Foraminifera and Origin of the Gardiners Clay (Pleistocene), Eastern Long Island, New York

By LAWRENCE WEISS

A SHORTER CONTRIBUTION TO GENERAL GEOLOGY

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By Lawrence Weiss

ABSTRACT

The Gardiners clay, an interglacial marine Pleistocene deposit, was examined for microfossils in connection with a ground-water investigation at the Brookhaven National Laboratory, Suffolk County, Long Island, N. Y. Twenty species of Foraminifera were identified, including one new species of the genus *Elphidium* and one new subspecies of the genus *Nonion*. The environmental conditions during deposition, as determined from a study of the microfauna, suggest that the Gardiners clay probably does not provide a tight hydraulic seal between the shallow water-table beds and the underlying Cretaceous aquifers.

INTRODUCTION

The United States Geological Survey has been making detailed ground-water studies for the Atomic Energy Commission at the Brookhaven National Laboratory, Long Island, N. Y., since 1948. During these investigations a number of test wells were drilled in the Brookhaven area (fig. 14) under the immediate supervision of the Geological Survey. Only 7 of these wells passed through the unfossiliferous glaciofluvial sand and gravel, 150 to 200 feet thick, and penetrated the underlying material. In 5 of the deeper wells a greenish-gray fossiliferous clay bed, 10 to 20 feet thick, was found beneath the glacial outwash and immediately above the gray clayey sands of the Magothy(?) formation of Late Cretaceous age. The fossil content and stratigraphic position of this clay indicate that it is the Gardiners clay, a Pleistocene interglacial deposit. (For a description of the geology of Long Island, see Fuller, 1914, and deLaguna and Perlmutter, 1949.)

In most of the test wells, the samples for microfossil study were taken from cores, and in these wells the limits of the fossiliferous clay zone could be determined within a few feet. In addition some samples of cuttings from privately drilled wells in the vicinity of Brookhaven were examined, and the results are included in the report. Because samples from the unconsolidated well cuttings may contain mixtures of materials from various depths, the boundaries of the zone cannot be established as accurately as with cores.

There were two reasons for studying the microfauna of this clay stratum. First, the clay bed is believed to form a seal between the water-table aquifer in the glacial sand and gravel above it and the Cretaceous artesian aquifers below it. Thus the thickness and continuity of the clay bed are of much importance. To determine whether the clay was deposited in fairly deep water and therefore presumably is extensive and uniform, or whether it was deposited in shallow water as discontinuous lenses, required an interpretation of the conditions of environment during deposition. The second purpose of this paper is to describe the microfauna in the clay.

Virtually all the knowledge of the subsurface geology of Long Island is based on information obtained from wells. Except along the north shore, outcrops of pre-Wisconsin material are extremely rare on Long Island, and the microfossils in the Pleistocene Gardiners clay, which include foraminifers, diatoms, small forms of mollusks, some ostracodes, and a few plant remains, are valuable in well-sample correlations. With the help of these microfossils it is hoped that the Gardiners clay can be more clearly defined so that it may be differentiated from the clays in the upper part of the Magothy(?) formation with which it has often been confused.

The Gardiners clay in eastern Long Island is variable in its thickness, lithology, and fossil content. The foraminiferal assemblage in the clay is indicative of shallow-water, probably brackish-water, deposition and suggests a depositional environment similar to the bays that fringe the southern shore of Long Island today. The most abundant Foraminifera in the Gardiners clay—those which might possibly be used as guide fossils—are *Elphidium clavatum* and *E. florentinae*. These species are still living in shallow water off the coast of New England, in the numerous bays on Long Island, and in Long Island Sound. They are therefore not restricted to the Pleistocene, and their use as guide fossils might be questioned. However,

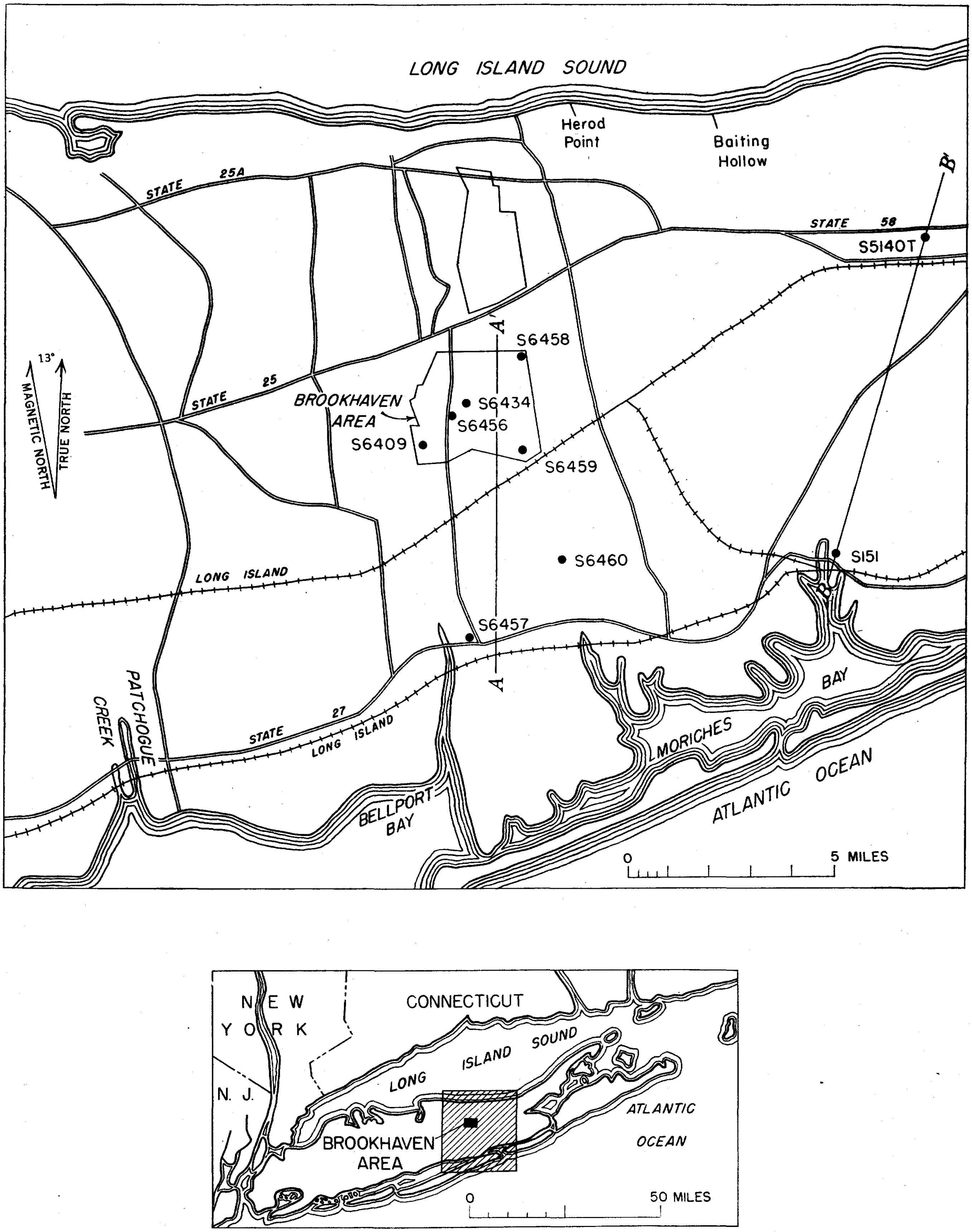

FIGURE 14.—Map of eastern Long Island showing location of wells in Brookhaven area.

there is no evidence of any other fossiliferous interglacial clay on Long Island; thus any fossiliferous material of Pleistocene age overlain by glacial deposits may be called Gardiners.

Another factor that might prove useful in differentiating the Gardiners clay from more recent deposits is the complete absence of arenaceous Foraminifera in the Gardiners in this area. Arenaceous species are numerous in the present-day shallow waters of New England and Long Island. The significance of this fact has not yet been determined, but it is not peculiar to this region. Voorthuysen (1949, p. 64) found that arenaceous species of Foraminifera are absent from the marine Pleistocene of the Netherlands but occur there today.

In many places the Gardiners clay of the Brookhaven National Laboratory area contains microfossils only, and it is suggested that future correlation work on the Gardiners clay be based on microscopic examination.

ACKNOWLEDGMENTS

The author is indebted to Dr. Brooks F. Ellis and Miss Angela R. Messina and staff of the Department of Micropaleontology, American Museum of Natural History, for invaluable criticisms and constructive suggestions. The type and figured specimens of the Foraminifera are deposited in the U. S. National Museum.

METHODS AND TECHNIQUES

Each core sample was prepared by scraping the outermost layer to remove possibly contaminated material, and a section 3 inches long and ½ inch in diameter was cut out for examination. This section was allowed to dry naturally or was heated to drive off moisture, and the sample was boiled in about 500 milliliters of water that contained 3 or 4 pellets of sodium hydroxide to aid in breaking up the clay. Next the clay was washed through a 200-mesh United States standard sieve, and a moderate stream of water was used to agitate the clay; only that part of the sample which remained in the sieve was saved. The samples bailed from cable-tool wells or washed from rotary-drill wells were treated in the same way.

The washed and sieved sample was dried and placed in a large evaporating dish. When carbon tetrachloride was poured over the sample, most of the foraminifers, diatoms, and plant material floated to the top so that they could be quickly poured off and caught on filter paper. (Whatman no. 12 paper, 24 centimeters in diameter, proved very satisfactory.) The floated material was dried and placed on a search plate for examination. The carbon tetrachloride was recovered for re-use. This method did not float the small mollusks, but, where present, they were large enough to be seen easily in the residue.

The flotation method of concentrating the microfossils proved very successful. It saved considerable time in examining core samples and was a necessity in working with other kinds of well samples. Bailer samples that were only washed and sieved seemed to be barren of microfossils, but samples concentrated with carbon tetrachloride yielded many specimens.

STRATIGRAPHY

GENERAL STRATIGRAPHY OF LONG ISLAND

Because so few of the geologic formations on Long Island are fossiliferous their identification and correlation are largely tentative. The Magothy(?) formation on Long Island, the oldest formation here considered, is known to be of Late Cretaceous age, although direct correlation with the type Magothy in New Jersey has not been made.

The Mannetto gravel, the oldest post-Cretaceous deposit on Long Island, is presumably Pleistocene glacial outwash, although some geologists have suggested that it is of late Tertiary age. The Mannetto gravel seems to be restricted to the Mannetto and Wheatley Hills areas and has not been observed in the eastern part of the island.

