FORAMINIFERAL BIOSTRATIGRAPHY AND PALEOECOLOGY OF THE AQUIA FORMATION NEAR HANOVER, VIRGINIA

by

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INTRODUCTION

In the last 25 years a considerable amount of study on planktonic foraminifera and their stratigraphic ranges has provided the means for a detailed zonation of the Tertiary (Bolli 1957, 1966a; Stainforth et al. 1975, and others).

Paralleling this work has been research on marine community structures including both fossil and recent benthonic foraminiferal assemblages. This work has given paleoecologists a framework for interpreting ancient depositional environments (Phleger, 1960; Walton, 1964; Margalef, 1968; Buzas and Gibson, 1969, and others).

With the concepts derived from this research the geologic age, bathymetry and paleoecology of a given stratigraphic interval can be surmised from data on foraminiferal abundance, taxonomy and biostratigraphy.

In this study the Paleocene Aquia Formation was sampled from outcrops along the Pamunkey River near Hanover, Virginia. Benthonic and planktonic foraminifera were studied in terms of their taxonomy, biostratigraphy and numerical abundance allowing for interpretations on the geologic age and depositional environment of the section.

The planktonic foraminiferal zones used here follow the work of Stainforth et al. (1975). These zones have been extensively used as the accepted standard in warm-water regions.

Benthonic foraminiferal communities described here are compared to similar assemblages from the Aquia located 50 miles north of the study area at Bull Bluff, Virginia and Cabin Branch, Maryland (Youseffnia, (1978).

The stratigraphic relationships and structural features of the Aquia Formation and the associated Cretaceous and Tertiary strata in the study area were studied by plotting each measured section on a scaled east-west cross-section perpendicular to strike. The results of this cross-section are discussed in conjunction with Mixon and Newell's (1978) study of the faulted Coastal Plain margin near Fredericksburg, Virginia.

Generalized Geologic Setting of the Aquia Formation

The Aquia Formation is part of an easterly thickening wedge of gently easterly dipping Cretaceous to Recent sediments forming the Coastal Plain of Virginia and Maryland. This sequence of predominantly clastic strata was laid down in a range of terrestrial (fluvial) to open marine environments. The Coastal Plain pinches out in its western outcrop area and thickens to over 3000 feet in the subsurface of eastern Virginia.

By the late Cretaceous the Atlantic Ocean had achieved approximately 60 percent of its present width via oceanic plate formation and spreading at the Mid-Atlantic Ridge (Scotese and Baker, 1975). Aquia deposition began as the oceans transgressed over the nonmarine Cretaceous sands and gravels to the present western limit of the Virginia Coastal Plain or possibly farther west. Erosion of the Piedmont and Blue Ridge highlands provided sediment which was transported by rivers into a downwarped depocenter in eastern Maryland, Delaware, and northeastern Virginia known as the Salisbury Embayment. The exposed Aquia Formation now extends in a northeast to southwest strike belt along the western fringes of the embayment, from Petersburg, Virginia, northeast to the Maryland-Delaware state line (Teifke, 1973).

Previous Work

The various publications on the Aquia Formation mostly treat localities and/or subsurface data in Maryland and the type locality at Aquia Creek, Virginia. There are relatively few geologic and/or paleontologic studies of the Aquia Formation south of Washington, D.C.

Darton (1891) originally described and designated the Paleocene and Eocene sediments in Maryland and Virginia as the Pamunkey Formation. Clark and Miller (1912) described river outcrops and the faunas of the Coastal Plain strata in Virginia. Drobnyk (1965) reported on the petrography of the Aquia in Maryland, Virginia, and Delaware; Teifke (1973) summarized the present stratigraphy of the Cretaceous through Miocene series in the Virginia Coastal Plain. Daniels and Onuschak (1974) mapped and reported on the geology of the four 7 1/2-minute quadrangles directly south of the study area of this report, and Weems (1974) mapped and studied the geology of the Hanover-Academy and Ashland quadrangles.

The first important study of the Foraminifera of the Aquia was by Cushman (1944a) who described 44 species from three localities in northern Virginia. Shifflett (1948) described Foraminifera from three outcrops (including the type locality), and from numerous wells in Maryland. The first attempt to date the Aquia using planktonic Foraminifera was by Loeblich and Tappan (1957a,b) who placed the Aquia in their upper Paleocene *Globorotalia acuta-G.velascoensis* Assemblage Zone. Nogan (1964) revised the taxonomy of Shifflett (1948) and described 22 planktonic and 89 benthonic species of Foraminfera. He considered the Aquia to be Late Paleocene to Early Eocene in age, and to be deposited in the shallow waters (<300 ft.) of a gradually shoaling sea. Youseffnia's (1978) study of Aquia Foraminifera from outcrops in northern Virginia and Maryland indicated a nearshore unstable environment.

Other paleontologic studies of the Aquia include Andrew's (1971) study of *Turritella mortoni* and the biostratigraphy of the Aquia Formation at the type locality and Witmer's (1975) study of the dinoflagellate taxonomy and biostratigraphy in the study area of this paper. Gibson et al. (1980) reported on the biostratigraphy of the Tertiary strata of the Oak Grove, Virginia core located 40 miles north-northeast of this study area.

Objectives

The objectives of this research are to: 1) describe the planktonic and benthonic foraminiferal fauna from the Aquia Formation in the Hanover, Virginia area, 2) determine the stratigraphic ranges of the Foraminifera and relate them to a standard zonation, and 3) describe the paleoecology and general paleoenvironments of the Aquia Formation in the study area.

Three field trips were made from the summer of 1978 to the spring of 1979 to: 1) study the stratigraphy of the Aquia Formation, 2) locate and sample the river outcrops reported by Witmer (1975), and 3) locate any other outcrops that might be used in this study.

STRATIGRAPHY

Local stratigraphic relations of the Aquia Formation

The Aquia Formation is exposed as a band of discontinuous and incomplete outcrops in the banks and bluffs along the Pamunkey River (Weems, 1974; Daniels and Onuschak, 1974; Witmer, 1975). In the study area it is exposed from a point 1000 feet N74°E of Wickham Crossing (Ashland U.S.G.S. 7 1/2-minute topographic quadrangle) downstream to a point 5600 feet in a line N69°E from the junction of the Pamunkey River and Route 301 (Hanover U.S.G.S. 7 1/2-minute topographic quadrangle) where the Marlboro Clay is exposed (figure 1). This belt is about 2.8 miles across. Several unweathered but fragmentary sections were measured and sampled along the outcrop belt. These sections have been correlated on the basis of geographical reconstructions, lithologic similarities, and faunal properties.

The geographical reconsgruction (figure 5) involved preparation of a scaled cross-sectional view, perpendicular to the strike, with an average dip of 14 feet per mile using a local maximum thickness of 70 feet for the Aquia as determined from a nearby well (W-2158). The fragmentary sections were plotted on this cross-section and then adjusted with respect to one another using lithologic characteristics and faunal correlations (planktonic foraminiferal zones).

Four partial sections have been studied. Localities 1, 2 and additional outcrop "D" of this study correspond to Localities 1, 2 and 3, respectively, of Witmer (1975); however additional outcrop "D" did not contain foraminifera.

Local Lithology of the Aquia Formation

The Aquia Formation is composed of light olive green to dark green glauconitic silty clays and quartz-glauconite sands with minor amounts of muscovite and phosphorite. Occurring locally in the Aquia are shell beds up to 8 feet thick, indurated limestone (concretion) layers, and a basal layer of quartzitic boulders and cobbles.

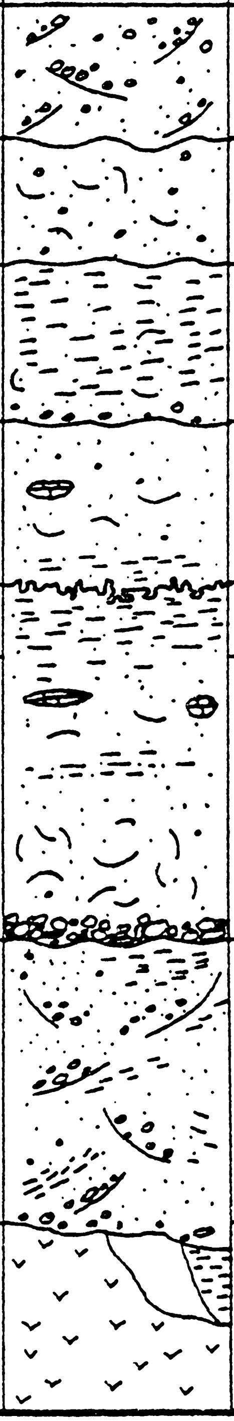
Calcium carbonate leaching is common and produces an orange-green to orange-gray color in the sediments, and an orange rust color in the shell molds.

Contact Relationships and Thickness

The Aquia Formation comprises the lower part of the Cenozoic Coastal Plain clastic wedge. It unconformably overlies non-marine Cretaceous sediments of the Patuxent Formation in Virginia. This regional unconformity is marked by an abrupt transition from the cross-bedded sands and gravels (with clay interbeds) of the Patuxent Formation to the glauconitic clays and sands of the Aquia Formation. A basal boulder bed in the Aquia persists along this contact in the study area. The entire Upper Cretaceous and possibly the Early and Middle Paleocene sections are missing. The absence of these units is noted by Reinhardt et al. (1980)

Table I. Geologic formations in the Coastal Plain of Virginia.
(Adapted from Teifke 1973; Mixon and Newell 1978.)

Age	Series	Name	Lithology	Description
Tertiary	Miocene or Pliocene (?)	Upland Gravels		Light colored, oxidized deposits; clays, silts, sands and gravels; some peat
Tertiary	Miocene	Yorktown Fm.		Gray to bluish gray silts, sands, shell beds; clay beds uncommon.
Tertiary	Miocene	Calvert Fm.		Drab greenish brown clays and silty clays, commonly consolidated. Plant fragments and mollusks common. Coarse basal sand.
Tertiary	Eocene	Nanjemoy Fm.		Quartz – glauconite sands; shell beds and cavernous shell limestone common.
Tertiary	? Paleocene	Marlboro Clay		Red and gray clays, leached.
Tertiary	Paleocene	Aquia Fm.		Drab green, gray and brown glauconite-bearing clays. Quartz-glauconite sands, shell beds and limestone.
Cretaceous	Lower	Patuxent Fm.		Medium-to very coarse grained sands and fine-grained gravels. Clay interbeds.
Precambrian-Triassic		"basement"		Igneous and metamorphic rocks of Precambrian and Paleozoic age; partially consolidated Triassic sediments.



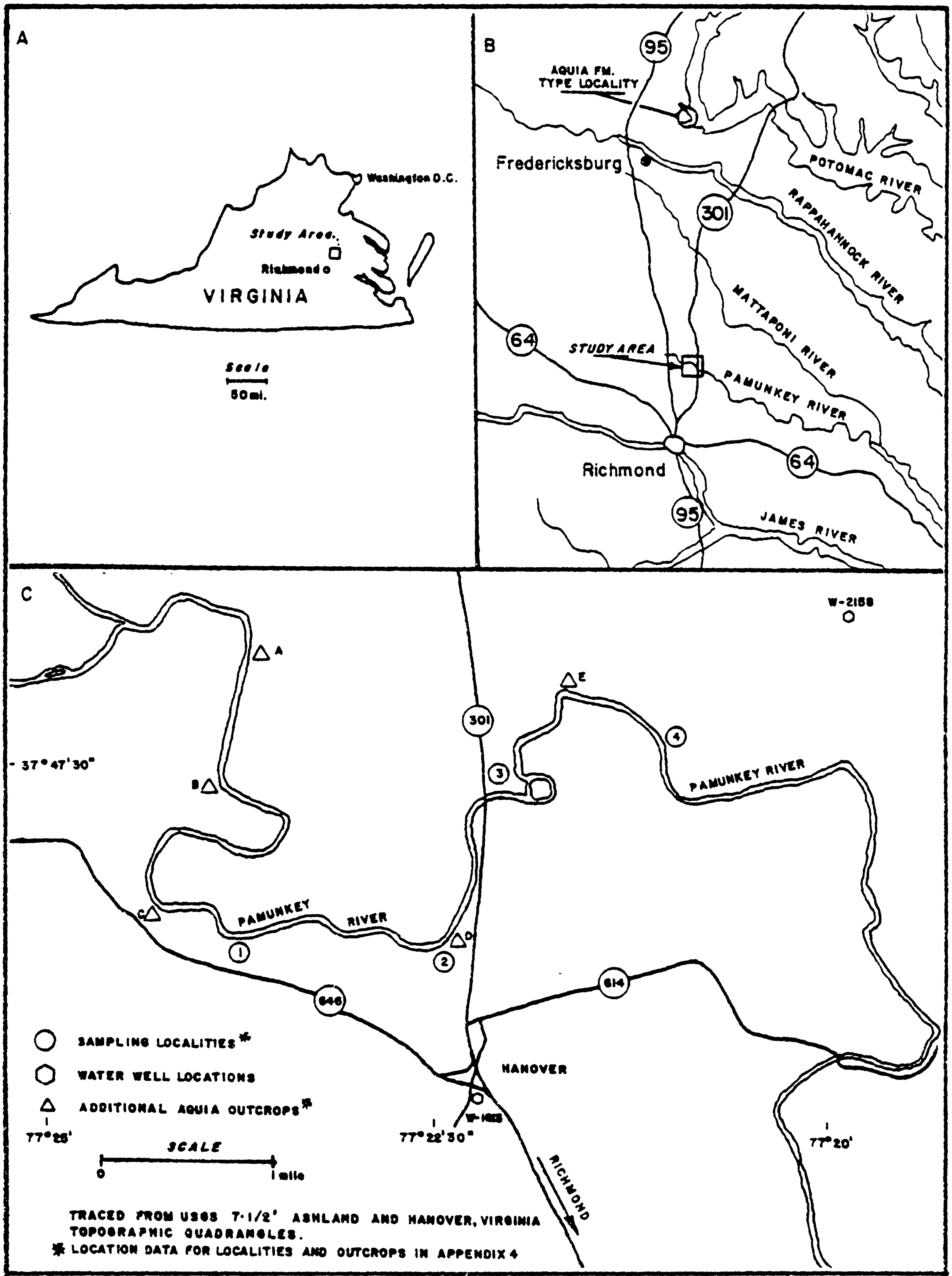


FIGURE 1 (A) Location of study area in eastern Virginia, 10 miles north of Richmond. (B) Index map of Virginia Coastal Plain. (C) Sketch map showing collecting localities.

in the Oak Grove, Virginia, core. The upper Aquia greensands grade over an 8-inch interval into the gray plastic clays of the Marlboro Clay. The top of the Marlboro Clay is marked by extensive burrows which are filled in with glauconitic clays and silts of the Nanjemoy Formation. The Marlboro Clay is present between the upper Aquia and lower Nanjemoy in a belt extending southward from east of Washington, D. C., to the Richmond, Virginia, area (Teifke, 1973; Reinhardt et al. 1980).

