County, Mississippi. The illustration of each is similar to *Vasiglobulina alabamensis,* but at present the writer cannot confirm their identity. The Gulf Coast stratigraphic occurrence of this species is illustrated in text figure 4.

Europe

A number of European spinose Polymorphinidae have been illustrated and described by Cushman and Ozawa (1930). The writer has examined topotypes and supplementary material of several of these species. It is inferred from the presence of spines that some were attached in the living state. Of the species examined, all of the following possess a radiate tubular apertural system rather than radial slits and, therefore, are now placed in the genus *Vasiglobulina.*

Topotypes Examined

1) *Vasiglobulina tuberculata* (d'Orbigny), 1846—pl. 10, figs. 1,4.
   Locality: The Miocene *Amphistegina* Marl near Grünes Kreuz, Nussdorf, Vienna, Austria.
2) *Vasiglobulina striata* (Egger), 1857—pl. 10, figs. 3,6.
   Locality: The Miocene at Blindham, near Ortenburg, Lower Bavaria.
3) *Vasiglobulina variata* (Jones, Parker, and Brady), 1866—pl. 10, fig. 13.
   Locality: The Pliocene Coralline Crag of Sutton, Suffolk, England.

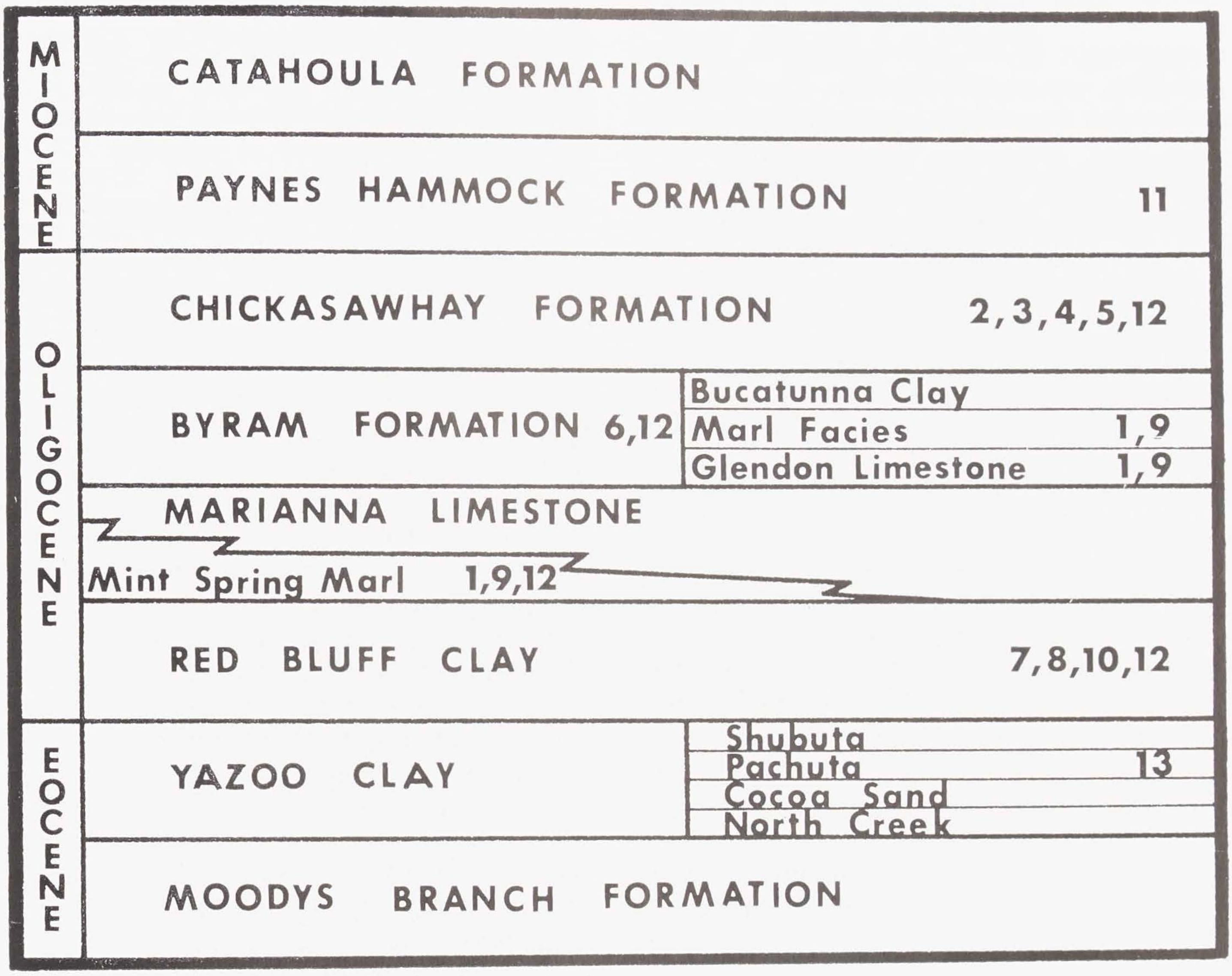
All specimens are deposited in the Chevron Oil Company Collection, New Orleans, Louisiana.

Supplementary Material Examined

1) *Vasiglobulina punctata* (d'Orbigny), 1846—pl. 10, figs. 2,5.
   Locality: The Pliocene Coralline Crag of Sutton, Suffolk, England; the Stampien beds at Jeurre, France; and specimens, possibly conspecific from the Pliocene near Piacenza, Italy.
2) *Vasiglobulina tuberculata?* (d'Orbigny), 1846—pl. 10, fig. 14.
   Locality: Specimens, possibly conspecific from the Pliocene near Piacenza, Italy.