The Jameco gravel is considered to be younger than the Mannetto gravel on the basis of the degree of weathering. In western Long Island the Jameco gravel is about 100 feet thick and is easily recognized in well samples because of its characteristically high content of diabase fragments and its position beneath the Gardiners clay. Although some geologists have thought that they could recognize the Jameco gravel throughout the island on the basis of lithology and stratigraphic position, its presence in the eastern part is doubtful. The exposures of possible Jameco age are obscure and strongly folded and in general present insufficient evidence for correlation. Well records also fail to indicate the presence of the Jameco gravel in eastern Long Island. There is no mention of a dark-colored or diabase-rich gravel in any of the well logs of this area. Some well records, however, show a thin sand or gravel beneath the Gardiners clay, and this zone, on stratigraphic position alone, has been correlated by some workers with the Jameco. The wells drilled in the Brookhaven area have shown that there are sand and gravel lenses in the Gardiners clay, and in many places gravel embedded in the clay itself. It is more reasonable to assume, therefore, that the thin sand or gravel bed beneath the Gardiners clay in some parts of eastern Long Island belongs to the Gardiners and that the Jameco gravel does not extend into this area.

The Gardiners clay is an interglacial deposit that overlies the Jameco gravel in western Long Island. In the eastern part the Gardiners lies directly above the Upper Cretaceous deposits. The Gardiners has been described as a bluish clay in the central part of Long Island, and as red and green clay near the eastern end of the island. At the type locality on Gardiners Island, Fuller (1914, p. 100) reported a succession of black, green, and red clays, 28 feet thick in all, merging upward into the Jacob sand. Only the green clay, composing about 10 feet of this clay zone, was fossiliferous.

The Jacob sand is supposedly the transitional zone between the interglacial Gardiners clay and the glacial Manhasset formation. The type locality for the Jacob sand is near Jacobs Hill on the north shore of Long Island, 8 miles northeast of Riverhead. There the Jacob is a buff fine-grained clayey sand, consisting chiefly of quartz grains, muscovite, and some dark minerals.

The Jacob sand is overlain by the Manhasset formation, a series of beds of glacial sand and gravel, 150 to 200 feet thick. The Manhasset contains a middle member of till, the Montauk, which is 40 to 60 feet thick in some areas. The lower unit of sand and gravel is known as the Herod gravel member of the Manhasset formation, and the upper unit as the Hempstead gravel member.

The youngest Pleistocene deposit on Long Island, the Wisconsin, consists of the till and associated outwash of the Ronkonkoma and Harbor Hill moraines. Fuller (1914, p. 220–221) believed the Manhasset formation to be of Illinoian age and that an interglacial erosional interval, the Vineyard stage, intervened between the period of deposition of the Manhasset formation and that of the younger Wisconsin drift. A number of more recent workers, however, feel that the lack of any noticeable difference in weathering between the Manhasset formation and the younger Wisconsin drift, and the absence of any generally recognized interglacial deposit, preclude the existence of an interglacial stage; thus they believe the Manhasset to be of Wisconsin age.

PLEISTOCENE STRATIGRAPHY OF THE BROOKHAVEN NATIONAL LABORATORY AREA

The Pleistocene deposits in the Brookhaven region can be divided into three parts (fig. 15) with the Gardiners clay at the base, overlain by a greenish clayey sand, and an upper unit of glacial sand and gravel. The stratigraphic relationship of these zones is shown in cross section *A–A′* (fig. 16).

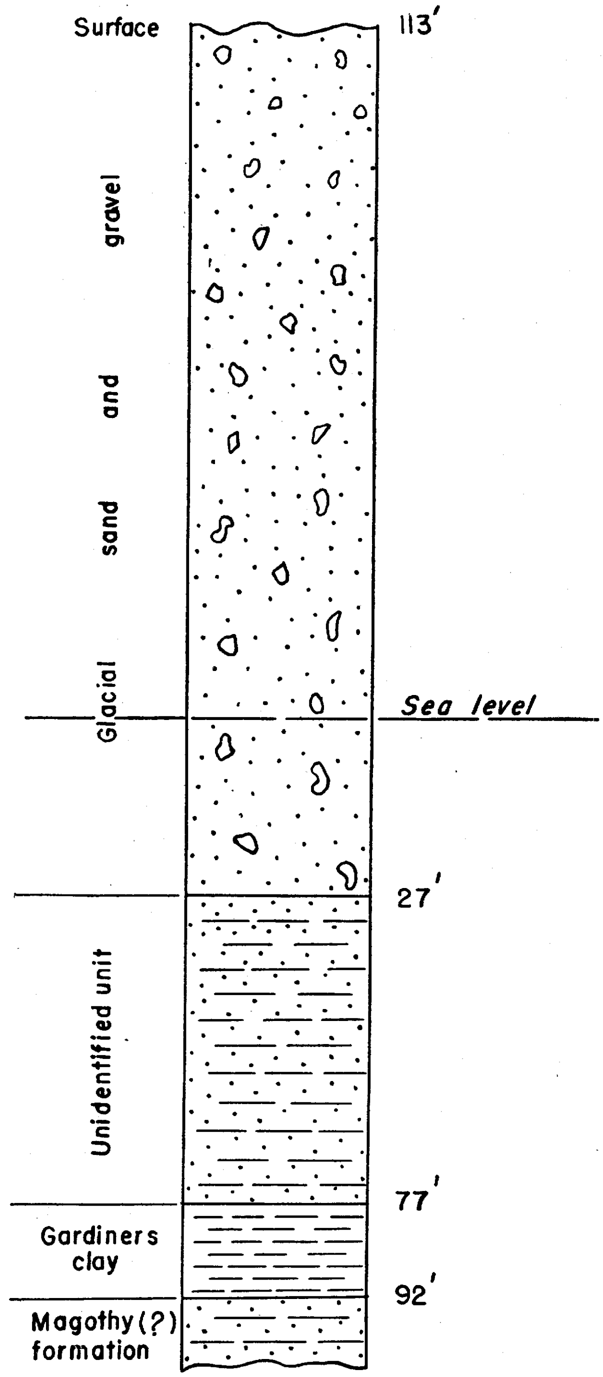

FIGURE 15.—Generalized columnar section in Brookhaven area.

The Gardiners clay underlying the Brookhaven area is a green-gray silty clay 10 to 20 feet thick. Many sections of the clay contain gravel, and some contain sand lenses. In general the zones of true clay of the Gardiners are fossiliferous, and the sand and gravel are not. However, samples from wells of the Riverhead Water District, about 10 miles northeast of the Brookhaven Laboratory, reveal 11 feet of greenish fossiliferous Gardiners clay lying beneath 7 feet of fossiliferous sand and gravel and above 10 feet of

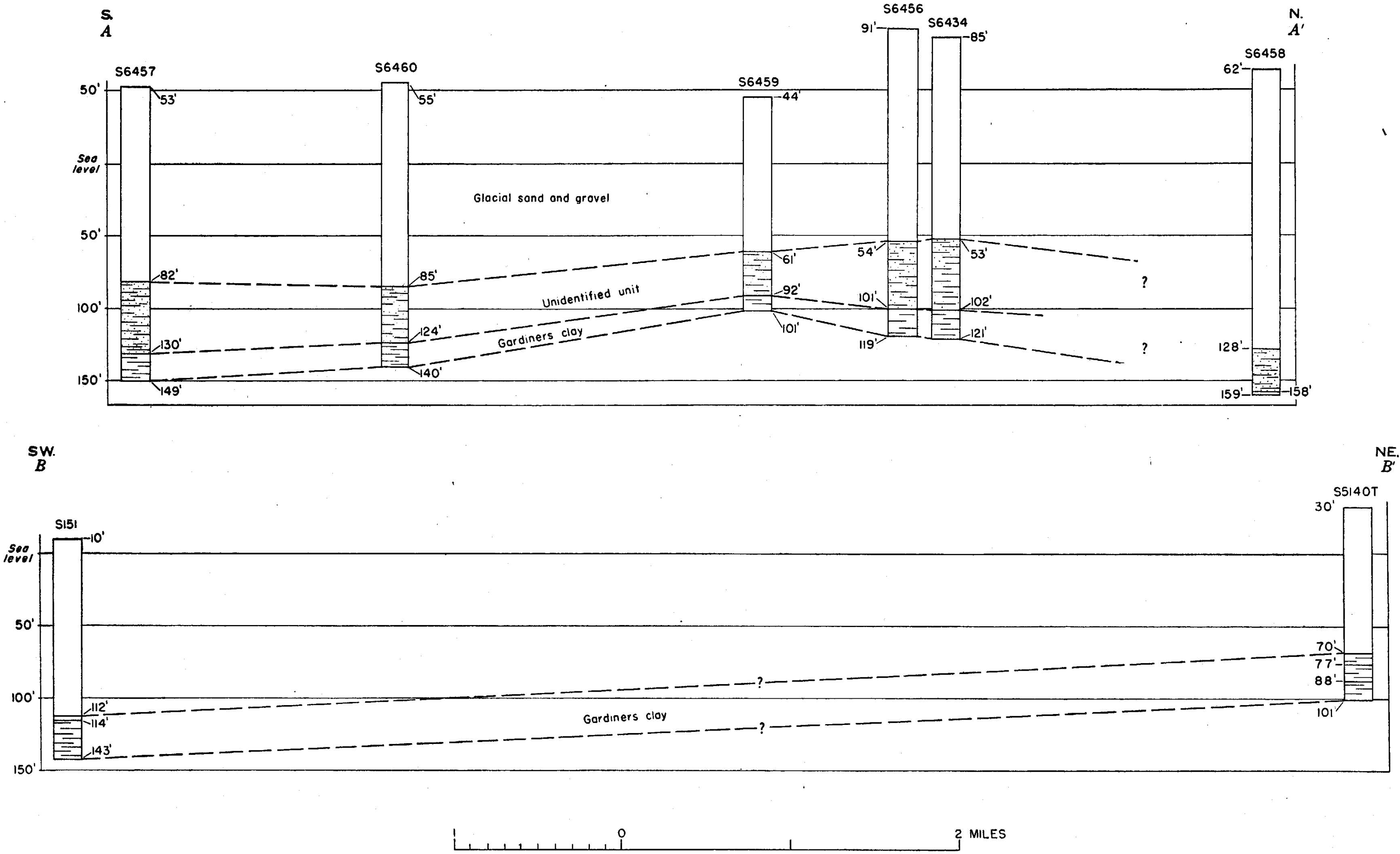

FIGURE 16.—Cross sections, *A–A′* and *B–B′*.

fossiliferous sand and gravel. The microfaunal assemblage of the clay is almost identical with that of the 2 zones of sand. The surface of this predominantly coarse-grained fossiliferous zone in Riverhead is 70 feet below sea level. It is overlain by about 45 feet of unfossiliferous gray and brown clay, which is overlain by about 50 feet of typical glacial sand.