The Aquia is about 40 feet thick in water well W-1613 and 70 feet thick 3.4 miles to the northeast in well W-2158. (See appendix 3 and 4). It thickens in an easterly downdip direction to the vicinity of Chesapeake Bay where it is over 400 feet thick (Teifke, 1973).

GENERALIZED PALEONTOLOGY

In the study area the Aquia Formation is richly fossiliferous containing large numbers of well preserved oysters, clams, gastropods, Foraminifera, ostracodes, vertebrate skeletal parts and palynomorphs (Clark and Miller 1912; Andrews 1971; Witmer 1975). Shell beds in the basal Aquia up to 8 feet thick contain Cucullea, Pitar, Venericardia Cubitostrea, Crassatella, Dosinopsis, and Turritella (locality 1). The upper sections of the Aquia contain 3 to 5 inch thick discontinuous horizons dominated by Turritella with few other molluscs present (localities 2, 3 and 4). These horizons are spaced vertically from a few inches to several feet apart.

The macrofossils tend to be randomly oriented, articulated, and range from about 1 inch to 6 inches in length. Many shells appear to be unbroken in the outcrops; however they usually break apart in the laboratory during attempts to remove them from the sediment matrix.

SAMPLE COLLECTION AND PREPARATION

All samples were collected from outcrops along the Pamunkey River, north of Hanover, Virginia. Sampling was at 1-foot vertical intervals from the lowest outcrop exposure (river level) to the top, except for areas of intense leaching or slumping. Outcrops were cleaned of weathered debris before sampling. Each sample was individually bagged and labelled. Sampling tools were cleaned to avoid contamination.

In the laboratory each sample was air-dried and weighed to the nearest gram. They were then washed in water and sieved (#60 sieve) to remove large shell debris, and again (#230 sieve) to remove clay sized particles. Samples were dried in an oven at approximately 150°F for 8 to 10 hours. Foraminifera were concentrated by flotation using acetone-diluted high density liquids (acetylene tetrabromide); 400 to 600 Foraminifera were picked, when possible, from each sample and mounted on slides. The samples were then re-examined for planktonic foraminifera specifically. Selected species were photographed using the JEOL S. E. M. of Virginia Polytechnic Institute and State University Blacksburg, Virginia and the JEOL S. E. M. and a WILD M-5 Apochromat light microscope at Phillips Petroleum Exploration and Production Services branch in Bartlesville, Oklahoma. Important diagonostic planktonic

Foraminifera and the more common benthonic species found in the Aquia Formation are illustrated.

SAMPLING RESULTS

Of the 62 samples analyzed, 31 contained Foraminifera. Samples 3 through 5 of locality 1, sample 7 of locality 2, and samples 8 and 10 of locality 4 were the only fossiliferous samples which contained less than 300 Foraminifera. Many of the samples were totally leached of their calcium carbonate. However the samples that contained fossils generally had excellently preserved Foraminifera, ostracodes, and molluscs.

BIOSTRATIGRAPHIC ZONATION

The planktonic foraminiferal zonation of Stainforth et al. (1975) is used in this study. That work presents a zonation that utilizes an extensive amount of published literature and Exxon Company's own world-wide studies, making it a widely used standard for micropaleontologists and biostratigraphers in warm-water regions.

Description of Zones, After Stainforth et al. (1975)

Paleocene

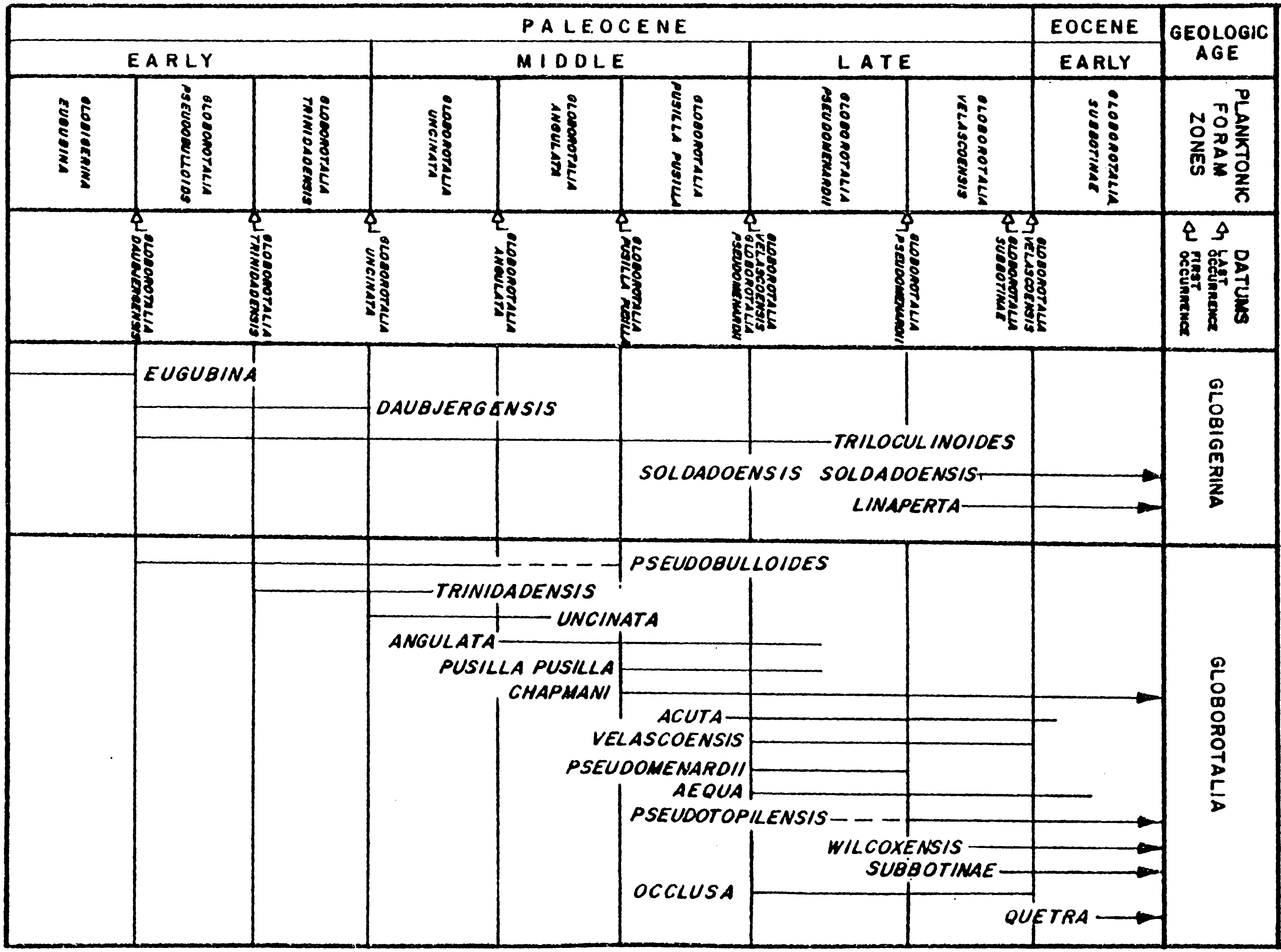


TABLE 2 Planktonic foraminiferal zonation for the Paleocene and earliest Eocene showing datums and ranges for selected species. From Stainforth et al.(1975)

Globigerina eugubina Zone

Category: Range Zone. Age: Early Paleocene.

Author: Luterbacher and Premoli Silva (1964)

Definition: Total range of *Globigerina eugubina*.

Globorotalia pseudobulloides Zone

Category: Interval Zone. Age: Early Paleocene.

Author: Leonov and Alimarina (1961) as *Globigerina pseudobulloides* - *Globigerina daubjergensis* Zone. Name shortened by Bolli (1966a,b)

Definition: Interval from the first occurrence of *Globorotalia pseudobulloides* to first appearance of *Globorotalia trinidadensis*.

Globorotalia trinidadensis Zone

Category: Interval Zone Age: Early Paleocene

Author: Bolli (1957a)

Definition: Interval from the first occurrence of *Globorotalia trinidadensis* to the first occurrence of *Globorotalia uncinata*.

Globorotalia uncinata Zone

Category: Interval Zone. Age: Middle Paleocene.

Author: Bolli (1957a); modified Bolli (1966a)

Definition: Interval from the first occurrence of *Globorotalia uncinata* to the first occurrence of *Globorotalia angulata*.

Globorotalia *angulata* Zone

Category: Interval Zone. Age: Middle Paleocene.

Author: Alimarina (1963) as *Acarinina* *angulata* Zone.

Present name introduced by Hillebrandt (1965)

Definition: Interval from first appearance of *Globorotalia* *angulata* to first occurrence of *Globorotalia* *pusilla* *pusilla*.

Globorotalia *pusilla* *pusilla* Zone.

Category: Interval Zone. Age: Middle Paleocene.

Author: Bolli (1957a)

Definition: Interval from first occurrence of *Globorotalia* *pusilla* *pusilla* to first occurrence of *Globorotalia* *pseudomenardii*.

Globorotalia *pseudomenardii* Zone

Category: Range Zone. Age: Late Paleocene.

Author: Bolli (1957a)

Definition: Total range of *Globorotalia* *pseudomenardii*.

Characteristics: This zone typically has *Globorotalia* *pusilla* *laevigata*, *Globorotalia* *acuta*, *Globorotalia* *occusa*, *Globorotalia* *aequa* and other species persisting from lower zones.

Globorotalia *velascoensis* Zone

Category: Interval Zone. Age: Late Paleocene

Author: Bolli (1957a)

Definition: Interval from the last occurrence of Globorotalia pseudomenardii to the last occurrence of Globorotalia velascoensis.

Eocene

Globorotalia subbotinae Zone

Category: Interval Zone. Age: Early Eocene.

Author: Bolli (1957a) (see Stainforth et al., 1975 for complete details).

Definition: Interval from last occurrence of Globorotalia velascoensis to first occurrence Globorotalia aragonensis.

Characteristics: This zone typically contains Globorotalia subbotinae, Globorotalia marginodentata, Globorotalia formosa gracilis, Globorotalia wilcoxensis, and others. Globorotalia aequa often appears in the lower part of the zone.

BIOSTRATIGRAPHY OF THE AQUIA FORMATION

Locality 1

The occurrence of Gg. triloculinoides and Gr. aequa in samples 12 and 13 of this locality places this section in the lower part of the Late Paleocene Gr. pseudomenardii Zone (Bolli 1957) according to the Tertiary zonation of Stainforth el al. (1975) (See range chart and table 2).

Samples 3 through 9 of locality 1 lack the diagnostic planktonic foraminifera of any one zone. The lack of planktonic foraminifera in those samples may be due to the nearshore shallow water environment of deposition of the lower part of that section which has a boulder conglomerate at its base. The occurrence in the Aquia at locality 1 of Gr. perclara from sample 4 to sample 13 indicates a Paleocene age for this part of the section (Loeblich and Tappan 1957b), and Gg. triloculinoides in sample 8 indicates that the Aquia section from sample 8 up to sample 10 could be in the Gr. pseudobulloides Zone (Early Paleocene) to the Gr. pseudomenardii Zone (Late Paleocene). Gr. acuta and Gg. triloculinoides in sample 10 and Gr. acuta in sample 11 place these samples in the Gr. pusilla pusilla Zone to the Gr. pseudomenardii Zone (table 2).

Witmer (1975) indicated that the first 6 feet of Aquia at locality 1 (samples 3 through 8 of this study) may be as old as Clark and Martins' (1901) lithologic "zone" 2 of the Aquia Formation at Friendly, Maryland. He based this correlation on the last occurrence of Fibradinium anetorpense in these two sections (see McLean, 1969).