All specimens are deposited in the Chevron Oil Company Collection, New Orleans, Louisiana.

In addition, on the basis of descriptions and illustrations, the following species are tentatively assigned to *Vasiglobulina*:



Text Figure 4

Stratigraphic distribution of *Vasiglobulina alabamensis* in the central Gulf Coast.

1 = Cushman, 1922b
2 = Howe, 1934
3 = Cushman and McGlamery, 1938
4 = Cushman and McGlamery, 1939
5 = Cushman and McGlamery, 1942
6 = Cushman and Todd, 1946
7 = Cushman and Todd, 1948
8 = Bandy, 1949
9 = Todd, 1952
10 = Deboo, 1965
11 = Poag, 1966
12 = Poag, this paper
13 = Unconfirmed specimens
[see Addendum, p. 70]

Guttulina schafferi Cushman and Ozawa, 1930; Austrian Miocene.
Globulina gibba ornata (Karrer), 1868; Austrian Miocene.
Globulina inaequalis spinata Cushman and Ozawa, 1930; German Oligocene.
Globulina gibba fissicostata Cushman and Ozawa, 1930; German Oligocene.
Globulina gibba verrucosa Cushman and Ozawa, 1930; French Eocene.

One stoutly spinose species, *Globulina lacrima ericia* Cushman and Ozawa, is recorded from the Cretaceous near Cambridge, England. The external spinose character is vasiglobuline, but further examination is required to determine its apertural type.

The geologic range of *Vasiglobulina*, therefore, is firmly established from the upper Eocene to the Pliocene Epoch. Further investigation of described species may extend the range from the Cretaceous Period to the Holocene Epoch. It is geographically confined to the U. S. Gulf Coast and Western Europe between latitudes 30° and 60° North.

X. Suggestions for Further Investigation

Two noteworthy areas for future investigation were revealed during the course of this work. First of all, it is apparent that several apertural systems occur within the Polymorphinidae in addition to the vasiglobuline and radiating slit types. A thorough reassessment of the entire group is needed, including a re-examination of the type species of presently accepted genera and their type specimens. In particular, it is quite probable that "*Globulina gibba*," which has for over forty years erroneously been considered the type species for this genus, possesses a tubular rather than a slit-like apertural system (see Poag and Skinner, 1968). Secondly, detailed knowledge of the intriguing variety of foraminiferal attachment modes is meager. Among the numerous reports of attached species, the precise mechanism of attachment has rarely been given more than casual thought. Cushman (1922a), for example, described a Holocene specimen of "*Globulina caribaea*" from the Dry Tortugas region, as attached to a calcareous fragment by "stolon-like processes." The writer has examined similar Holocene specimens from the Gulf of Mexico, whose attaching "stolon like processes" are acicular spines similar to those of *Vasiglobulina alabamensis.* A diligent probe into this poorly understood phenomenon of foraminiferal attachment should yield rewarding results.

XI. Acknowledgments

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XII. Methods of Study

Light photomicrographs were taken on a Bausch and Lomb Dynazoom Laboratory Microscope using Polaroid Polapan 400, type 32 black and white film. Three Nicholas illuminators were used for reflected light. Whole specimens were dyed with green food coloring and mounted with gum tragacanth on clear glass slides. Thin sections were mounted in Lakeside 70 thermoplastic and ground under a low power binocular stereomicroscope. For stereopairs, the angle of tilt between exposures was not measured. Each specimen was tilted between exposures so that a distance of approximately twice the diameter of the field of vision (at 90 X magnification) was traversed by the specimen.

Scanning electron photomicrographs were taken through the courtesy of the JEOLCO (U.S.A.), Inc. during a demonstration of their JSM-2 instrument at the 1968 annual convention of EMSA in New Orleans. Specimens were not coated.

Addendum

While this paper was in press, *Vasiglobulina alabamensis* was identified from the Forest Hill Sand at St. Stevens Quarry, near Jackson, Alabama, and from the Moodys Branch Formation at its type locality near Jackson, Mississippi. The Moodys Branch specimen (TGC 13-1) is the oldest known to date, and extends the range of this species and the genus into the upper Eocene.

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THE PLIOCENE-PLEISTOCENE BOUNDARY IN THE GULF COAST REGION

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Introduction

Beard and Lamb (1968) focused renewed attention on the Gulf Coast Plio-Pleistocene boundary by describing the stratigraphic sequence of planktonic foraminifera in a piston-core recovered from one of the Sigsbee Knolls in the Gulf of Mexico. Upon this single core they base the late Neogene biostratigraphy for the entire Gulf of Mexico region. This is ill advised especially since the authors fail to reconcile their data with information available in published reports. The following comments are offered with the hope that a clearer perspective can be gained.

1) *Previous Gulf Coast data are ignored.* To ignore prior published ranges of Neogene planktonic foraminifera from the Gulf Coast area is not in the best interest of objectively deciphering the geologic history of this region. Among others, Poag and Akers (1967) presented data gathered from hundreds of well samples (both rotary cuttings and cores) from numerous locations widely scattered along the Louisiana continental shelf. Some of the foraminiferal ranges listed by Poag and Akers (1967) are compared below with those of Beard and Lamb (1968).

2) *Contradictory interpretations of paleotemperature changes across proposed Pliocene-Pleistocene boundaries have not been satisfactorily resolved.*

Beard and Lamb (1968) express little doubt that the transition from a warm late Pliocene to a cool early Pleistocene is represented by the extinction level of *Globoquadrina altispira* which . . . corresponds closely with the disappearance of other warm-water species such as *G. venezuelana, Globorotalia menardii,* and *Globigerinoides*