Fuller (1914, p. 98) has reported outcrops of the Gardiners clay beneath the Jacob sand on the north shore of Long Island at Roanoke Point and Jacobs Hill, 3 miles north of Riverhead. The writer examined the clay in these outcrops and found it to be unfossiliferous. Because more recently obtained evidence indicates that Gardiners clay is 70 feet below sea level 3 miles south of Roanoke Point and Jacobs Hill, and because the Gardiners clay seems to thin toward the north and to grade into a shoreline sand and gravel facies, the writer believes that the clays described by Fuller are not part of the Gardiners clay but are equivalent to the 45-foot section of unfossiliferous clay that overlies the Gardiners in the Riverhead area.

The most recent work on Gardiners Island has shown that the beds called the interglacial Gardiners clay actually consist of two clays of entirely different origin. The upper part (probably the red clay referred to by Fuller) is a reddish-brown varved glacial clay, and the lower part is a predominantly green fossiliferous interglacial clay.

The reddish-brown varved clay on Gardiners Island and the gray-brown clays at Roanoke Point and Jacobs Hill both grade upward into the Jacob sand; so perhaps these clays are correlative, as Fuller has suggested. However, they are not part of the interglacial Gardiners clay but a younger glacial deposit.

The Manhasset formation is now generally assumed to be of Wisconsin age, and the Gardiners clay apparently represents deposition during the most recent interglacial stage, the Sangamon. The Gardiners seems to be the only marine fossiliferous clay in the Pleistocene deposits of Long Island and is, therefore, a key bed in stratigraphic work, especially as many geologic correlations on the island are based on the examination of well samples.

The middle unit of the Pleistocene deposits in the Brookhaven area overlies the Gardiners clay; it consists of about 50 feet of a fine- to medium-grained greenish clayey sand, whose color is due to a clay mineral, nontronite. This bed in the well logs is referred to as an unidentified unit. Its stratigraphic position suggests that this sand may correlate with the Jacob sand; but the glacial clay found on Gardiners Island and at Roanoke Point and Jacobs Hill is missing here, and, until more is known about the geology of eastern Long Island far too much guesswork would be involved in an attempt to correlate this zone.

The uppermost Pleistocene deposit in the Brookhaven area, which probably includes both the Manhasset formation and later drift, consists of about 150 feet of glacial outwash. This zone is predominantly coarse sand and gravel, typically poorly sorted, brown to tan, with some boulders and numerous smaller fragments of granite, gneiss, and schist. If there are any morainal deposits in this area, they were not revealed by the drilling. Although many of the wells were cored, nothing resembling a clayey till was found in the Brookhaven area.

WELL DATA

Samples were obtained from three sources: rotary-drill and cable-tool test wells drilled for the Brookhaven National Laboratory and privately drilled wells in the Brookhaven area.

ROTARY-DRILL TEST WELLS

Two test holes, 10 and 12 inches in diameter, were drilled to a depth of 1,600 feet to bedrock to obtain core samples of it and of the Cretaceous formations. These wells were drilled with a 64-foot rotary rig by the Layne-New York Co., Inc. Continuous coring was attempted, and flume samples were collected at 10-foot intervals. The core recovery in the sands and clays of the Cretaceous formations was satisfactory, but all attempts to core the coarse glacial sand and gravel with the rotary wire-line coring apparatus were unsuccessful.

In one of these rotary-drill wells, S6409, the first core obtained was 7 feet of fossiliferous clay below the glacial outwash material. Because core samples of the glacial outwash were desired and because the relation of the clay to the underlying formations is also of importance, the following partially cored cable-tool wells were drilled in the Brookhaven area.

CABLE-TOOL TEST WELLS

Five wells 4 inches in diameter were driven by C. W. Lauman & Co., Inc. Bailer samples were taken at each formational change, and cores 2 feet long were cut at intervals of 10 feet or less. These cores provided excellent samples of the glacial outwash material, of the fossiliferous clay bed where it is present beneath the glacial outwash, and of the clayey sands of the Magothy(?) formation below the fossiliferous clay.

PRIVATELY DRILLED WELLS

It was possible to obtain samples from several private wells in the Brookhaven area, although they were not drilled under the supervision of the U. S. Geological Survey. These are bailer samples from cable-tool wells, taken at each formational change.

The samples and cores from all wells are described below.

Description of samples from wells in the vicinity of Brookhaven National Laboratory

Formation	Method of recovery	Description of material	Fossils	Thickness of zone (feet)	Altitude (top of zone)	Remarks
Well S6409						
Glacial outwash	Rotary wash sample.	Sand, fine to coarse, brown, some gravel. Boulders in upper part of section, hard green-gray clay chips in wash sample from −43 to −53 ft.	None	166	+113	Poor core recovery.
		Sand with gravel	do	24	−53	Increase in fine to medium gravel content.
Gardiners clay	Core and rotary wash sample.	Clay, silty and fine sandy, green when wet, dries to blue gray. Few inches of packed brown peaty vegetation at bottom of clay.	Diatoms, small mollusks, some plant megaspores, a few ostracodes, and numerous foraminifers, including: Abundant: *Elphidium florentinae.* Common: *Elphidium clavatum.* *E. incertum.* *E. ellisi.* *Nonion pauciloculum albiumbilicatum.* *Rotalia beccarii tepida.* *Quinqueloculina seminulum.* Rare: *Bulimina exilis.* *Buliminella elegantissima.* *Globigerina bulloides.* *Nonion* cf. *N. labradoricum.* *Fissurina laevigata.* *Quinqueloculina seminulum jugosa.*	15	−77	The microfossils were found in a 7-foot core from −85 to −92 ft.
Magothy(?) formation.	Rotary wash sample.	Sand, fine to medium, gray, and fine gravel.	None	10	−92	This represents the top few feet of the Magothy(?) formation, which is known to be approximately 900 ft thick in this area.
Well S6434						
Glacial outwash	Rotary wash sample.	Sand and gravel, fine to coarse, brown. Boulders in upper part of section.	None	138	+85	
Unidentified unit.	Small cores and rotary wash sample.	Sand, fine to medium, gray, clayey (green-gray clay).	do	49	−53	Cores were greenish owing to a small amount of green clay.

Description of samples from wells in the vicinity of Brookhaven National Laboratory—Continued

Formation	Method of recovery	Description of material	Fossils	Thickness of zone (feet)	Altitude (top of zone)	Remarks
Well S6434—Continued						
Gardiners clay	Clay lumps in rotary wash sample.	Clay, green-gray and black, micaceous. Some gravel at −115 ft and below.	Diatoms	19	−102	Only diatoms similar to the diatom assemblage of S6409 were found in these clay lumps. Other microfossils may have been present, but no core was obtained; and only a small fraction of the clay stratum was examined.
Magothy(?) formation.	Small core and rotary wash sample.	Sand, medium, clayey, gray.	None	8	−121	Top few feet of the Magothy(?) formation.
Well S6456						
Glacial outwash	Drive cores and bailer samples.	Sand and gravel, fine to coarse, white to tan; some boulders in first 10 ft. Thin brown clay streaks at +60, +42, and +8 ft.	None	145	+91	
Unidentified unit.	do	Sand, fine to medium, gray, clayey (green-gray clay).	do	47	−54	Characterized by green color due to clay content.
Gardiners clay	do	Clay, silty, dark greenish-gray. Gravel, medium to coarse, and clay lumps in bailer sample.	do	4	−101	
		Sand, white, medium to coarse; some gravel.	do	4	−105	
		Clay, dark-gray, brown at bottom. Brown peaty material at bottom.	Diatoms	10	−109	Diatoms, similar to those of S6409, were the only microfossils found in a 2½-foot core.
Magothy(?) formation.	do	Sand, medium to coarse, dark-gray, micaceous, and traces of fine gravel.	None	7	−119	Top few feet of the Magothy(?) formation.
Well S6457						
Glacial outwash	Drive cores and bailer samples.	Sand, medium to coarse, light-brown, and fine to coarse gravel; boulders from +53 to +30 ft.	None	95	+53	
		Sand, fine to medium, light-brown. Thin dark-gray clay streak between −69 and −71 ft.	do	30	−42	
		Sand, coarse, and fine gravel, light yellow-brown. Some boulders at bottom of this zone.	do	10	−72	
Unidentified unit.	do	Sand, fine to medium, gray to buff, clayey; slightly coarser zones at −111 and from −122 to −130 ft.	do	48	−82	Characterized by green color due to clay content.
Gardiners clay	do	Sand, medium to coarse, light-brown, and gravel, fine to medium.	do	11	−130	Probably coarse lens in Gardiners clay.
		Clay, solid, gray-brown. Contains glacial erratic material.	do	1	−141	

Description of samples from wells in the vicinity of Brookhaven National Laboratory—Continued

Formation	Method of recovery	Description of material	Fossils	Thickness of zone (feet)	Altitude (top of zone)	Remarks
Well S6457—Continued						
Gardiners clay	Drive cores and bailer samples.	Sand, clayey and loose, gray; very poorly sorted.	None	2	−142	
		Clay, solid, blue-gray	do	5	−144	Although samples of this clay contained no microfossils, its stratigraphic position shows it to be Gardiners clay.
Magothy(?) formation.	do	Sand, fine to medium, slightly clayey, gray. Some lignite.	do	9	−149	Characteristic of the top few feet of the Magothy(?) formation in this area.
Well S6458						
Glacial outwash	Drive cores and bailer samples.	Sand, fine to medium, tan-brown; some muscovite. Boulders at +20 ft.	None	45	+62	
		Sand, medium to coarse, tan. Some medium to coarse gravel at +12 ft.	do	10	+17	
		Sand, fine to coarse, tan-brown. Fine to medium gravel at −12 ft.	do	50	+7	
		Sand, fine, brown, becoming coarser with some gravel near bottom of zone.	do	19	−43	
		Sand, medium to coarse, yellow-brown, and some fine gravel.	do	66	−62	
		Sand, predominately fine, brown, well-sorted micaceous.	do	12	−128	These sands may represent a reworked zone. They have many of the characteristics of a typical sand of the Magothy(?) formation, but, in addition, contain some erratic material which, on Long Island, is commonly confined to the glacial deposits.
		Sand, medium to coarse, gray.	do	18	−140	
Magothy(?) formation.	Drive core	Clay, silty, tough, light-gray.	Plant megaspores	1	−158	Plant spores indicate Cretaceous age. Probable reworked zone, plus absence of greenish sand and Gardiners clay, strongly suggest post-Gardiners erosion, possibly by glacial streams.
	Drive cores and bailer samples.	Sand, fine to medium gray. Thin clay and lignite streaks at −190 and −195 ft.	None	36	−159	This sand and thin clay at −158 ft represent the top of the Magothy(?) formation.