Samples 1 and 2 of locality 1, occur below the boulder conglomerate and are composed of light green dense clay which is barren of fossils. Weems (1975) considered this underlying unit to be the Cretaceous Patuxent Formation on the basis of local stratigraphy and lithology. Witmer (1975) found it barren of palynomorphs and accepted Weems (1974) age assignment. Teifke's (1973) description of the Patuxent Formation would seem to include this unit (see table 1). Since Reinhardt, Newell, Mixon (1980), Weems (1974), and Teifke (1973) indicate an Early Cretaceous age for the Patuxent Formation, a considerable hiatus exists between sample 2 (Patuxent Formation) and sample 3 (Aquia Formation) at

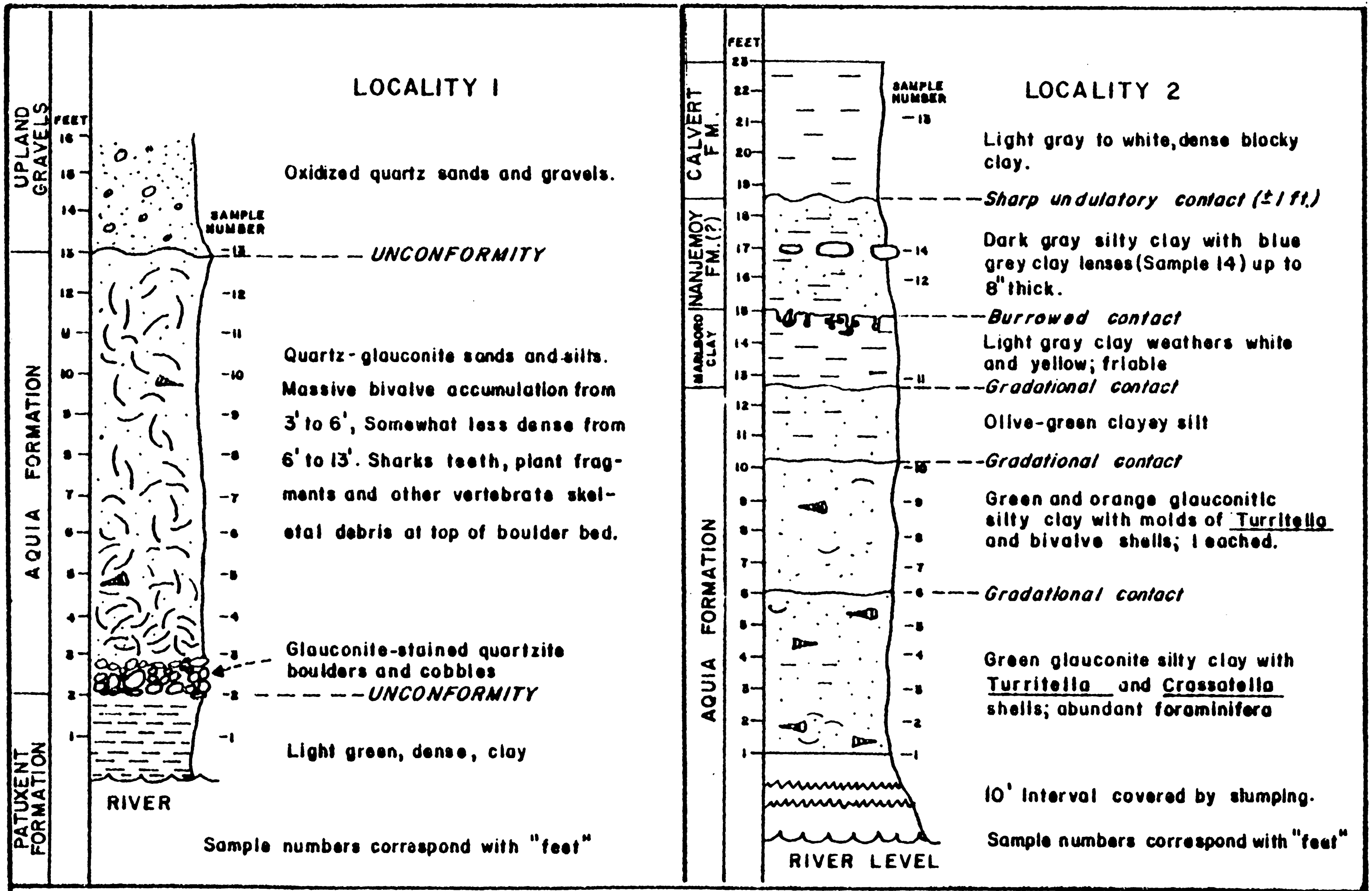


FIGURE 2. Locality I and 2 on the banks of the Pamunkey River near Hanover, Virginia.

locality 1. That is, in addition to the Arundel and Patapsco formations of the Lower Cretaceous, all of the Upper Cretaceous Raritan, Magothy, Matawan, and Monmouth formations and the Paleocene Brightseat Formation are missing. These units crop out in Maryland and Delaware, near the deepest part of the Salisbury Embayment. Also, if the Gr. pseudomenardii Zone is the oldest Paleocene zone in the Hanover area, then all of the Early and Middle Paleocene foraminiferal zones are also missing (see table 2).

Locality 2

Samples 1 through 6 of this locality are fossiliferous and appear to be in a continuous sequence without lithologic breaks. Samples 2 and 5 contain Globorotalia aequa and Globigerina triloculinoides indicating that this interval is in the Globorotalia pseudomenardii Zone (Bolli, 1957), (see table 2 and figure 4). Since sample 6 contains Gr. aequa and Gr. acuta it could be placed from the Globorotalia pseudomenardii Zone to the Early Eocene Globorotalia subbotinae Zone (Bolli 1957). However since this sample occurs 9 feet below the Marlboro Clay - Nanjemoy Formation contact, which crosses the Paleocene - Eocene boundary (Gibson et al. 1980), its age must be within the Globorotalia pseudomenardii Zone to the Late Paleocene Globorotalia velascoensis Zone (Bolli 1957). Sample 1 contains Gg. triloculinoides, only, which ranges from the Early Paleocene Globorotalia pseudobulloides Zone (Leonov and Alimarina, 1961) to the Late Paleocene Globorotalia pseudomenardii Zone. However, since this sample is bounded above (sample 2, locality 2) and below (sample 13, locality 1) by strata in the _Globorotalia_ _pseudomenardii_ Zone, it must also be included in that zone.

Samples 7 through 10 appear to be the same lithology as samples 1 through 6 except that they are leached. This fact coupled with the gradational nature of the contact between samples 6 and 7 seems to indicate that samples 7 through 10 are within the Aquia Formation and conformable with the interval of samples 1 through 6.

Directly above sample 10 to the 18.5-foot level (figure 3), olive green clayey silts grade into a light grey clay which has a burrowed top. Infilling the burrows are dark gray silty clays of the overlying formation. Using the lithologic descriptions of the Coastal Plain strata (table 1) it seems that the section in the 10-to 12.7-foot interval is the uppermost Aquia Formation which grades into the Marlboro Clay (12.7 to 15 feet), and the section from 15 to 18.5 feet is the Eocene Nanjemoy Formation. From 18.5 to 23 feet is a light gray to white, blocky, clay identified on the basis of lithology and regional stratigraphy to be part of the Miocene Calvert Formation.

Locality 3

At this locality samples 1, 7 and 8 contained Foraminifera and form a continuous sequence of strata. Sample 1 contains _Gr._ _aequa_ and _Gr._ _triloculinoides_ placing it in the _Globorotalia_ _pseudomenardii_ Zone. Samples 7 and 8 contained _Gr._ _aequa_ only, which ranges from the _Gr._ _pseudomenardii_ Zone to the Early Eocene _Gr._ _subbotinae_ Zone. Because of the lithologic continuity between samples 1 and 8, it is believed that these samples are from the Aquia Formation.

Samples 9 through 15 appear to be from the Nanjemoy Formation because of the lithology and stratigraphic position of that interval (figure 3 and 5). If this is correct,then the Marlboro Clay is absent at this locality. The concretion layer below sample 8 (figure 3) may be a remnant of the burrows that are usually associated with upper most Aquia and Marlboro Clay.

Samples 16 through 19 are composed of an iron-stained gray-green silt and fine sand with bivalve molds scattered through the section. Although no fossils were recovered from these samples,the lithology and stratigraphic position of this unit indicate that it belongs to the Miocene Calvert Formation.

Locality 4

At this locality the occurrence of Gr. subbotinae and Gr. occlusa from sample 3 to sample 9 places this section in the Late Paleocene Gr. velascoensis Zone (Bolli, 1957) of Stainforth et al. (1975), (figure 4). Also recovered from this interval are Gr. aequa, Gr. acuta, Gr. chapmani, Gr. wilcoxensis, Gr. pseudotopilensis, Gg. primitiva, Gg. soldadoensis soldadoensis and Gg. linaperta. The range of each of these planktonic Foraminifera extends into the Gr. velascoensis Zone (table 2 and Stainforth et al. 1975).

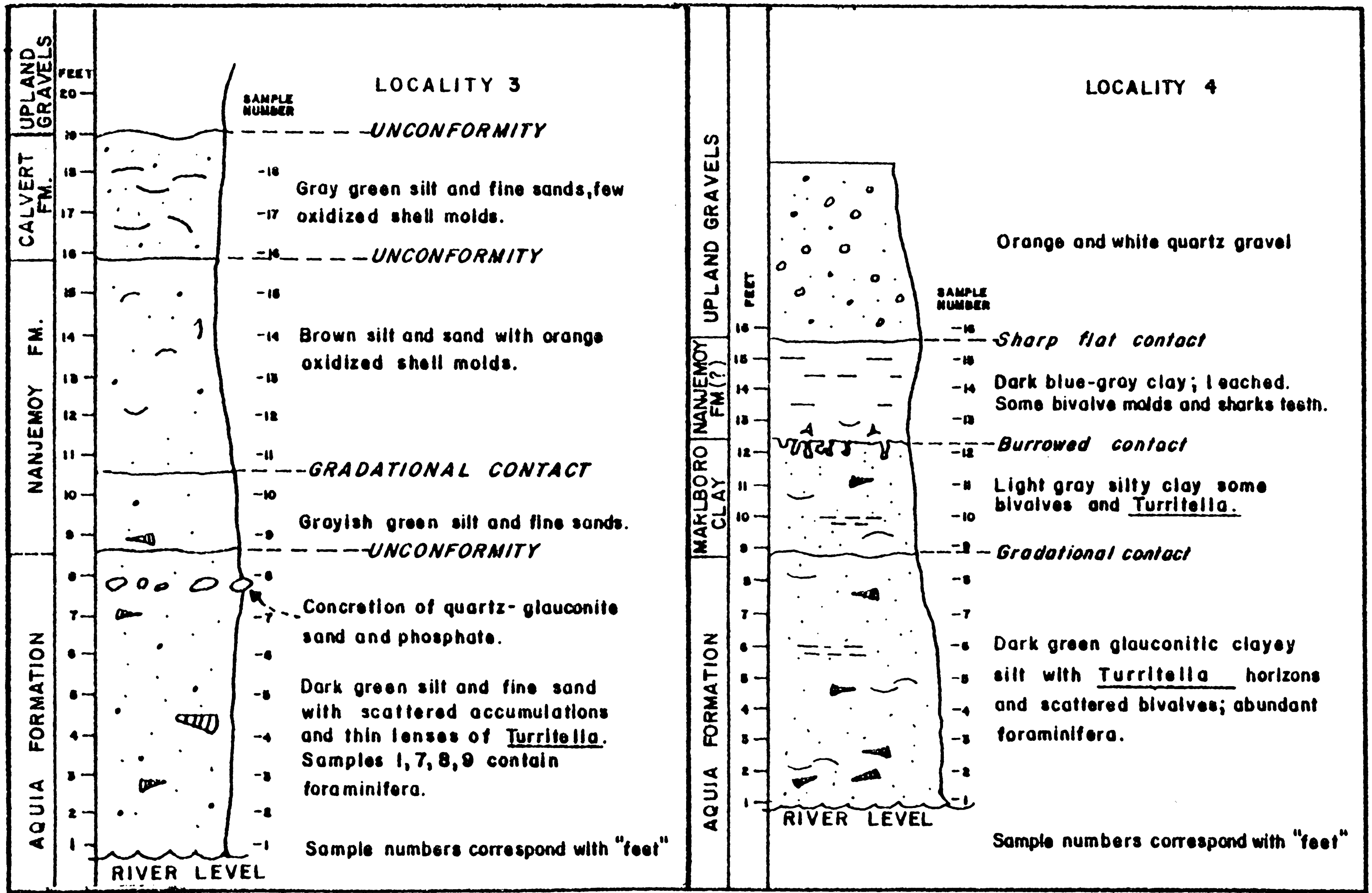


FIGURE 3. Localities 3 and 4 on the banks of the Pamunkey River near Hanover, Virginia.

Sample 10 contains Gg. linaperta, Gr. chapmani, and Gr. wilcoxensis placing it in the Late Paleocene Gr. velascoensis Zone to the Early Eocene Gr. subbotinae Zone (Bolli, 1957) (see table 2).

Samples and 2 did not contain diagnostic planktonic Foraminifera.

From this data and the lithologic description of the outcrop, samples 1 through 8 are in the Aquia Formation and samples 9 through 12 in the Marlboro Clay. Sample 13 to sample 15 occur in a blue-gray clay which infills the burrowed top of the Marlboro Clay. This unit appears to be the Eocene Nanjemoy Formation on the basis of lithology and regional stratigraphy.