Description of samples from wells in the vicinity of Brookhaven National Laboratory—Continued

Formation	Method of recovery	Description of material	Fossils	Thickness of zone (feet)	Altitude (top of zone)	Remarks
Well S6459						
Glacial outwash	Drive cores and bailer samples.	Sand, medium to coarse, light-brown; medium to coarse gravel throughout.	None	55	+44	
		Sand, predominantly medium, tan.	do	15	−11	
		Sand, medium to coarse, light-brown; with fine to medium gravel.	do	10	−26	
		Sand, chiefly coarse, yellow-brown.	do	25	−36	
Unidentified unit.	do	Sand, fine to medium (coarser zone with some gravel at −66 to −69 ft), gray with green tint when wet.	do	31	−61	
Gardiners clay	do	Clay, silty and sandy, green when wet, dries to blue-gray. Medium to coarse well-rounded gravel in lower part of clay.	Diatoms	9	−92	A few specimens of only one very small diatom species were found here.
Magothy(?) formation.	do	Sand, fine to medium, clayey, gray.	None	15	−101	Represents the top of the Magothy(?) formation.
Well S6460						
Glacial outwash	Drive cores and bailer samples.	Sand, fine to coarse, tan, poorly sorted; some fine to medium rounded gravel.	None	45	+55	
		Sand, predominantly medium tan; with a few well-rounded pebbles.	do	15	+10	
		Sand, medium to coarse, tan; fine to coarse gravel scattered throughout.	do	55	−5	
		Sand, fine to medium, micaceous, tan.	do	25	−60	
Unidentified unit.	do	Sand, predominantly medium, finer near base, well-sorted; distinct yellow-tan color.	do	39	−85	
Gardiners clay	do	Clay, silty and fine sand. Green when wet, dries to blue gray.	Foraminifera: Abundant: *Elphidium clavatum.* *E. florentinae.* *Eponides frigidus calidus.* Common: *Elphidium incertum.* *E. ellisi.* Rare: *Bulimina exilis.*	5	−124	Clay zone contained Foraminifera only, with a varied *Elphidium* assemblage predominating as in S6409. *Eponides frigidus calidus*, abundant here, was not seen in S6409.
		Clay, green-gray, with much sand; fine gravel; and some coarse gravel.	None	11	−129	
Magothy(?) formation.	do	Sand, fine to medium, clayey, gray.	do	5	−140	Top few feet of the Magothy(?) formation.

Description of samples from wells in the vicinity of Brookhaven National Laboratory—Continued

Formation	Method of recovery	Description of material	Fossils	Thickness of zone (feet)	Altitude (top of zone)	Remarks
Well S151						
[Description from samples furnished by driller and examined by F. G. Wells]						
Glacial outwash	Bailer samples	Sand and gravel, yellow	None	29	+10	
		Sand, fine, yellow	do	15	−19	
		Gravel, coarse	do	7	−34	
		Sand, straw-colored	do	30	−41	
		Gravel, coarse, rounded; quartz pebbles as much as 2 cm, angular fragments of schist and diabase.	do	14	−71	
		Sand, gray, with much mica.	do	10	−85	
		Gravel, dirty-gray	do	11	−95	
Gardiners clay	do	Clay, very fine, blue, sandy; fine brown sand. Some shell fragments.	Sample at −112 ft: One *Elphidium incertum*. Sample at −127 ft: Abundant: *Elphidium incertum*. Rare: *Eponides frigidus calidus*. *Nonion pauciloculum albiumbilicatum*. *Globulina glacialis*. *Pseudopolymorphina novangliae*.	21	−106	Only small samples examined from the sand lenses in this clay, but the incomplete fossil record reveals a foraminiferal assemblage characteristic of the Gardiners clay.
		Clay, blue, sandy	Sample at −143 ft: Rare: *Elphidium incertum*. *Eponides frigidus calidus*. *Quinqueloculina seminulum*.	16	−127	
		Sand, black, silty		3	−143	No samples.
		Sand, salt-and-pepper, very dark gray.	None	6	−146	High glauconite content. Probably Gardiners clay.
Magothy(?) formation.	do	Sand, fine micaceous, very gray.	do	40	−152	
Well S5140T						
Glacial outwash	Bailer samples	Sand, fine to coarse, brown	None	48	+30	
		Clay, solid, brown	do	5	−18	There are numerous reports of clay in the glacial outwash of the Riverhead area, but the origin of the clay is as yet unknown.
		Clay, solid, light-gray	do	38	−23	
		Gravel, fine to coarse, with sand and light yellow-brown clay mixed.	do	4	−61	
		Sand, medium, clayey, gray	do	5	−65	
Gardiners clay	do	Sand, medium to coarse, green-gray, clayey; some coarse gravel and shell fragments.	Foraminifera Abundant: *Elphidium clavatum*. *E. florentinae*. Common: *Quinqueloculina seminulum*. Rare: *Elphidium incertum*. *E. ellisi*. *Eponides frigidus calidus*.	7	−70	The fossiliferous sand zones in this well, with coarse gravel and thick shell fragments, are indicative of shoreline deposition. This suggests that the Gardiners clay in the Brookhaven area was a deposit whose

Description of samples from wells in the vicinity of Brookhaven National Laboratory—Continued

Formation	Method of recovery	Description of material	Fossils	Thickness of zone (feet)	Altitude (top of zone)	Remarks
Well S5140T—Continued						
Gardiners clay	Bailer samples	Clay, silty, green-gray	One diatom specimen and numerous foraminifers including: Abundant: *Elphidium clavatum.* *E. florentinae.* Common: *Nonion pauciloculum albiumbilicatum.* *Fissurina laevigata.* Rare: *Elphidium incertum.* *E. ellisi.* *Eponides frigidus calidus.* *Discorbis globularis.* *Entosolenia marginata.*	11	−77	shoreline sand facies was somewhat north of the laboratory grounds, although more information would be necessary to determine the northernmost extent of the clay.
		Clay, sand, and coarse gravel mixed; shell fragments.	Diatoms numerous and numerous foraminifers, including: Abundant: *Elphidium clavatum.* *E. florentinae.* Rare: *Elphidium incertum.* *E. ellisi.* *Discorbis globularis.* *Pseudopolymorphina novangliae.* *Nonionella* sp.	2	−88	
		Chiefly coarse gravel and very thick shell fragments.	Pelecypod shell fragments as much as ¼ in. thick.	6	−90	Sample bottle contained only coarse gravel and thick shell fragments.
		Sand, gravel, and clay, mixed; shell fragments.	Some small mollusks, two diatom specimens, and numerous foraminifers, including: Abundant: *Elphidium clavatum.* *E. florentinae.* Common: *Rotalia beccarii tepida.* Rare: *Elphidium incertum.* *E. ellisi.* *Eponides frigidus calidus.* *Quinqueloculina seminulum.* *Entosolenia laevigata.* *Nonion pauciloculum albiumbilicatum.* *Patellina corrugata.*	7	−96	
		Sand, medium, light yellowish-brown.	None	2	−103	
Magothy(?) formation.	do	Clay, light-gray, silty, and fine sand.	do	21	−105	Top of Magothy(?) formation.

CONDITIONS OF DEPOSITION

EVIDENCE FROM WELL SAMPLES

A core 7 feet long, taken with a rotary wire-line core barrel in well S6409, was studied in detail. This core represents the lower 7 feet of a clay zone about 15 feet thick, extending from 77 to 92 feet below sea level.

Sections of the core were examined at 6-inch intervals, and a total of 15 samples were obtained. The method of washing and concentrating was similar to that described above, except that 2 additional sieves were used, 80- and 325-mesh. This resulted in better sorting and hence a more accurate systematic search. Each sieve sample was examined separately on a search plate with numbered squares, and the abundance of each species was noted.

The core is a blue-gray sandy silty clay that is green when wet. It contains much finely divided muscovite and silt-sized quartz grains, a great deal of woody and fibrous plant material, and some small fragments of hard black lignitized plant material. At the base of the core is a few inches of hard, tightly packed brown peatlike plant matter.

There are various microfossils in this clay core. Figure 17 shows how the comparative abundance of the more common forms varies with depth in the clay. Environmental changes of some sort are indicated near the top of the core and between 4 and 6 feet. Inasmuch as Foraminifera throughout the core suggest deposition in very shallow water (Parker, 1948, p. 221), one might expect that some changes occurred in the environment during deposition, with perhaps an accompanying change in the microfauna.

The uppermost part of the core contains numerous diatoms but no other microfossils. The same diatom species are found associated with the foraminifers and other microfossils throughout the rest of the core. In two other wells in the area, S6434 and S6436, similar diatom species were the only microfossils found in the clay. In well S6459 only a few very small specimens of one diatom species were found. The clay in another well, S6460, contains only foraminifers, and in still another, S5140T, only 2 feet of a 30-foot fossiliferous zone contains diatoms.

It would seem, therefore, that the foraminifers and diatoms were not always favored by the same environment. The question is, What type of environment, what set of conditions, suited one group and not the other?

Under conditions of very shallow water deposition a change in depth of water would not in itself affect the faunal assemblage, but the possible environmental changes due to a slight fluctuation of sea level probably would have great influence on the paleontology and lithology of the sediment. Such a small absolute change of sea level in the littoral zone would result in a large relative change, possibly affecting currents, salinity, and temperature, which would change that area of deposition exposed between high and low tides.

A change in currents and in the position of the tidal

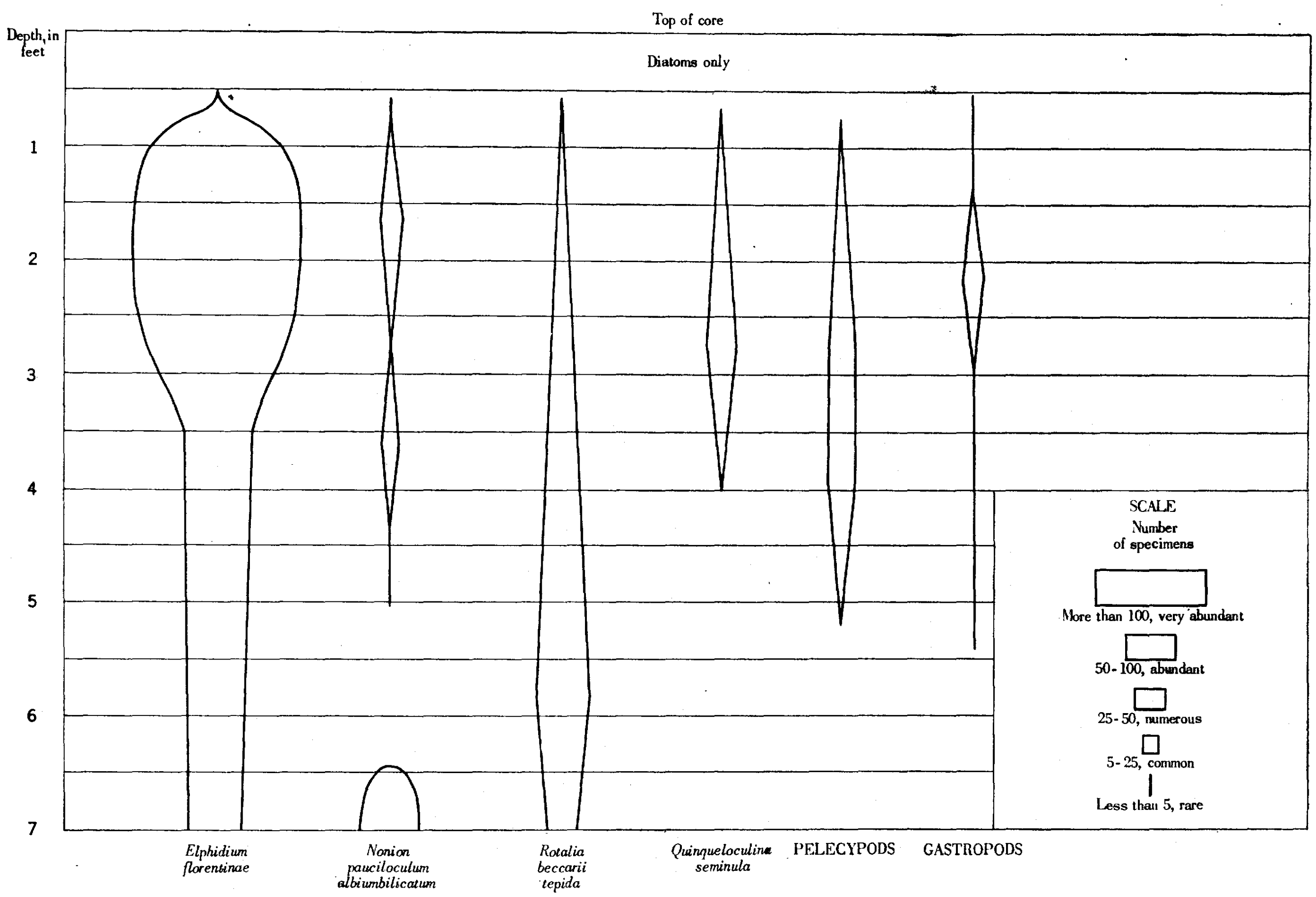

FIGURE 17.—Relative abundance of microfossils in well S6409.

zone would result in variable deposition. Such deposition is suggested by the lithologic changes in the clay underlying the Brookhaven area. For example, there are unfossiliferous lenses of sand in wells S6456 and S6457; coarse sand and gravel mixed with unfossiliferous clay in wells S6434, S6456, S6459, and S6460; and much peaty material in wells S6456 and S6409. Vegetal matter was rare in the other wells.

However, the fossiliferous clay sections of the Brookhaven wells are quite similar lithologically, all consisting of sandy and silty clay, but, as stated above, some have different microfossil assemblages. This might suggest that the microfossils are found only in the finer textured zones of the clay, but in well S5140T there are both sand and clay zones that contain a fossil fauna similar to that of well S6409. Although bottom conditions changed during deposition of the clay, some uniform clay beds contain different microfossil assemblages, and, on the other hand, some sand beds and some clay beds contain similar microfossil assemblages—a point which indicates that the occurrence of the various microfossils was not governed primarily by differences in the type of sediment.

Another factor to be considered as a cause of changing biofacies is that of variation in salinity. The foraminiferal assemblage, with *Elphidium*, *Rotalia*, and *Nonion* the most abundant genera, suggests a brackish-water environment (Glaessner, 1947, p. 190–191).

Other Foraminifera in the fossiliferous sediments of the Brookhaven area that have been found occasionally in water of low salinity are *Eponides frigidus*, *Quinqueloculina*, *Fissurina*, and *Discorbis*. Another indication of low salinity is the presence of some specimens of *Pinnularia major*, a fresh-water diatom. However, there are also some specimens of a typical marine pelagic foraminifer, *Globigerina bulloides*, in the clay. These fossils would seem to indicate a brackish lagoonal or bay area, influenced both by fresh-water streams and by some access to the open ocean.

The Brookhaven area during Gardiners time was principally one of clay deposition. However, the sand and gravel in some zones of the clay indicate that coarser material, presumably derived locally, was occasionally swept into the quiet waters. This type of sedimentation in shallow, probably brackish, water also suggests a bay or lagoonal deposit perhaps somewhat similar to those in the bays protected by the offshore bar on the present south shore of Long Island. The formation of an offshore bar during Gardiners time is compatible with the theory that an interglacial sea rose along a gently shelving coast, conditions that are very favorable to the formation of bars and related depositional features.

An occasional increase in the transporting power of the streams emptying into this Pleistocene bay, possibly during flood stages, or perhaps a more vigorous advance of the ocean through a break in the bar, might very well lead to deposition of a gravel-clay mixture in the quiet waters of the bay.

With the numerous small streams now flowing into Great South Bay and with its ocean inlets, one might expect bottom conditions similar to those of Gardiners time. Previous studies have shown that the salinity of Great South Bay is not uniform. The chloride content ranges from 6,000 ppm in the eastern end of the Bay to 17,000 ppm in the western end near the Fire Island Inlet (Whipple, 1912, p. 474–490).

EVIDENCE FROM DREDGED SAMPLES

Samples were dredged from several locations in the Patchogue Bay area of Great South Bay. The chloride content of the water in this area is about 11,600 ppm, whereas in the open ocean it is 19,000 to 20,000 ppm.

A bottom sample taken 1 mile off the Patchogue shore, in 9 feet of brackish water, consisted of a soft dark-gray mud containing a microfauna strikingly similar to that of the Gardiners clay. The Foraminifera predominant in both are *Elphidium clavatum*, *E. florentinae*, *Rotalia beccarii tepida*, *Nonion pauciloculum albiumbilicatum*, and *Eponides frigidus calidus*. The main difference between the Recent and Pleistocene foraminiferal faunas is the presence of arenaceous Foraminifera in the Recent material. It has long been thought that arenaceous Foraminifera prefer a cold-water environment. However, to assume on this basis that the climate during Gardiners time was warmer than that of the present is highly speculative.

The Gardiners clay and the Recent mud of Great South Bay contain many similar diatom species also. Although a complete study was not made of the diatoms, such genera as *Campylodiscus*, *Triceratium*, *Coscinodiscus*, and *Auliscus* were recognized in both deposits. One very noticeable difference in the diatom faunas is the abundance of *Pleurosigma* in the Recent material and its absence from the Pleistocene clay.

Some bottom samples were taken from Patchogue Creek, a small estuary modified by dredging, which has a chloride content of 9,800 ppm, and from several locations in Long Island Sound where the chloride content is 18,500 ppm.

Foraminifera are very scarce in Patchogue Creek. Only five specimens of *Elphidium clavatum*, two of *Nonion*, one of *Eponides frigidus calidus*, and two of arenaceous Foraminifera were found in this sample. All these specimens are small and have indistinct characters. Diatoms, however, are numerous in this dredge sample. Because the creek is highly polluted, it is difficult to determine whether the paucity of

Foraminifera is due to the pollution or to their being less tolerant than diatoms of water of this salinity. Among the common diatoms in this sample are *Campylodiscus*, *Coscinodiscus*, *Triceratium*, and *Pinnularia major*, a fresh-water diatom species rarely present in the Gardiners clay fauna.

A thoroughly systematic dredging program was not attempted in Long Island Sound. Two small areas were sampled, one extending from Herod Point half a mile offshore and the other from Baiting Hollow to a point a mile offshore. Between Herod Point and Baiting Hollow, in an area that extends from a few feet to half a mile offshore, there is a sand bottom at depths from 10 to 25 feet. The most abundant foraminifer in this zone is a species of *Elphidium* that is not found in the Gardiners clay. Other microfossils in this zone are present in the Gardiners clay: *Eponides frigidus calidus*, *Quinqueloculina seminula*, *Globulina glacialis*, a few immature *Elphidium florentinae*, and a few diatom species. Arenaceous Foraminifera were found in all the samples dredged from the sound.

One sample was dredged 1 mile off Baiting Hollow, where the depth to the mud bottom is 60 feet. *Elphidium florentinae* and *Eponides frigidus calidus* are abundant, and *Elphidium clavatum* is fairly common. *Coscinodiscus*, *Triceratium*, and *Auliscus* are among the diatom genera found in this sample.

The abundance of *Elphidium florentinae* and *Eponides frigidus calidus* in both the fairly deep water of Long Island Sound and the shallow water of Great South Bay is some indication of the degree of tolerance these forms have for variations of depth and salinity. Both locations have mud bottoms, but neither of the Foraminifera is restricted to a mud-bottom environment. *Eponides frigidus calidus* is found in samples dredged from a sandy bottom in the sound, and *Elphidium florentinae* is present in some sandy zones of the Gardiners clay.

To summarize the results of the dredging in waters near the Brookhaven area, the sample that contained a microfossil assemblage most similar to that of the Gardiners clay was dredged from the shallow brackish water of Great South Bay. This similarity of fossil assemblages is the most convincing evidence for the theory that the Gardiners clay was deposited in an environment not unlike that of the present Great South Bay.

The bay lies between the mainland of Long Island and a barrier beach on the south. The barrier beach is continually changing in shape and extent. There is slow migration of the inlets as sand is deposited on one side of an inlet and eroded on the other. Tidal currents carry sand an appreciable distance through these inlets and deposit it on the bottom of the bay, and the same currents probably scour some of the previously deposited mud from the bottom and locally replace it with sand. Waves sweep across the barrier beach and form new inlets during heavy storms. At such times it is reasonable to expect major local changes in the nature of the bottom of the bay.