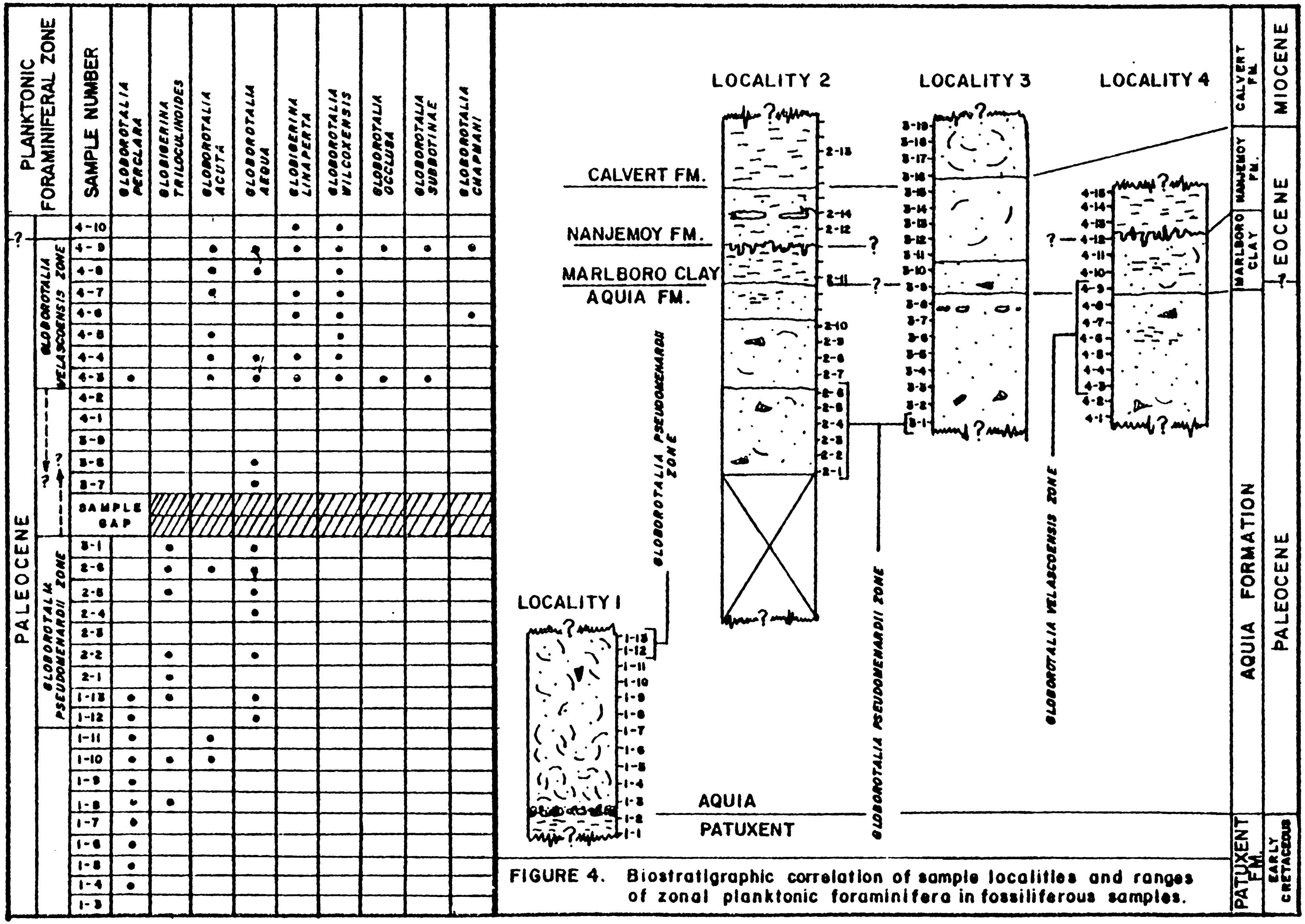


FIGURE 4. Biostratigraphic correlation of sample localities and ranges of zonal planktonic foraminifera in fossiliferous samples.

PALEOECOLOGY OF BENTHONIC FAUNA

Two assemblages of benthic Foraminifera are seen in the study area. The first assemblage, seen at locality 1, consists mainly of Anomalinoides midwayensis, Cibicides praecursorius, Globulina gibba, and Sigmomorphina terquemiana. This assemblage shows a very high dominance by A. midwayensis, high morphologic variability within that species, low species diversity (1 to 5 species account for 95 percent of the total number of individuals), large populations of dominant species, and a low percentage of planktonic Foraminifera. Planktonic Foraminifera account for 0.2 to 7 percent of the total number of individuals in samples with 400 or more Foraminifera (figure 6).

Youseffnia (1978) described the foraminiferal communities of the Aquia Formation from Bull Bluff, Virginia and Cabin Branch, Maryland, which are very similar to the A. midwayensis assemblage at locality 1 of this study. He noted that the foraminiferal communities were dominated by 1 to 7 species (usually 4) including Anomalinoides umboniferus (A. midwayensis and Cibicides praecursorious of this study), Globulina gibba, Alabamina midwayensis, Cibicides mortoni, Pararotalia perclara, Globoratalia perclara of this study), Nonion mauricense, and Spiroplectammina wilcoxensis. High morphologic variability, low species diversity, large populations and low percentage of planktonic Foraminifera also characterized the foraminiferal communities in his study.

Youseffnia (1978) concluded that the Aquia was deposited in a nearshore, shallow water, unstable environment. His interpretation is based on Margalef's (1968) model of communities in unstable environments. Youseffnia also contrasted the Aquia faunas with foraminiferal communities of the middle continental shelf, typified by high species diversity and small populations. These factors indicate more stable normal marine conditions.

The foraminiferal assemblage of locality 1 occurs in a densely packed shell bed dominated by Cucullea, Pitar, Venericardia, Cubitostrea Dosinopsis, and Crassatella. The bivalve shells are generally unbroken, unweathered, articulated, and randomly oriented. At the base of the Aquia is a 1-foot thick bed composed of subangular boulders and cobbles up to 1 foot in diameter. Numerous shark teeth, ray dental plates, and wood fragments occur directly on top of the boulder bed (figure 2). This data also seems to support a shallow water unstable environment for this area. The boulder bed indicates a high energy environment as the Aquia seas transgressed the area, and the wood fragments indicate a nearby terrestrial area. Andrews (1971) study of the macrofossils of the Aquia Formation at Aquia Creek, Virginia,lends support to the unstable environment interpretation for locality 1. He concluded that the massive bivalve beds at the Aquia Formation type locality are the result of deposition by intense storms in a shallow subtidal setting. However, in the Pamunkey River exposure at locality 1 the randomly oriented, unbroken, articulated valves, with little sign of abrasion, some with outer priostracum preserved, suggest rapid burial. Andrews also postulates that the lack of crossbeds, the thickness of the deposit, and the unweathered nature of the valves indicate a subtidal environment.

The second foraminiferal assemblage, seen at localities 2, 3 and 4 is characterized by *Lenticulina midwayensis*, *Cibicides praecursorius*, *Spiroplectammina wilcoxensis*, *Alabamina wilcoxensis*, and *Dentalina colei*. This assemblage is very similar to the first except that it shows a slight increase in species diversity in both benthonic and planktonic Foraminifera and slightly lower dominance. These factors indicate a somewhat deeper water environment of deposition than for locality 1 (Phleger, 1960, Walton, 1964, Buzas and Gibson, 1969). The second assemblage is found in a quartz-glauconite, clayey silt with small amounts of fine sand. Numerous lenses of *Turritella* shells up to 3 inches thick, spaced vertically 6 inches to 2 feet apart, occur with this assemblage. Other macrofossils such as *Crassatella* appear only rarely.

Andrews (1971) described a similar paleoenvironment for the Aquia Formation at Aquia Creek, Virginia, where 1-to 3-inch lenses of *Turritella* shells dominate certain sections of the outcrop. Using modern communities of *Turritella* and comparing them to the Aquia macrofauna, he concluded that the *Turritella* associated layers were deposited in a deeper water setting than the bivalve community described for locality 1. Andrews pointed out that modern species of *Turritella* are generally infaunal, gregarious, and live in great numbers in offshore sublittoral waters with few other shelled organisms present. Dense layers of *Turritella* shells will accumulate on the ocean floor as these communities develop. This generally prohibits burrowing organisms from existing with *Turritella* and explains their general absence (Andrews 1971).

This data coupled with the generally finer grained sediments in the last three outcrops indicate a somewhat lower energy, more stable environment than in locality 1.

INTERPRETATION OF CROSS-SECTION

Examination of the cross-section (figure 5) reveals some structural and stratigraphic anomalies which imply faulting in the study area. The most obvious structural feature is the 15.5-foot offset of the burrowed top of the Marlboro Clay and associated Tertiary Strata from locality 2 eastward to additional outcrop "D". Accompanying this offset is the break in the easterly dip of the Patuxent - Aquia contact. This horizon dips at a rate of 14.6 feet per mile between additional outcrop "C" and locality 1, and 23 feet per mile between locality 1 well W-1613. Also noteworthy is the nearly 90° bend in the Pamunkey River in the vicinity of locality 2. The river returns temporarily to an easterly direction approximately 4,500 feet north of locality 2 (see index map on figure 5). From additional outcrop "D", east, to well W-1613, locality 3, and locality 4, the tops of the Aquia, Marlboro Clay, Nanjemoy Formation and the base of the Calvert Formation, remain on a nearly horizontal plane when encountered.

From locality 4 to well W-2158 the tops of the Aquia and Patuxent may again be anomalously offset. The Aquia - Patuxent contact dips at 26.4 feet per mile between well W-1613 and well W-2158, and the top of the Aquia drops 25 feet from locality 4 to well W-2158. Also noteworthy is the increase in thickness of the Aquia, Nanjemoy and Calvert formations between these wells. However, it should be noted that the data from well W-1613 and well W-2158 are based on well cuttings sampled at 10-foot intervals. This fact and other potential inaccuracies in sample collection decrease the level of confidence for this data. Even with these possible errors it is remarkable that the tops from well

W-1613 are in good accord with outcrop data. Well W-2158 needs more control before final conclusions are made on faulting east of locality 4.

Mixon and Newell (1978) describe several northeast-southwest striking high angle reverse faults in the Coastal Plain near Fredericksburg, Virginia. These faults were located by studying anomalies in topography and changes in stratigraphy. Passing from the northwest (upthrown) to the southeast (downthrown) side of a fault was characterized by changes in surface elevation, course changes of streams, offsetting of strata, and addition of Tertiary formations between the Cretaceous and overlying units on downthrown blocks.

Although no fault planes or scarps were seen in the study area, the anomalies mentioned above and the documented faulting in Coastal Plain sediments less than 50 miles north strongly suggest that the Hanover area is faulted.

SYSTEMATIC PALEONTOLOGY

The Foraminifera recovered in this investigation were identified and classified using the revised classification of Loeblich and Tappan (1964, 1974). The fauna was illustrated by Nogan (1964) so only selected planktonic and benthonic species are illustrated. Brief diagnoses of the common and significant Virginia species are given below.

A total of 45 genera and 79 species of Foraminifera were described of which 2 genera and 20 species were planktonic Foraminifera. The total number of specimens examined was 12,577. Chilostomella ovoidea, Bulimina cacumenata, Globorotalia esnaensis, Globigerina linaperta, Globorotalia subbotinae, Globorotalia pseudotopilensis, Globigerina primitiva and Globigerina soldadoensis soldadoensis have never been previously reported in the Aquia.

Several of the Foraminifera used for the illustrations were lost in the handling process after they were photographed. Lost specimens are noted in the "Remarks" after each synonomy.

Phylum PROTOZOA

Class SARCODINA

Order FORAMINIFERIDA

Family SACCAMMINIDAE

Genus *Lagenammina* Rhumbler, 1911

Lagenammina pseudodifflugiformis Nogan

Lagenammina pseudodifflugiformis Nogan, 1964, p. 19, pl. 1, fig. 1.

Remarks: Diagnostic features include an elongate test tapering toward the aperture with a coarsely arenaceous wall composed of white translucent grains of quartz and mica. This species is highly variable in appearance and is difficult to distinguish in sandy samples.

Genus *Saccammina* M. Sars in Carpenter, 1869

Saccammina sp.

Plate 1, figure 7

Saccammina sphaerica Cushman (*non* M. Sars), 1944c, p. 18, pl. 3, fig. 20.

Remarks: This species is characterized by its small, single, spherical chamber; outer finely agglutinated layer and smooth inner wall.

Family AMMODISCIDAE

Genus *Ammodiscus* Reuss, 1862

Ammodiscus incertus (d'Orbigny)

Plate 1, figure 8

Operculina incerta d'Orbigny, 1839, p. 49, pl. 6, figs. 16, 17.

Ammodiscus incertus (d'Orbigny). Plummer, 1926, p. 63, pl. 13, fig. 1; Shifflett, 1948, p. 44, pl. 1, fig. 4.

Ammodiscus cf. *A. incertus* (d'Orbigny). Nogan 1964, p. 20.

Remarks: This species has a small, thin, planispiral, evolute test with a finely textured arenaceous wall.

Family LITUOLIDAE

Genus *Haplophragmoides* Cushman 1910

Haplophragmoides aquiensis Nogan 1964

Plate 1, figure 1

Haplophragmoides aquiensis Nogan, 1964, p. 20, pl. 1, figs. 2, 3.

Remarks: This form has a small, planispiral, closely coiled, arenaceous test with inflated chambers. The sutures are radiate and depressed and the aperture is a simple opening at the base of the last chamber (specimen lost).

Genus *Ammobaculites* Cushman, 1910

Ammobaculites sp.

Ammobaculites sp. Cushman, 1944c, p. 19, pl. 3, fig. 25; Nogan, 1964, p. 21.

Family TEXTULARIIDAE

Genus *Spiroplectammina* Cushman, 1927

Spiroplectammina wilcoxensis Cushman and Ponton

Plate 1, figure 5

Spiroplectammina wilcoxensis Cushman and Ponton, 1932, p. 51, pl. 7, fig. 1; Nogan, 1964, p. 21, pl. 1, fig. 4 (*see* this reference for furthur synonomy).