If the Gardiners clay in eastern Long Island was deposited under conditions similar to those existing in Great South Bay, similar variations in the deposits, particularly in the lenses of sand, are to be expected in the Gardiners clay.

CONCLUSIONS

1. The Gardiners clay in the Brookhaven area, a Pleistocene interglacial clay, is variable in its thickness, lithology, and fossil content—indicating some environmental changes during deposition.
2. The clay, therefore, probably does not constitute a complete hydraulic seal between the water-table aquifer and the underlying Cretaceous aquifers except in localized areas.
3. The foraminiferal assemblage in the Gardiners clay is very similar to that of the mud at the bottom of Great South Bay at present and is therefore indicative of shallow-water, probably brackish-water, deposition.
4. The fauna, gravel-clay mixtures found in some wells, and the probable type of Pleistocene seacoast during Gardiners time all indicate deposition in a bay or lagoonal area protected by an offshore bar.
5. The Recent foraminiferal fauna of Great South Bay differs from that of the Gardiners clay mainly in the presence of arenaceous Foraminifera. This may indicate that the climate during Gardiners time was warmer than that of the present, but more investigation is necessary before definite conclusions can be drawn.

SYSTEMATIC DESCRIPTIONS

FORAMINIFERA

Family NONIONIDAE

Genus NONION Montfort, 1808

Nonion pauciloculum albiumbilicatum Weiss, n. subsp.

Plate 32, figures 1, 2

Test small, bilaterally symmetrical, compressed, periphery rounded, margin entire or very slightly lobulate, biumbilicate, umbilical regions very finely papillate with minute granules of shell material extending along sutures and on apertural face, and covering first chamber of last whorl. Papillose areas whiter than rest of wall material, giving test a distinctive appearance. Chambers few, 7 to 9 in last formed whorl, slightly inflated, distinct; sutures distinct, slightly curved, depressed, limbate, wide in umbilical region, gradually tapering towards periphery. Wall calcareous hyaline, smooth, transparent, coarsely perforate. Aperture not visible in last chamber, but short slightly curved slit may be seen at base of penultimate septal face with minute ridges fanning out from aperture.

Diameter as much as 0.35 mm, thickness as much as 0.15 mm.

Nonion cf. N. labradoricum (Dawson)

Plate 32, figure 3

Nonion labradoricum (Dawson). Cushman, 1939, U. S. Geol. Survey Prof. Paper 191, p. 23.
Cushman, 1944, Special Pub. 12, Cushman Lab. Foram. Research, p. 24, pl. 3, fig. 23.
Cushman, 1948, Special Pub. 23, Cushman Lab. Foram. Research, p. 52, pl. 6, fig. 2.

Test small, completely involute, umbilical regions depressed, margin entire except last 2 to 3 chambers slightly lobulate, periphery rounded; chambers as numerous as 10 in last whorl, indistinct in early stages, slightly inflated, in apertural view widening rapidly toward axis of coiling; early sutures indistinct, later ones slightly depressed and curved; wall calcareous hyaline, perforate; aperture a thin arched slit at base of last septal face.

Diameter as much as 0.36 mm.

Common in some sections of the Gardiners clay, rare or absent in others.

Genus NONIONELLA Cushman, 1926

Nonionella sp.

Plate 32, figure 4

Typical Nonionella, involute on one side, slightly evolute on other, with chambers rapidly increasing in height. As only one specimen was found and the last chamber (and perhaps even more) of this specimen was missing, no attempt at specific identification was made.

Genus ELPHIDIUM Montfort, 1808

Cushman (1944, p. 25) states that *Elphidium* is—

> The most common genus in the New England material and there are either many species or else a great amount of variation. It would make a good problem for someone to make cultures of some of these forms and determine what the limits of variation really are.

The writer has found a similar situation in the forms in the Gardiners clay. The genus *Elphidium* predominates in the foraminiferal assemblage and shows a tremendous amount of variation in certain species.

Cushman (1944) further states:

> For the most part the different forms are usually found in the colder waters north of Cape Cod or in the warmer waters to the south, thus seeming to show that they are probably not simply variants. An attempt has been made to assign specific names to some of the more common and best characterized forms.

Altogether, four species of *Elphidium* are represented in the Gardiners clay in the Brookhaven region. These are *Elphidium incertum*, *E. florentinae*, *E. clavatum*, and *E. ellisi*, n. sp. The writer is of the opinion, however, that most of the specimens of *Elphidium* in the Gardiners clay, and perhaps those of the New England waters, are variants of one species, *E. clavatum*. The variations are probably due to slight changes in environment. Cushman (1944) stated that his *Elphidium incertum* (Williamson) var. *clavatum* was more common in the New England waters than the typical *E. incertum*. This condition also prevails in the Gardiners clay assemblage where *E. clavatum* shows a great range of characters. Examination of the literature has revealed that other authors have also found extreme variation in this form (Voorthuysen, 1949, p. 63; Brady, 1884, p. 734; and Sidebottom, 1909, p. 14).

Elphidium clavatum differs from *E. incertum* in having a number of large distinct bosses in the umbilical region. It is the size and distribution of these bosses on the test and the degree of opacity of the test (both results of superficial deposition) that are the major variables within the group of *E. clavatum* in the Gardiners clay. On this basis, it seems that the group comprises two forms:

One form contains individuals with white opaque tests, indistinct sutures, and numerous irregularly arranged bosses confined mainly to the umbilical region. This is the form in which most of the variation occurs. The opacity appears to be due to deposition of shell material that obscures the characters of the test and variously ornaments the shell.

The second form includes specimens with yellowish-brown commonly translucent tests, also with irregularly arranged bosses in the umbilical region, but, in the fully matured form, with a definite row of bosses filling in the pores along the sutures. Shupack's species *Elphidium florentinae* falls in this group (Shupack, 1934).

That these forms are related can be shown in three ways. First, by breaking away some of the chambers of the opaque specimens belonging in the first form, the young stage of the second form can be seen—the brownish translucent test with limbate sutures of clear shell material. Second, intermediate individuals, such as large opaque specimens with bosses along the sutures, or young translucent individuals with a tendency towards opacity, show the transition from one stage to another. Finally, thin sections show no internal difference between the two forms. Obviously the difference between the forms is due to superficial deposition.

Because the variation in the *Elphidium clavatum* group is so great, it appears best to follow Shupack's example in giving specific rank to *E. clavatum*. The second form of the *E. clavatum* group is so distinctive and so predominant in the Pleistocene and Recent of Long Island that it deserves to be differentiated. Inasmuch as Shupack's *Elphidium florentinae* is representative of this form, it seems best to retain the name *E. florentinae* for it.

Elphidium(?) ellisi Weiss, n. sp.

Plate 32, figures 5, 6

Test small, slightly longer than broad, compressed, periphery rounded, margin entire except last 3 or 4 chambers slightly lobulate, umbilical regions with a large boss of clear calcite, often slightly raised. Chambers numerous, 14 to 16 in last whorl, very slightly inflated, distinct. Sutures distinct, straight to very slightly curved, early sutures limbate, flush with surface of test, last 3 or 4 sutures depressed and show characteristic septal pores, about 5 on each side of test. Owing to difference in length of alar prolongations, last septal face is slightly canted in apertural view, giving test a somewhat asymmetrical appearance. Species tends to become slightly evolute—more so on side of test where shorter alar prolongations do not extend to umbilical boss—and the first few chambers of the previous whorl may be seen. Where umbilical area is raised, a slight depression or trench on both sides of test between the end of the chambers and the large boss is often present. Wall calcareous hyaline, smooth, coarsely perforate. Aperture a row of small pores at base of last septal face, often with a few supplementary pores on septal face itself.

In general appearance, this species is similar to *Nonion chapapotense* Cole in possessing the large central boss and the grooved area between the boss and the inner ends of the chambers. However, the presence of septal pores and the characteristic aperture suggest that this form be placed in the genus *Elphidium*.

Length as much as 0.32 mm, breadth as much as 0.24 mm, thickness as much as 0.12 mm.

Elphidium incertum (Williamson)

Plate 32, figure 7

Polystomella umbilicatula (Walker and Jacob) var. *incerta* Williamson, 1858, Recent Foraminifera of Great Britain, p. 44, pl. 3, figs. 82, 82a.

Polystomella striato-punctata (Fichtel and Moll) var. *incerta* Kiaer, 1900, Norwegian Fishery and Marine Inv. Rept., v. 1, no. 7, p. 51, Kristiana.

Elphidium incertum (Williamson). Cushman, 1930, U. S. Natl. Mus. Bull. 104, pt. 7, p. 18, pl. 7, figs. 4–9.

Shupack, 1934, Am. Mus. Novitates 737, p. 12, figs. 10a, b.

Cushman, 1939, U. S. Geol. Survey Prof. Paper 191, p. 57, pl. 15, figs. 21–24.

Cushman, 1944, Special Pub. 12, Cushman Lab. Foram. Research, p. 25, pl. 3, figs. 28–31.

Cushman, 1948, Special Pub. 23, Cushman Lab. Foram. Research, p. 56, pl. 6, fig. 7.

Test small, bilaterally symmetrical, compressed, periphery rounded, margin entire or with last few chambers slightly lobulate, umbilical region slightly raised owing to a single boss or knob of shell material. Chambers few, commonly nine in last whorl, slightly, if at all, inflated, distinct; sutures distinct, depressed, narrow, slitlike near umbilical region, with a single row of indistinct retral processes. Aperture a row of large pores at base of last septal face.

This species is most similar in appearance to Cushman's *Elphidium incertum* from Casco Bay, Maine (Recent).

Diameter as much as 0.35 mm, thickness as much as 0.15 mm.

Elphidium florentinae Shupack

Plate 32, figures 8–11

Elphidium florentinae Shupack, 1934, Am. Mus. Novitates 737, p. 9, pl., figs. 5a, b.

Elphidium brooklynense Shupack, ibid., p. 10, pl., figs. 7a, b.

Elphidium incertum (Williamson) var. *clavatum* Cushman. Voorthuysen, 1949, Nederlandsch Geol.-Mijnb. Genoot. Verh. Geol. ser., Deel 15, stuk 1, p. 65, pl., figs. 4b, c.

Test bilaterally symmetrical, compressed, periphery rounded, margin entire except last 3 chambers slightly lobulate, umbilical regions flush or slightly raised owing to numerous irregularly arranged bosses of clear shell material. Chambers 10 to 13 in last formed whorl, usually 10 to 11, slightly, if at all, inflated, distinct; sutures distinct, straight to slightly curved, limbate, well marked by bosses of clear shell material filling in pores, except for first few sutures of last whorl that are filled with smooth bands of clear calcite, and last 2 or 3 sutures that show a single row of indistinct retral processes. Sutural bosses less distinct on smaller, immature forms, and, although the number varies, about half the early sutures on young forms are limbate and filled with clear calcite. Wall calcareous hyaline, smooth, finely perforate, generally yellow-brown. Aperture a row of pores at base of last septal face, with a series of ridges bordering pores and extending along first chamber of last whorl. When specimen is sectioned or cut into, these ridges can also be seen along peripheral edge of preceding whorl.

Diameter, 0.40 to 0.60 mm, thickness, 0.20 to 0.30 mm.

Elphidium clavatum Cushman

Plate 32, figures 12–14

Elphidium incertum (Williamson) var. *clavatum* Cushman, 1930, U. S. Natl. Mus. Bull. 104, pt. 7, p. 20, pl. 7, figs. 10a, b.
Cushman, 1939, U. S. Geol. Survey Prof. Paper 191, p. 57, pl. 16, figs. 1, 2.
Cushman, 1944, Special Pub. 12, Cushman Lab. Foram. Research, p. 25, pl. 3, figs. 32, 33.
Cushman, 1948, Special Pub. 23, Cushman Lab. Foram. Research, p. 57, pl. 6, fig. 8.

Test small, bilaterally symmetrical, periphery rounded, margin entire or very slightly lobulate, more so in last few chambers; umbilical regions flush or slightly raised owing to numerous, irregularly arranged bosses, some opaque and others of clear shell material: chambers few, commonly less than 10 in last formed whorl, slightly, if at all inflated, indistinct; sutures generally indistinct, narrow and depressed as in *Elphidium incertum* in some specimens, flush and limbate in others, and rarely with a few indistinct bosses along some sutures. Many specimens combine two or all three conditions. Retral processes few, and usually can only be seen along last or next to last suture. Wall calcareous, perforate, with various degrees of opacity, white to yellowish-brown. Aperture a row of pores at base of last septal face, a few specimens with pores on septal face itself, and with faint ridges bordering pores and extending along first chamber of previous whorl.

Diameter as much as 0.65 mm, thickness as much as 0.35 mm.

Family ROTALIIDAE

Genus ROTALIA Lamarck, 1804

Rotalia beccarii tepida Cushman

Plate 33, figure 1

Rotalia beccarii (Linné) var. *tepida* Cushman, 1926, Carnegie Inst. Pub. 344 (Dept. Marine Biology Papers, v. 23), p. 79.

Test small, biconvex, dorsal side slightly more so than ventral, as many as 10 chambers in last whorl; peripheral margin rounded, slightly lobulate; sutures limbate on dorsal side, depressed on ventral; ventral chambers end in angular points in umbilical region; wall calcareous hyaline, perforate; aperture a narrow slit beneath inner angle of last formed chamber, often supplemented by a small nearly circular opening at base of last septal face.

The Gardiners clay specimens of this variety closely agree with Cushman's original description except that Cushman's forms have 6 to 7 chambers in the final whorl.

Diameter as much as 0.35 mm.

Abundant.

Genus EPONIDES Montfort, 1808

Eponides frigidus calidus Cushman and Cole

Plate 33, figure 2

Eponides frigida (Cushman) var. *calida* Cushman and Cole, 1930, Contr. Cushman Lab. Foram. Research, v. 6, p. 98, pl. 13, fig. 13.
Cushman, 1944, Special Pub. 12, Cushman Lab. Foram. Research, p. 34, pl. 4, figs. 19, 20.

Test small, biconvex, more so on dorsal than on ventral side; 6 to 7 chambers in last whorl; peripheral margin rounded, slightly lobulate; dorsal sutures oblique, slightly depressed, distinct; ventral sutures distinct, depressed, slightly curved, radial, limbate, filled with finely papillate white shell material also covering umbilical region and apertural area. Wall calcareous hyaline, perforate.

Diameter as much as 0.40 mm.

Abundant in some sections of the Gardiners clay, rare or absent in others.

Genus DISCORBIS Lamarck, 1804

Discorbis globularis (d'Orbigny)

Plate 33, figure 3

Rosalina globularis d'Orbigny, 1826, Annales sci. nat., sér. 1ere, tome 7, p. 271, pl. 13, figs. 1–4, Paris.
Discorbis globularis (d'Orbigny). Cushman, 1915, U. S. Natl. Mus. Bull. 71, pt. 5, p. 11–12, pl. 9, fig. 4; pl. 12, figs. 10, 11.
Cushman, 1948, Special Pub. 23, Cushman Lab. Foram. Research, p. 68, pl. 7, fig. 12.

Test small, planoconvex, ventral side flattened; chambers distinct, commonly five in last whorl, with ventral flap partly covering umbilical region; sutures slightly depressed and slightly curved; wall calcareous hyaline, perforate; aperture at base of last septal face, extending toward ventral side of test, often with a lip.

Diameter as much as 0.32 mm.

Rare.

Genus PATELLINA Williamson, 1858

Patellina corrugata Williamson

Plate 33, figure 4

Patellina corrugata Williamson, 1858, Royal Soc. London, pl. 3, figs. 86–89, 89a.
Cushman, 1948, Special Pub. 23, Cushman Lab. Foram. Research, p. 67–68, pl. 7, fig. 11.

Test small, dorsal side conical, ventral flat, long crescentic chambers divided into chamberlets by short internal radial septa; wall calcareous hyaline, perforate, thin; aperture elongate, at base of ventral side of last chamber.

Diameter as much as 0.25 mm.

Rare.

Family GLOBIGERINIDAE

Genus GLOBIGERINA d'Orbigny, 1826

Globigerina bulloides d'Orbigny

Plate 33, figure 5

Globigerina bulloides d'Orbigny, 1826, Annales sci. nat., sér. 1ere, tome 7, p. 277, Paris; Modeles, nos. 17 and 76.

Test small, umbilicate, early chambers in trochoid spire; chambers round, inflated, four in last whorl; wall calcareous hyaline, coarsely perforate; aperture large, round, opening into umbilicus.

The Gardiners clay specimens of *Globigerina bulloides* are smaller than d'Orbigny's type specimen.

Diameter 0.17 mm.

Rare.

Family BULIMINIDAE

Genus BULIMINA d'Orbigny, 1826

Bulimina exilis H. B. Brady

Plate 33, figure 6

Bulimina elegans d'Orbigny var. *exilis* H. B. Brady, 1884, *Challenger* Rept, Zoology, v. 9, p. 399, pl. 50, figs. 5, 6.
Bulimina exilis H. B. Brady. Cushman and Parker, 1940, Contr. Cushman Lab. Foram. Research, v. 16, pt. 1, p. 11–12, pl. 2., figs. 18a, b, 19–21.
Cushman, 1948, Special Pub. 23, Cushman Lab. Foram. Research, p. 62, pl. 7, fig. 1.

Test small in loose, elongate, spiral coil, greatest width near middle; chambers inflated, elongate, distinct; sutures distinct, depressed; wall calcareous hyaline, perforate; aperture a high narrow arch extending from top of last chamber down into last septal face.

Length as much as 0.31 mm.

Rare.

Genus BULIMINELLA Cushman, 1911

Buliminella elegantissima (d'Orbigny)

Plate 33, figure 7

Bulimina elegantissima d'Orbigny, 1839, Voyage dans l'Amérique méridionale, tome 5, pt. 5, Foraminifères, p. 54, pl. 7, figs. 13, 14.
Buliminella elegantissima (d'Orbigny). Cushman, 1919, U. S. Natl. Mus. Proc., v. 56, no. 2302, p. 606.
Cushman, 1944, Special Pub. 12, Cushman Lab. Foram. Research, p. 27, pl. 3, figs. 43, 44.

Test small, elongate, in a close spire; chambers commonly four to a whorl, compressed, distinct; sutures distinct, depressed; wall calcareous hyaline, perforate; aperture virguline, in depression between base of last septal face and preceding whorl.

Length as much as 0.16 mm.

Rare.

Genus FISSURINA Reuss, 1850

Fissurina laevigata Reuss

Plate 33, figure 8

Fissurina laevigata Reuss, 1850, K. Akad. Wiss., Vienna, Math.-naturh. Denkschr., Band 1, p. 366, pl. 46, fig. 1.
Lagena laevigata (Reuss), Terrigi, 1880, Accad. pont. nuovi Lincei Atti, v. 33, p. 177–178, pl. 1, fig. 6, Rome.
Entosolenia laevigata (Reuss). Cushman and McGlamery, 1942, U. S. Geol. Survey Prof. Paper 197–B, p. 70, pl. 5, figs. 19–21.
Cushman, 1944, Special Pub. 12, Cushman Lab. Foram. Research, p. 28, pl. 4, fig. 12.
Cushman, 1948, Special Pub. 23, Cushman Lab. Foram. Research, p. 63, pl. 7, fig. 4.

Test small, unilocular, pyriform; wall calcareous hyaline, perforate, opaque except for lateral band of clear shell material; aperture fissurine, with short internal tube.

Cushman's specimens reported in his Special Publication 23 on Arctic Foraminifera are identical in all respects except that they are as much as 1.0 mm long.

Common.

Fissurina marginata (Montagu)

Plate 33, figure 9

Vermiculum marginatum Montagu, 1803, Testacea Britannica, p. 524, pl. 1, fig. 7.
Entosolenia marginata (Montagu). Williamson, 1848, Annals and Mag. Nat. History, ser. 2, v. 1, p. 17, pl. 2, figs. 15, 16.
Cushman, 1948, Special Pub. 23, Cushman Lab. Foram. Research, p. 65, pl. 7, fig. 7.

Test small, unilocular, subrounded; wall calcareous hyaline, perforate; aperture fissurine, with a long, expanding internal tube.

Length 0.18 mm.

Only one specimen was found in the Gardiners clay material.

Family MILIOLIDAE

Genus QUINQUELOCULINA d'Orbigny, 1826

Quinqueloculina seminulum (Linné)

Plate 33, figure 11

Serpula seminulum Linné, 1767, Systema Naturae, 12th ed., p. 1264.
Quinqueloculina seminulum (Linné). d'Orbigny, 1826, Annales sci. nat., sèr. 1ere, tome 7, p. 303, Paris.
Quinqueloculina seminula (Linné). Cushman, 1944, Special Pub. 12, Cushman Lab. Foram. Research, p. 13, pl. 2, fig. 14.
Cushman, 1948, Special Pub. 23, Cushman Lab. Foram. Research, p. 34–35, pl. 3, figs. 14, 15.