Remarks: Diagnostic features include a broad, triangular, biseral, arenaceous test with many small interlocking chambers and a slit-like aperture at the base of the last chamber.

Family TROCHAMMINIDAE

Genus *Trochammina* Parker and Jones, 1859

Trochammina howei Cushman

Trochammina howei Cushman, 1944c, p. 20, pl. 3, fig. 28; Nogan, 1964. p. 22, pl. 1, figs. 9, 10.

Family ATAXOPHRAGMIIDAE

Gaudryina d'Orbigny, 1839

Gaudryina sp.

Remarks: A single specimen of this form was found in sample 9, locality 1. Cushman (1944c) and Shifflett (1948) also found rare specimens of *Gaudryina* sp. in the Aquia Formation at the type locality at Aquia Creek, Virginia and at Friendly, Maryland, respectively.

Family NODOSARIIDAE

Genus *Dentalina* d'Orbigny, 1826

Dentalina cocoaensis Cushman

Nodosaria cocoaensis Cushman, 1925, p. 66, pl. 10, figs. 5, 6.

Remarks: Characteristic features are the narrow uniserial test with elongated slightly inflated chambers. Only broken specimens were recovered.

Dentalina colei Cushman and Dusenbury

Plate 8, figure 3

Dentalina colei Cushman and Dusenbury, 1934, p. 54, pl. 7, figs. 10-12; Nogan, 1964, p. 24, pl. 1, fig. 18 (*see* this reference for further synonmy).

Dentalina virginiana Cushman

Dentalina virginiana Cushman, 1944c, p. 22, pl. 4, figs. 8, 9; Nogan, 1964, p. 24, pl. 1, fig. 20.

Dentalina wilcoxensis Cushman

Dentalina wilcoxensis Cushman, 1944a, p. 8, pl. 1, figs. 5, 6; Nogan, 1964, p. 25, pl. 1, fig. 21.

Genus Nodosaria Lamarck 1812

Nodosaria latejugata carolinensis Cushman

Nodosaria latejugata var. carolinensis Cushman, 1933a, p. 5, pl. 1, fig. 16; Nogan, 1964, p. 25, pl. 1, fig. 22 (see this reference for further synonomy).

Remarks: This species is characterized by its large straight test, inflated chambers, and raised longitudinal costae. Only broken specimens were recovered.

Genus Lagena Walker and Jacob 1798

Lagena adepta Jennings

Plate 1, figure 2

Lagena adepta Jennings, 1936, p. 24, pl. 3, fig. 2; Nogan, 1964, p. 26. pl. 1. fig. 25.

Lagena distincta Olsson

Lagena distincta Olsson, 1960, p. 24, pl. 3, fig. 24; Nogan, 1964, p. 26, pl. 1, fig. 26.

Lagena pseudocostata Olsson

Plate 1, figure 3

Lagena pseudocostata Olsson, 1960, p. 24, pl. 3, fig. 27; Nogan, 1964, p. 26, pl. 1, fig. 27 (see this reference for further synonomy).

Remarks: Diagnostic features are a small, spherical test with numerous longitudinal costae and a long thin neck.

Lagena rancocasensis Olsson

Plate 1, figure 6

Lagena rancocasensis Olsson, 1960, p. 24, pl. 3, fig. 20, Nogan, 1964, p. 26, pl. 1, fig. 28.

Remarks: This species has an ovate test with a short dorsal neck which is encircled below its terminus by a flange. The wall is smooth and thick, the aperture is simple and located at the end of the neck. (Specimen lost).

Genus Pseudonodosaria Boomgaart, 1949

Pseudonodosaria tenuistriata (Franke)

Plate 1, figure 4

Glandulina tenuistriata Franke, 1927, p. 18, pl. 1, fig. 25a.

Rectoglandulina tenuistriata (Franke). Nogan, 1964, p. 25, pl. 1, fig. 23 (see this reference for further synonomy).

Remarks: Diagnostic features are the short stout test with tapering ends, numerous longitudinal costae that run two-thirds the length of the test, and a dorsal aperture.

Pseudonodosaria aquiensis (Nogan)

Rectoglandulina aquiensis Nogan, 1964, p. 25, pl. 1, fig. 24.

Remarks: This species is characterized by its short stout test, tapering ends, and latitudinal sutures on the lower third of the test.

Family VAGINULINIDAE

Genus Marginulina d'Orbigny, 1826

Marginulina toulmini Cushman

Plate 9, figures 4, 5

Marginulina toulmini Cushman, 1944d, p. 34, pl. 5, fig. 16; Nogan, 1964, p. 23 (see this reference for further synonomy).

Remarks: Characteristics include the compressed, vaginulinaform test with raised beaded sutures.

Genus Lenticulina Lamarck, 1804

Lenticulina midwayensis (Plummer)

Plate 9, figures 1-3, 6-8

Cristellaria midwayensis Plummer, 1926, p. 95, pl. 13, fig. 5.

Robulus midwayensis (Plummer) Nogan, 1964, p. 22, pl. 1, figs. 13-16 (see this reference for further synonomy).

Robulus indistinctus McLean, 1953, p. 5, pl. 1, fig. 13; Nogan, 1964, p. 22, pl. 1, figs. 11, 12.

Remarks: The range in variation of this species includes forms referrable to Lenticulina (Robulus) midwayensus and L. indistinctus as described by Nogan (1964). Transitional forms show considerable variation in test size, thickness of keel, degree of raised or depressed sutures and total number of sutures. It is very difficult to separate these intermediates into either of the two species.

Family POLYMORPHINIDAE

Genus *Polymorphina* d'Orbigny, 1826

Polymorphina subrhombica Reuss

Polymorphina subrhombica Reuss, 1862, p. 339, pl. 7, fig. 3; Nogan, 1964, p. 27, pl. 2, fig. 1 (*see* this reference for further synonomy).

Genus *Sigmomorphina* Cushman and Ozawa, 1928

Sigmomorphina terquemiana (Cushman)

Plate 8, figures 2, 5

Sigmomorphina semitecta (Reuss) var. *terquemiana* (Fornasini) Cushman and Ozawa, 1930, p. 129, pl. 33, figs. 4, 5; pl. 34, figs. 2, 3; pl. 35, fig. 1; Cushman, 1951, p. 34, pl. 10, figs. 2, 3 (*see* this reference for further synonomy); Nogan, 1964, p. 27.

Remarks: This species is characterized by its elongate, compressed, lanceolate test with 2 to 3 elongate chambers visible and an acute apertural end. Size, degree of elongation, and shape of apertural end varies considerably. Cushman and Ozawa (1930) noted that some small specimens of *S. terquemiana* resemble a compressed *Globulina*. The same similarity exists in this fauna causing difficulty in separating some specimens of *Globulina gibba* and *S. terquemiana*. Nogan

(1964) reported *S. semitecta* and *S. semitecta* var. *terquemiana* at Aquia Creek, Virginia, considering the latter to be a variant of the former. No specimens resembling *S. semitecta* were found in this study; hence the elevation of *S. semitecta* var. *terquemiana* to the species level, *S. terquemiana*.

Genus *Guttulina* d'Orbigny, 1826

Guttulina irregularis (d'Orbigny)

Globulina irregularis d'Orbigny, 1846, p. 226, pl. 13, figs. 9, 10.

Guttulina irregularis (d'Orbigny). Nogan, 1964, p. 28 (*see* this reference for further synonomy).

Guttulina problema d'Orbigny

Plate 2, figures 1, 2

Guttulina problema d'Orbigny, 1826, p. 266, no. 14; Nogan, 1964, p. 28 (*non* Nogan, 1964, pl. 2, fig. 3 = *G. problema*; *see* this reference for further synonomy).

Genus *Globulina* d'Orbigny, 1839

Globulina gibba d'Orbigny

Plate 8, figures 8, 9

Polymorphina (*Globulina*) *gibba* d'Orbigny, 1826, p. 266

Globulina gibba (d'Orbigny). Nogan, 1964, p. 29 (*see* this reference for further synonomy).

Remarks: This common species is characterized by an ovate, somewhat compressed test with a broadly rounded base tapering toward the aperture. Chambers are few and strongly overlapping, the sutures are usually flush with the test surface, and the wall is smooth. This species varies widely in test size, amount of compression, and degree of chamber inflation.

Family GLANDULINIDAE

Genus *Oolina* d'Orbigny, 1839

Oolina virginiana Nogan

Oolina virginiana Nogan, 1964, p. 27, pl. 1, fig. 29.

Family CERATOBULIMINIDAE

Genus *Ceratobulimina* Toula, 1915

Ceratobulimina perplexa (Plummer)

Rotalia perplexa Plummer, 1926, p. 156, pl. 12, fig. 2.

Ceratobulimina perplexa (Plummer). Nogan, 1964, p. 36, pl. 3, figs. 12, 13 (*see* this reference for further synonomy).

Genus *Lamarckina* Berthelin, 1881

Lamarckina marylandica Cushman

Lamarckina marylandica Cushman, 1926, p. 8, pl. 1, fig. 5; Nogan, 1964, p. 37, pl. 3, figs. 14, 15.

Family EPISTOMINIDAE

Genus *Epistominella* Husezima and Maruhasi, 1944

Epistominella minuta (Olsson)

Plate 4, figures 4-6

Pseudoparrella minuta Olsson, 1960, p. 40, pl. 6, figs. 7-9.

Epistominella minuta (Olsson), Nogan, 1964, p. 36, pl. 3, figs. 7, 8.

Remarks: Diagnostic features include the small concavo-convex test, slightly depressed umbilical area, and sutures flush with the test surface to slightly depressed.

Family ROBERTINIDAE

Genus *Robertina* d'Orbigny, 1846

Robertina wilcoxensis Cushman and Ponton

Robertina wilcoxensis Cushman and Ponton, 1932, p. 66, pl. 8, fig. 19; Nogan, 1964, p. 37 (*see* this reference for further synonomy).

Family TURRILINIDAE

Genus *Turrilina* Andreae, 1884

Turrilina robertsi (Howe and Ellis)

Bulimina robertsi Howe and Ellis, *in* Howe, 1939, p. 63, pl. 8, figs. 32, 33.

Turrilina robertsi (Howe and Ellis). Nogan, 1964, p. 31, pl. 2, fig. 15 (*see* this reference for further synonomy).

Genus *Buliminella* Cushman, 1911

Buliminella marylandica Nogan

Buliminella marylandica Nogan, 1964, p. 31, pl. 2, fig. 18

Family BULIMINIDAE

Genus Bulimina d'Orbigny, 1826

Bulimina cacumenata Cushman and Parker

Plate 2, figure 4

Bulimina cacumenata Cushman and Parker, 1936, p. 40, pl. 7, figs. 3a, b.

Remarks: This species is characterized by its small triserial test which tapers towards the initial end. The chambers are numerous and become slightly inflated near the aperture. The sutures are obscured at the initial end becoming distinct in the last two whorls. The wall is coarsely perforate and covered with irregular, low, closely spaced, longitudinal costae with the last whorl being smooth. The aperture is a looped shaped opening in the last chamber.

Bulimina ovata d'Orbigny

Plate 2, figure 9

Bulimina ovata d'Orbigny, 1846, p. 185, pl. 11, figs. 13, 14; Nogan, 1964, p. 32, pl. 2, fig. 19 (see this reference for further synonomy).

Remarks: Characteristics features include the elongate test with rounded initial and apertural ends, slightly inflated chambers and a curved aperture.

Bulimina virginiana (Cushman)

Plate 9, figure 9

Angulogerina virginiana Cushman, 1944c, p. 25, pl. 4, fig. 23; Shifflett, 1948, p. 64, pl. 3, fig. 17.

Bulimina virginiana (Cushman), Nogan, 1964, p. 32, pl. 2, fig. 20.

Remarks: Characteristics of this form are its minute, elongate, somewhat triangular test which is triserial at its initial end becoming uniserial in the final 3 to 4 chambers. Chambers are indistinct in the early portion of the test, becoming separated and inflated near the apertural end. Sutures are indistinct initially becoming depressed and defined between last 4 to 5 chambers. The wall is coarsely perforate and ornamented with low, closely spaced, longitudinal costae. The aperture is a small arch on the last chamber.

Family UNIGERINIDAE

Genus *Pseudouvigerina* Cushman, 1927

Pseudouvigerina triangularis Jennings

Pseudouvigerina triangularis Jennings, 1936, p. 29, pl. 3, fig. 6; Nogan, 1964, p. 31, pl. 2, fig. 14 (*see* this reference for further synonomy).

Genus *Trifarina* Cushman, 1923

Trifarina wilcoxensis (Cushman and Ponton)

Pseudouvigerina wilcoxensis Cushman and Ponton, 1932, p. 66, pl. 8, fig. 18.

Angulogerina wilcoxensis (Cushman and Ponton). Nogan, 1964, p. 34, pl. 2, fig. 30 (*see* this reference for further synonomy).

Family DISCORBIDAE

Genus *Neoconorbina* Hofker, 1951

Neoconorbina humilis (Le Calvez)

Discorbis humilis Le Calvez, 1949, p. 24, pl. 3, figs. 48-50.

Neoconorbina humilis (Le Calvez). Nogan, 1964, p. 34, pl. 2, figs. 32, 33.

Family EPONIDIDAE

Genus Eponides Montfort, 1808

Eponides lotus (Schwager)

Plate 3, figures 7-9

Pulvinulina lota Schwager, 1883, p. 132, pl. 28, fig. 9.

Eponides lotus (Schwager). Cushman and Ponton, 1932, p. 71, pl. 9, fig. 8; Nogan, 1964, p. 35, pl. 3, figs. 1, 2 (see this reference for further synonomy).

Remarks: Diagnostic features include the strongly bi-convex test, umbilical depression, radial sutures, and the interiomarginal umbilical-extraumbilical aperture.

Family CIBICIDIDAE

Genus Cibicides Montfort, 1808

Cibicides howelli Toulmin

Plate 10, figures 1-3

Cibicides howelli Toulmin, 1941, p. 609, pl. 82, figs. 16-18; Nogan, 1964, p. 46, pl. 7, figs. 7-9 (see this reference for further synonomy).

Remarks: This species is characterized by its strongly plano-convex test, coarsely perforated wall, sutures flush with test surface except for last three to four chambers and its aperture, which extends from the umbilical side across the periphery to the spiral side.

Cibicides irenae van Bellen

Plate 10, figures 7-9

Cibicides irenae van Bellen, 1946, p. 82, pl. 12, figs. 19-21; Nogan, 1964, p. 46, pl. 7, figs. 10-12 (see this reference for further synonomy).

Remarks: Diagnostic features are the large, flattened, plano-convex test with a finely perforate wall.

Cibicides marylandicus Shifflett

Cibicides marylandicus Shifflett, 1948, p. 74, pl. 5, figs. 4-6; Nogan, 1964, p. 46, pl. 7, figs. 13-15 (see this reference for further synonomy).

Cibicides neelyi Jennings

Cibicides neelyi Jennings, 1936, p. 39, pl. 5, fig. 4; Nogan, 1964, p. 47, pl. 7, figs. 16-18 (see this reference for further synonomy).

Cibicides praecursorius (Schwager)

Plate 11, fig. 1-3

Discorbina praecursoria Schwager, 1883, p. 125, pl. 29(6), fig. 16 a-c.

Anomalinoides umboniferus Nogan (non Schwager), 1964, p. 42, pl. 6, figs. 16-18; (non pl. 6, figs, 19-21, pl. 7, figs. 1-3 = Anomalinoides midwayensis). See this reference for further synonomy under Anomalina umbonifera.

Remarks: This species is typically characterized by its plano-convex test, finely perforate wall, sutures flush with test surface, and an interiomarginal umbilical-extraumbilical aperture. There is considerable morphologic variability in the specimens in this study; the test may vary from plano-convex to slightly biconvex, involute to partially evolute, chambers not inflated to moderately inflated, and sutures flush with test to slightly depressed.

Family CHILOGUEMBELINIDAE

Genus Chiloguembelina Loeblich and Tappan, 1956

Chiloguembelina crinita (Glaessner)

Plate 4, figure 9

Gumbelina crinita Glaessner, 1937, p. 383, pl. 4, fig. 34.

Chiloguembelina crinita (Glaessner). Nogan, 1964, p. 30, pl. 2, figs. 9, 10 (see this reference for further synonomy).

Family GLOBOROTALIIDAE

Genus Globorotalia Cushman, 1927

Globorotalia acuta Toulmin, 1941

Plate 6, figures 4-6

Globorotalia wilcoxensis Cushman and Ponton var. acuta Toulmin, 1941. p. 608, pl. 82, fig. 6-8.

Globorotalia acuta Toulmin. Loeblich and Tappan, 1957a, p. 185, pl. 47, fig. 5; pl. 55, fig. 4-5; pl. 58, fig. 5; Nogan, 1964, p. 39, pl. 4, figs. 13-15; Stainforth et al. 1975, p. 163, fig. 30. (see these last two references for further synonomy).

Remarks: Diagnostic features of this form are the umbilico-convex, planar to slightly elevated spiral sided test with angular chambers, sharp umbilical shoulders, keeled periphery, and spiny test surface. Forms found in this study resembled specimens from the Velasco Formation of Mexico illustrated by Stainforth et al. (1975, fig. 30, 1-5) having a more closed umbilicus and less ornamented umbilical shoulders than shown by Loeblich and Tappan (1957a, pl. 59, fig. 5) and Nogan (1964, p. 4, figs. 13-15).

Globorotalia aequa Cushman and Renz

Plate 6, figures 1-3

Globorotalia crassata (Cushman) var. aequa Cushman and Renz, 1942, p. 12, pl. 3, fig. 3.

Globorotalia aequa Cushman and Renz. Nogan, 1964, p. 39, pl. 4, figs. 16-18; Stainforth et al. 1975, p. 163, fig. 31 (see these two references for further synonomy).

Globorotalia apanthesma Loeblich and Tappan

Globorotalia apanthesma Loeblich and Tappan, 1957a, p. 187, pl. 48, fig. 1, pl. 55, fig. 1, pl. 58, fig. 4, pl. 59, fig. 1; Nogan, 1964, p. 39, pl. 5, figs. 4-6.

Globorotalia chapmani Parr

Plate 6, figures 7-9

Globorotalia pseudoscitula Glaessner var. *elongata* Glaessner, 1937, p. 3, text-figs. 3d-f.

Globorotalia elongata Glaessner. Bolli, 1957a, p. 77, pl. 20, figs. 11-13; Nogan, 1964, p. 40, pl. 5, figs. 13-15 (*see* this reference for further synonomy).

Globorotalia chapmani Parr, 1938, p. 87, pl. 9, fig. 8-9; Stainforth et al. 1975, p. 176, fig. 42 (*see* this reference for further synonomy).

Globorotalia esnaensis (LeRoy)

Plate 5, figures 7-9

Globigerina esnaensis LeRoy 1953, p. 31, pl. 6, figs. 8-10.

Globorotalia esnaensis (LeRoy) Loeblich and Tappan 1957b, p. 189, pl. 61, figures 1a-2c, 9a-c; Berggren 1960, pp. 92-93, pl. 5, fig. 3a-d; pl. 6, fig. 1a-c; pl. 10, fig. 3a-c (specimen lost).

Globorotalia hispidicidaris Loeblich and Tappan

Globorotalia hispidicidaris Loeblich and Tappan, 1957a, p. 190, pl. 58, fig. 1.

Globorotalia imitata Subbotina

Plate 7, figs. 7-9

Globorotalia imitata Subbotina, 1953, p. 206, pl. 16, figs. 14-16; Nogan, 1964, p. 40, pl. 5, figs. 16-18 (*see* this reference for further synonomy).

Globorotalia occlusa Loeblich and Tappan

Globorotalia occlusa Loeblich and Tappan, 1957a, p. 191, pl. 55, fig. 3 pl. 64, fig. 3; Stainforth et al. 1975, p. 208, fig. 70.

Globorotalia perclara Loeblich and Tappan

Plate 5, figures 1-3; Plate 8, figures 1,4

Globorotalia perclara Loeblich and Tappan, 1957a, pl. 1, p. 191, pl. 40, fig. 7, pl. 41, fig. 8, pl. 42, fig. 4, pl. 45, fig. 11, pl. 46, fig. 3, pl. 47, fig. 6, pl. 50, fig. 1, pl. 54, figs. 6, 7, pl. 57, figs. 3, 4, pl. 60, fig. 5; Nogan, 1964, p. 41, pl. 5, figs. 22-24 (see this reference for further synonomy).

Remarks: This form is characterized by its low trochospiral biconvex test (umbilical side strongly convex, spiral side slightly convex), perforate wall with spines (last chamber often lacks spines), inflated chambers, and strongly depressed sutures.

Globorotalia pseudotopilensis Subbotina

Plate 7, figures 4-6

Acarinina pseudotopilensis Subbotina, 1953, p. 227-228, pl. 21, fig. 8, 9; pl. 22, fig. 1-3.

Globorotalia pseudotopilensis (Subbotina) Stainforth et al. 1975, p. 217, fig. 78 (see this reference for further synonomy).

Remarks: This species is characterized by its quadrate test with flattened spiral side and inflated umbilical side. Chambers are longer than broad and greatly increase in size in last whorl. The sutures are depressed, umbilicus deep and fairly wide, and the aperture extraumbilical-umbilical in position. The test surface is distinctly cancellate (plate 7, fig. 6) with some small spines on the umbilical side (plate 7, fig. 4).

Globorotalia reissi Loeblich and Tappan

Globorotalia reissi Loeblich and Tappan, 1957a, p. 194, pl. 50, fig. 3, pl. 58, fig. 3, pl. 60, fig. 7.

Globorotalia strabocella Loeblich and Tappan

Globorotalia strabocella Loeblich and Tappan, 1957a, p. 195, pl. 61, fig. 6; Nogan, 1964, p. 42, pl. 6, figs. 10-12 (*see* this reference for further synonomy).

Globorotalia subbotinae Morozova

Globorotalia subbotinae Morozova, 1939, p. 80-81, pl. 2, fig. 16; Stainforth et al. 1975, p. 230, fig. 89 (*see* this reference for further synonomy).

Globorotalia tribulosa Loeblich and Tappan

Plate 7, figs. 1-3

Globorotalia tribulosa Loeblich and Tappan, 1957a, p. 195, pl. 56, figs. 3a-c; pl. 61, figs. 7 a-c.

Remarks: This form is characterized by a small plano-convex to biconvex test, small deep umbilicus, globular chambers, and distinct sutures. The wall is coarsely perforate with the typical spinose test surface (plate 7, fig. 1). The aperture is interiomarginal, extra-umbilical-umbilical, shown in plate 7, fig. 2 as a high arch.

Globorotalia wilcoxensis Cushman and Ponton

Globorotalia wilcoxensis Cushman and Ponton, 1932b, p. 71, pl. 9, fig. 10; Stainforth et al. 1975, p. 243, fig. 98 (*see* this reference for further synonomy).

Family GLOBIGERINIDAE

Genus *Globigerina* d'Orbigny, 1826

Globigerina aquiensis Loeblich and Tappan

Plate 5, figures 4-6

Globigerina aquiensis Loeblich and Tappan, 1957a, p. 180, pl. 51, fig. 4, 5; pl. 56, figs. 4-6; Nogan, 1964, p. 37, pl. 3, figs. 16-18.

Remarks: This species has a high spired trochospiral to subglobular test. There are commonly 4 subglobular chambers in the last whorl, an open umbilicus, and a moderately wide aperture expressed as an open arch (plate 5, fig. 4). The test surface is spinose especially in the umbilical area, finely perforate on portions of the final chamber and somewhat cancellate on the early chambers (spiral side, plate 5, fig. 6).

Globigerina linaperta Finlay

Plate 8, figures 6, 7

Globigerina linaperta Finlay, 1939, p. 125, pl. 13, figs. 54-57; Stainforth et al. 1975, p. 201, fig. 63 (see this reference for further synonomy).

Remarks: This species is characterized by its tightly coiled trochospiral test, trilobate outline with a broadly rounded axial periphery, depressed sutures, coarsely perforate test, and an extra-umbilical-umbilical aperture with an apertural lip.

Globigerina primitiva (Finlay)

Globoquadrina primitiva Finaly, 1947, p. 291, pl. 8, Figs. 129-134. Globigerina primitiva (Finlay). Stainforth et al. 1975, p. 215, fig. 75 (see this reference for further synonomy).

Globigerina soldadoensis soldadoensis Bronnimann

Globigerina soldadoensis Bronnimann, 1952, p. 7, 9, pl. 1, fig. 1-9. Globigerina soldadoensis soldadoensis Bronnimann. Bolli, 1957, p. 71, pl. 16, fig. 7-12; Stainforth et al. 1975, p. 229, fig. 87 (see this reference for further synonomy).

Globigerina triloculinoides Plummer

Plate 4, figures 7, 8

Globigerina triloculinoides Plummer, 1926, p. 134, pl. 8, fig. 10; Nogan, 1964, p. 38, pl. 4, figs. 7-9; Stainforth et al. 1975, p. 234, fig. 92 (see the last two references for further synonomy).

Remarks: Diagnostic features of this species are the rather small, trochospiral tightly coiled test with a rounded margin, depressed sutures, coarsely perforate wall and an umbilical to slightly extraumbilical aperture with a distinct lip.

Family CAUCASINIDAE

Genus *Caucasina* Khalilov, 1951

Caucasina marylandica (Nogan)

Plate 2, figure 3

Aeolostreptis marylandica Nogan, 1964, p. 31, pl. 2, figs. 16, 17.

Genus *Fursenkoina* Loeblich and Tappan, 1961

Fursenkoina wilcoxensis (Cushman and Ponton)

Plate 2, figures 7, 8

Virgulina wilcoxensis Cushman and Ponton, 1932, p. 67, pl. 8, fig. 32.
Fursenkoina wilcoxensis (Cushman and Ponton), Nogan, 1964, p. 33, pl. 2, fig. 27.

Family NONIONIDAE

Genus *Chilostomella* Reuss *in* Czjzek, 1849

Chilostomella c.f. *C. ovoidea* Reuss

Chilostomella cf. *C. ovoidea* (Reuss) Olsson, 1960, p. 41, pl. 7, figs. 9, 10 (*see* this reference for further synonomy).

Genus *Nonion* Montfort, 1808

Nonion mauricense Howe and Ellis

Plate 2, figures 5, 6

Nonion mauricense Howe and Ellis, in Howe, 1939, p. 57, pl. 8, figs. 1, 2; Nogan, 1964, p. 29, pl. 2, figs. 4, 5 (see this reference for further synonomy).

Genus Nonionella Cushman, 1926

Nonionella aquiensis Nogan

Nonionella aquiensis Nogan, 1964, p. 29, pl. 2, figs. 6, 7.

Family ALABAMINIDAE

Genus Alabamina Toulmin, 1941

Alabamina wilcoxensis Toulmin

Plate 4, figures 1-3

Alabamina wilcoxensis Toulmin, 1941, p. 603, pl. 81, figs. 10-14, text fig. 4; Nogan, 1964, p. 36, pl. 3, figs. 9, 10 (see this reference for further synonomy).