Test small, typical quinqueloculine coil with chambers added successively in planes 144° apart but each chamber 72° from its next adjacent one; chambers half a coil in length, distinct; sutures distinct, depressed; wall calcareous porcellaneous, imperforate, thick; aperture large, at end of last chamber, rounded, simple, some with a simple tooth.

Length as much as 0.40 mm, breadth as much as 0.29 mm.

Numerous in some sections of the Gardiners clay, rare or absent in others.

Quinqueloculina seminulum jugosa Cushman

Plate 33, figure 10

Quinqueloculina seminula (Linné) var. *jugosa* Cushman, 1944, Special Pub. 12, Cushman Lab. Foram. Research, p. 13–14, pl. 2, fig. 15.

This variety differs from the species in possessing faint costae.

Rare.

Family POLYMORPHINIDAE

Genus GLOBULINA d'Orbigny, 1839

Globulina glacialis Cushman and Ozawa

Plate 33, figure 12

Globulina glacialis Cushman and Ozawa, 1930, U. S. Natl. Mus. Proc., v. 77, no. 2829, art. 6, p. 71, pl. 15, figs. 6, 7. Cushman, 1948, Special Pub. 23, Cushman Lab. Foram. Research p. 50–51, pl. 5, figs. 15, 16.

Test, small, pyriform, appearing somewhat quinqueloculine in side view and triserial in apertural view; chambers elongate, slightly inflated, distinct; sutures distinct, depressed; wall calcareous hyaline, perforate, thin; aperture terminal, round, and radiate.

Length as much as 0.28 mm, breadth as much as 0.16 mm.

Rare.

Genus PSEUDOPOLYMORPHINA Cushman and Ozawa, 1928

Pseudopolymorphina novangliae (Cushman)

Plate 33, figure 13

Polymorphina lactea (Walker and Jacob) var. *novangliae* Cushman, 1928, U. S. Natl. Mus. Bull. 104, p. 146–147, pl. 39, figs. 6–8.

Pseudopolymorphina novangliae (Cushman). Cushman and Ozawa, 1930, U. S. Natl. Mus. Proc., v. 77, no. 2829, art. 6, p. 90–91, pl. 23, figs. 1, 2. Cushman, 1944, Special Pub. 12, Cushman Lab. Foram. Research, p. 23, pl. 3, figs. 12–14.

Test elongate, compressed, tapering at both ends; chamber slightly if at all inflated, longer than broad, embracing, early chambers nearly quinqueloculine, later becoming more or less biserial; sutures very slightly depressed, indistinct; wall calcareous hyaline, finely perforate, smooth; aperture terminal, round, and radiate.

This is the largest species of Foraminifera in the Gardiners clay assemblage.

Length as much as 1.48 mm, breadth as much as 0.65 mm.

Rare.

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PLATE 32

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2. Paratype, × 40, USNM 548853; well S6409, 190–205 feet.

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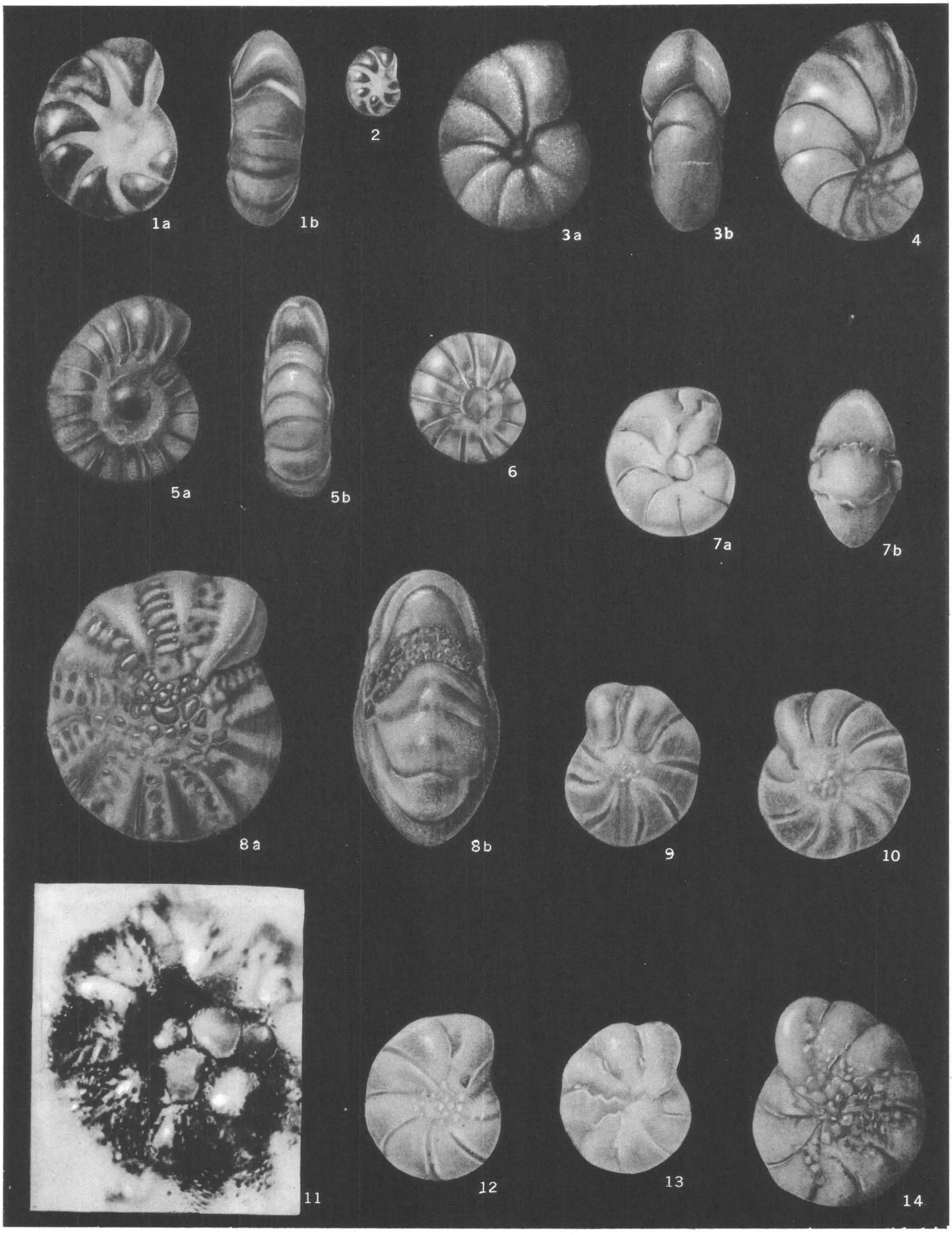
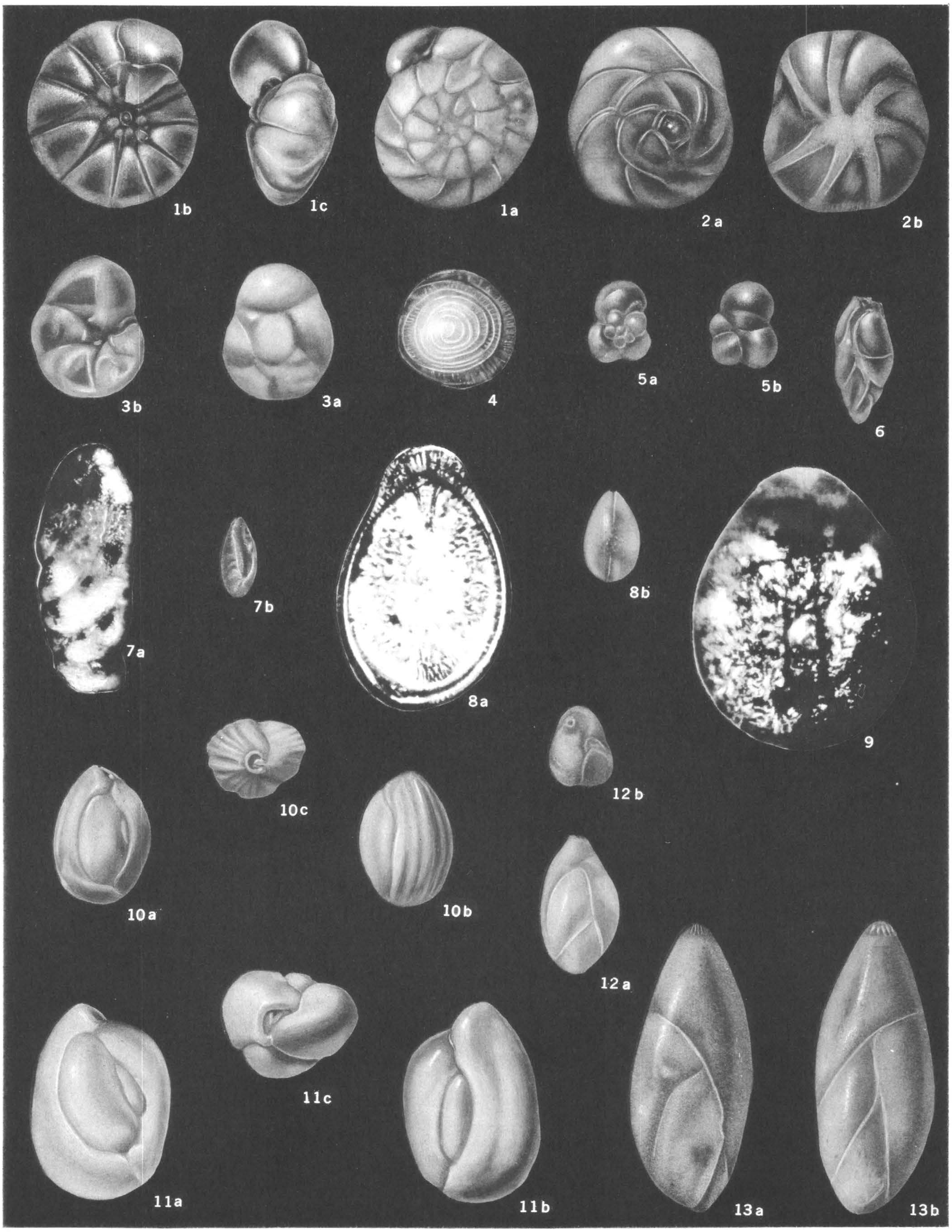


NONIONIDAE



ROTALIIDAE, GLOBIGERINIDAE, BULIMINIDAE, MILIOLIDAE, AND POLYMORPHINIDAE

PLATE 33

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