Remarks: Diagnostic features of this form are the closely coiled, trochospiral, biconvex test, smooth wall, and interiomarginal aperture.

Family OSANGULARIIDAE

Genus Gyroidinoides Brotzen, 1942

Gyroidinoides octocameratus (Cushman and Hanna)

Plate 3, figures 1-3

Gyroidina soldanii var. octocamerata Cushman and Hanna, 1927, p. 223, pl. 14, figs. 16-18.

Gyroidinoides octocameratus (Cushman and Hanna), Nogan, 1964, p. 35, pl. 3, figs. 3-5 (*see* this reference for further synonomy).

Remarks: Characteristics of this species are the plano-convex trochospiral test, depressed umbilical area, depressed sutures on the umbilical side and and umbilical-extraumbilical aperture.

Family ANOMALINIDAE

Genus *Anomalinoides* Brotzen, 1942

Anomalinoides midwayensis (Plummer)

Plate 11, figures 4-9

Truncatulina midwayensis Plummer, 1926, p. 141, pl. 9, figs. 7a-c, pl. 15, figs. 3a, b.

Truncatulina midwayensis Plummer var. *trochoidea* Plummer, 1926, p. 142, pl. 9, figs. 8a-c.

Anomalinoides midwayensis (Plummer). Brotzen, 1948, p. 88, pl. 14, fig. 3, Olsson, 1960, p. 51, pl. 11, figs. 6-8 (*see* this reference for further synonomy).

Discorbis calyptra Shifflett, 1948, p. 65, pl. 3, fig. 20.

Valvulineria scrobiculata Cushman (*non* Schwager), 1944, p. 26, pl. 4, fig. 27; Shifflett, 1948, p. 66, pl. 3, figs. 22, 23.

Valvulineria wilcoxensis Cushman (*non* Cushman and Ponton), 1944, p. 26, pl. 4, fig. 26; Shifflett, 1948, p. 66, pl. 4, fig. 1.

Valvulineria sp. Shifflett, 1948, p. 67.

Anomalinoides umboniferus Nogan (*non* Schwager), 1964, p. 42, pl. 6, fig. 19-21, pl. 7, figs. 1-3; (*non* pl. 6, figs. 16-18 = *Cibicides praecursorius*).

Remarks: This species is identified by its concavo-convex to slightly biconvex, evolute to slightly involute test, finely perforate wall, and slightly to moderately inflated chambers. Sutures may be slightly raised in earliest whorl becoming flush with test surface to depressed in final whorl. The aperture is interiomarginal umbilical-extraumbilical and may be partially covered by umbilical lips.

A. midwayensis is the most abundant and most variable of all the Foraminifera represented in the Aquia Formation. Plummer, in her original description,noted that transitional forms between *Truncatulina* (*Anomalinoides*) *midwayensis* (involute) and its variety *trochoidea* (evolute) were common and that it was not possible to sharply divide the different varieties. Nogan (1964) named this species *Anomalinoides umboniferus* and subdivided it into involute, evolute, and partially evolute groups. Nogan's illustration of the involute group (Nogan, 1964, pl. 6, figs. 16-18) is *Cibicides praecursorius* (Schwager). His illustrations of the evolute and partially evolute groups are nearly identical to Plummer's *T. midwayensis* and *T. midwayensis* var. *trochoidea* respectively. Nogan also noted numerous transitional forms between his groupings of *A. umboniferus*.

Anomalinoides pseudowelleri Olsson

Plate 10, figures 4-6

Anomalinoides pseudowelleri Olsson, 1960, p. 52, pl. 12, figs. 1-3; Nogan, 1964, p. 42, pl. 6, figs. 13-15.

Remarks: Diagnostic features include the nearly involute, planispiral test, finely perforate wall, somewhat inflated chambers, limbate to slightly depressed sutures, and an interiomarginal, umbilical-extraumbilical aperture extending across the periphery to the spiral side. Umbilical lips extend over the aperture on both sides.

Genus *Cibicidoides* Brotzen, 1936

Cibicidoides hilgardi (Garrett)

Cibicides hilgardi Garrett, 1941, p. 155, pl. 26, figs. 13, 14.

Cibicidoides hilgardi (Garrett). Olsson, 1960, p. 54, pl. 12, figs. 19-21; Nogan, 1964, p. 47, pl. 7, figs. 19-21.

Genus *Karreria* Rzehak 1895

Karreria cervicula (Shifflett)

Stichocibicides cerviculus Shifflett, 1948, p. 76, pl. 5, fig. 10.

Karreria cervicula (Shifflett), Nogan, 1964, p. 35, pl. 3, fig. 6.

Genus *Pulsiphonina* Brotzen, 1948

Pulsiphonina prima (Plummer)

Plate 3, figures 4-6

Siphonina prima Plummer, 1926, p. 148, pl. 12, fig. 4.

Pulsiphonina prima (Plummer). Olsson, 1960, p. 39, pl. 7, figs. 1-3; Nogan, 1964, p. 36, fig. 11 (*see* this reference for further synonomy).

Remarks: Distinguishing features include the biconvex compressed test, sharply acute axial periphery (figure 5), and punctate walls.

SUMMARY

Planktonic and benthonic Foraminifera of the Aquia Formation from outcrops near Hanover, Virginia, were studied in regard to their taxonomy, stratigraphic distribution and abundance.

A total of 45 genera and 79 species of Foraminifera were described, of which 2 genera and 20 species were planktonic Foraminifera. Eight species have never been reported in the Aquia. A total of 12,577 specimens of Foraminifera were examined.

The stratigraphic ranges of the Foraminifera are illustrated in figures 4, 6a, and 6b. The lowest 7 feet of Aquia contain only long ranging Paleocene Foraminifera. The next 2-foot interval may range from the upper part of the Middle Paleocene *Globorotalia pusilla pusilla* Zone to the Late Paleocene *Globorotalia pseudomenardii* Zone using the overlapping ranges of *Globigerina triloculinoides* and *Globorotalia acuta*. The following section, from 9 feet above the basal Aquia to a point 6 feet below the Marlboro Clay, is referred to the *Globorotalia pseudomenardii* Zone. This zonal assignment is based on the occurrence of *Gg. triloculinoides* and *Gr. aequa*. The upper 6 feet of Aquia and the lowest 1 foot of Marlboro Clay occurs in the Late Paleocene *Globorotalia velascoensis* Zone based on the overlapping ranges of *Gr. subbotinae* and *Gr. occlusa* in that section.

The Early Cretaceous Patuxent Formation, the Early Eocene Nanjemoy Formation, the Miocene Calvert Formation, and the Upland Gravels of Miocene(?) to Pliocene age were identified in the study area by their stratigraphic position and lithology. All the Late Cretaceous, Early

Paleocene and possibly the Middle Paleocene strata found in Maryland and Delaware appear to be absent in the Hanover vicinity.

Within the study area are two closely related benthonic foraminiferal faunas. The first fauna, occurring in the basal Aquia, is characterized by low species diversity, high dominance, high morphologic variability within dominant species and large populations. Associated with this fauna is a typically nearshore macrofauna, vertebrate skeletal debris, wood fragments and a boulder conglomerate all which overlies terrestial sands and gravels of the Patuxent Formation. This data indicates a nearshore, shallow water, unstable environment for this section (Youseffnia, 1978, Andrews, 1975, Bretsky and Lorenz, 1969).

The second fauna from the upper part of the Aquia has a slightly higher species diversity, a decrease in dominance, and smaller populations. The fauna is associated with large populations of Turritella indicating a subtidal and more stable environment than in the basal portion of the Aquia.

A scaled cross-section of the study area constructed from formation tops measured at outcrops and two nearby water wells reveals anomalous offsets in bedding planes and rapid eastward thickening of formations (figure 5). Accompanying these features are abrupt changes in the direction of the Pamunkey River. This data suggests faulting in the study area which may similar to the faults reported in Coastal Plain strata near Fredericksburg, Virginia (Mixon and Newell 1978).

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PLATE 1

All illustrations are SEM photographs.

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6.	Lagena rancocasensis Olsson. Lateral view. x100	36
7.	Saccamina sp. Side view. x175	
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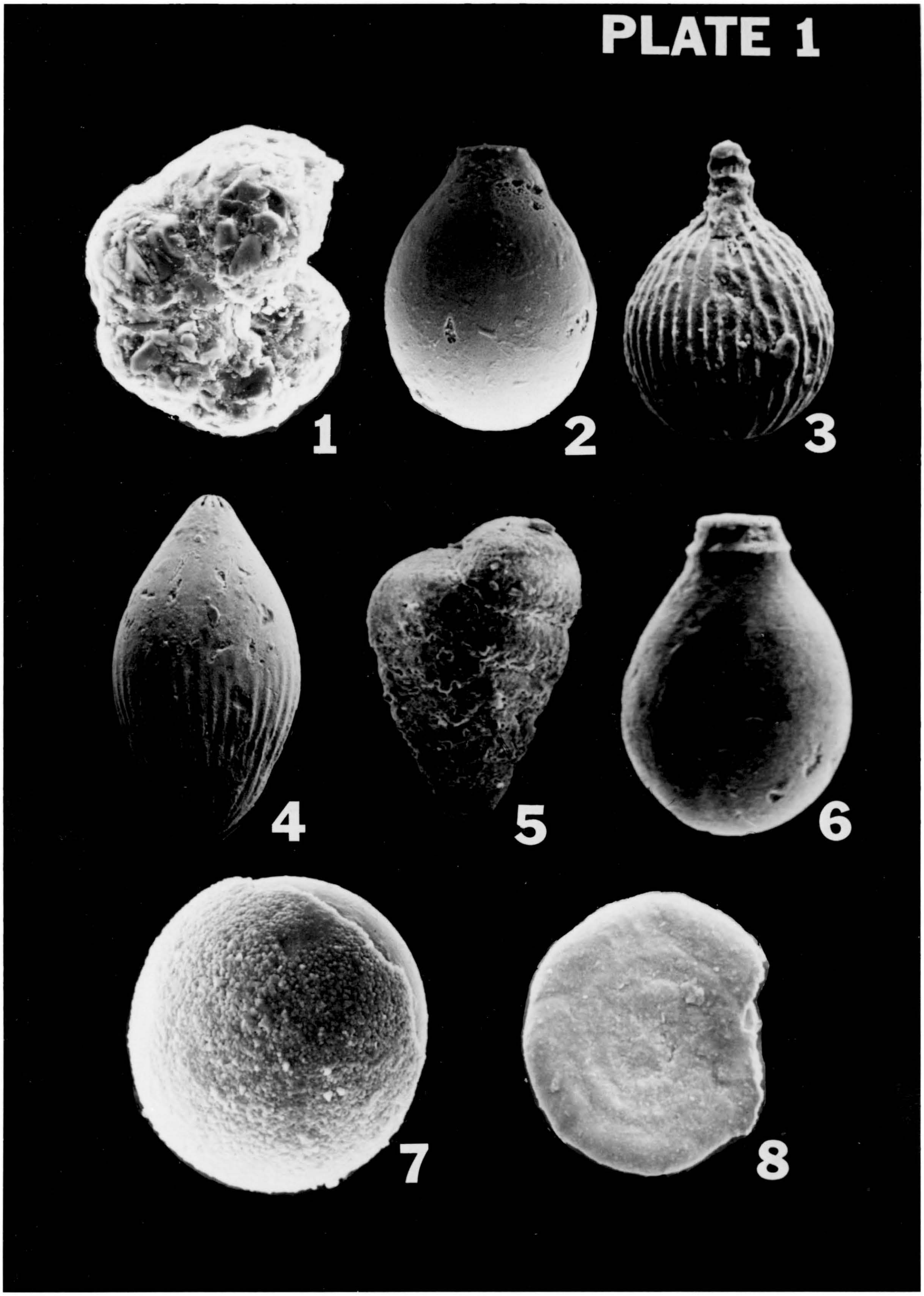
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PLATE 2

All illustrations are SEM photographs except those noted.

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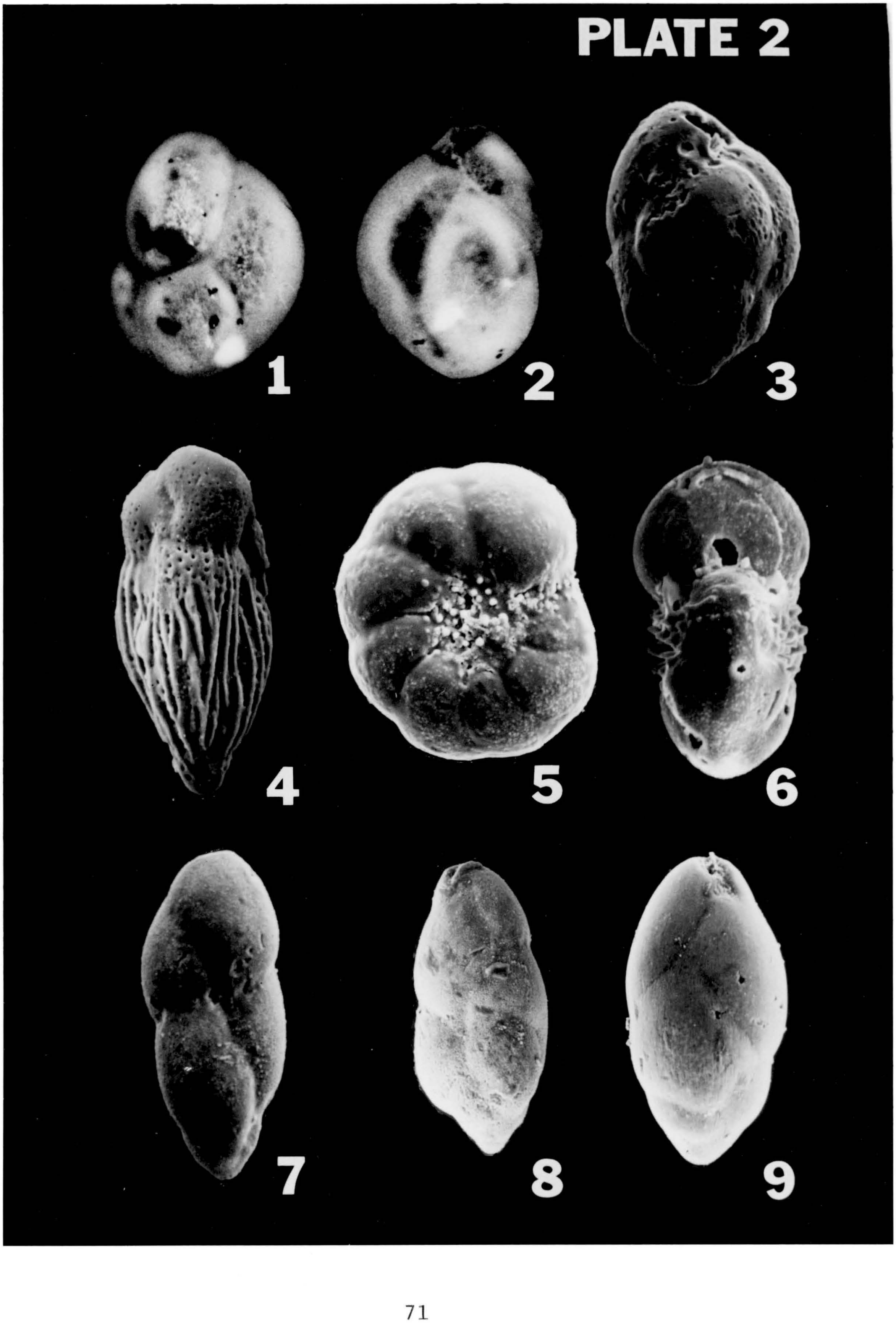
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All illustrations are SEM photographs.

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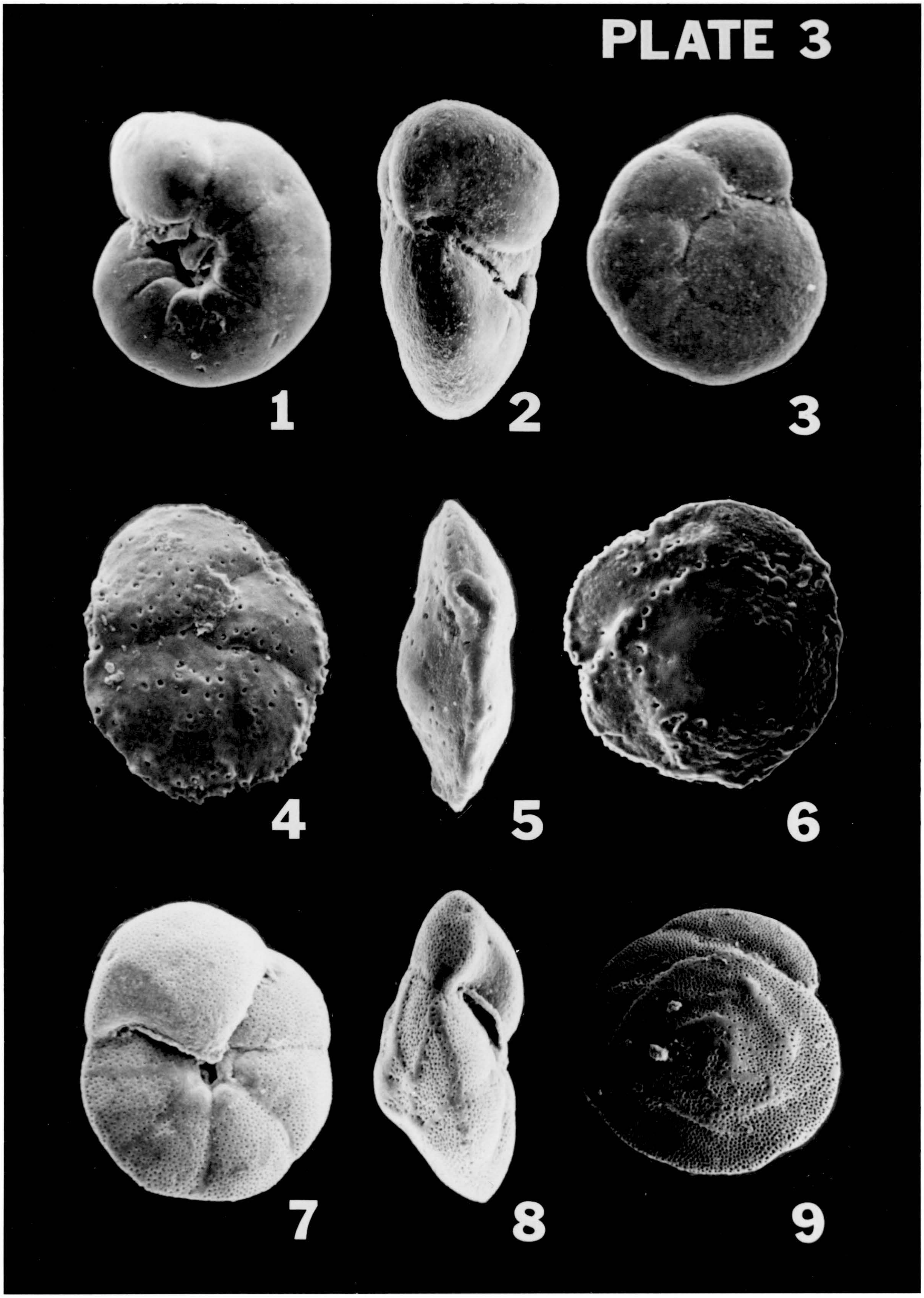
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All illustrations are SEM photographs.

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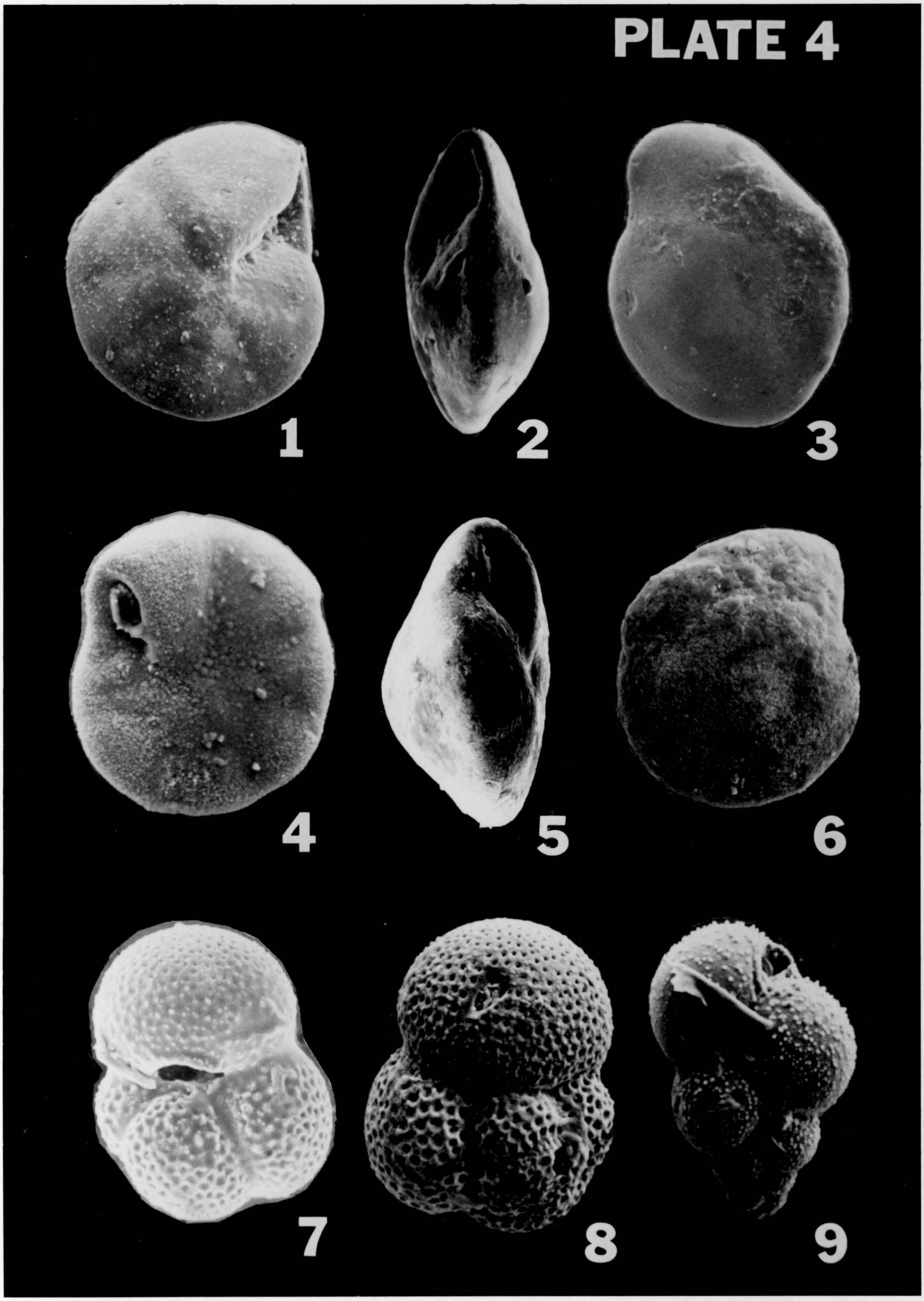
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All illustrations are SEM photographs.

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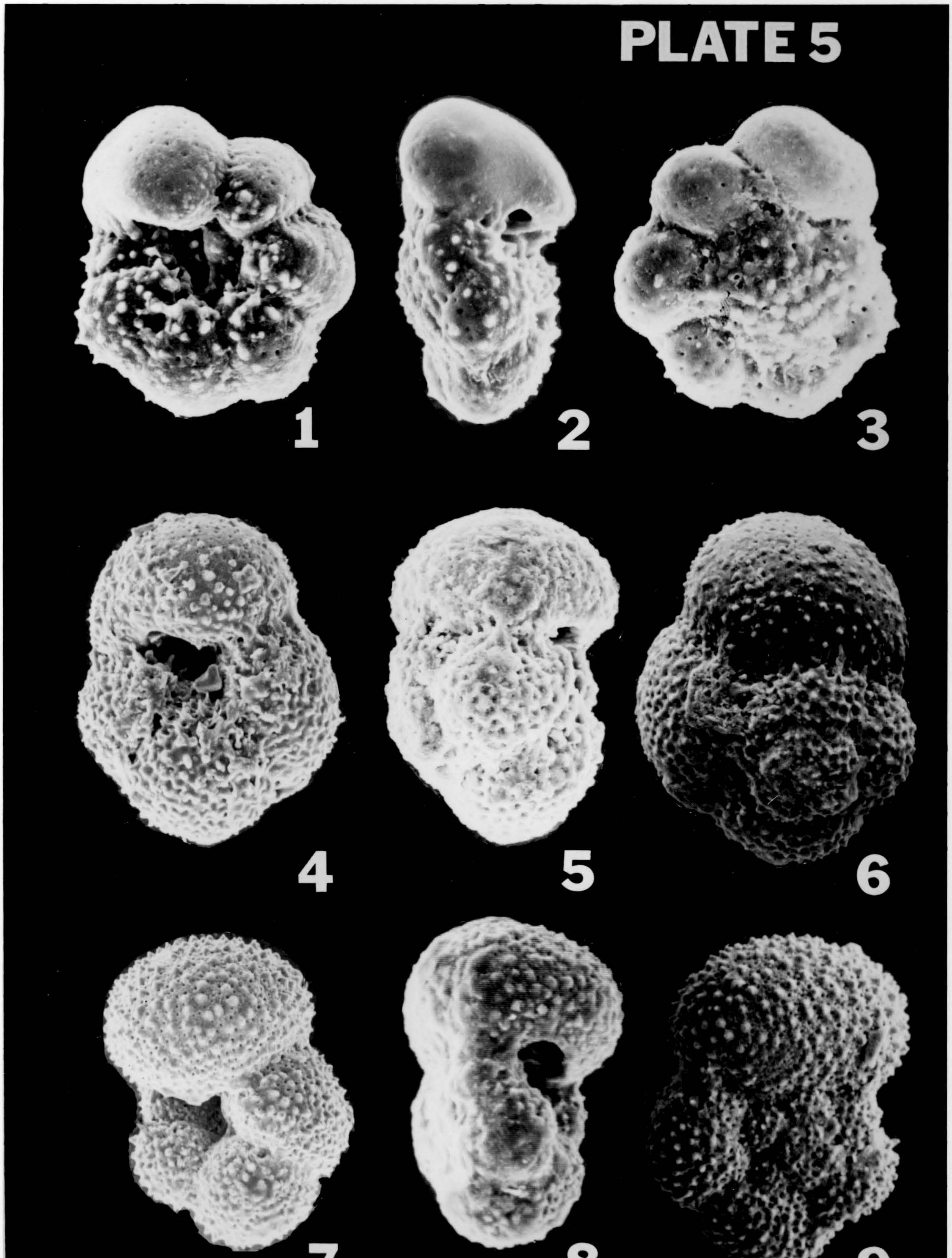
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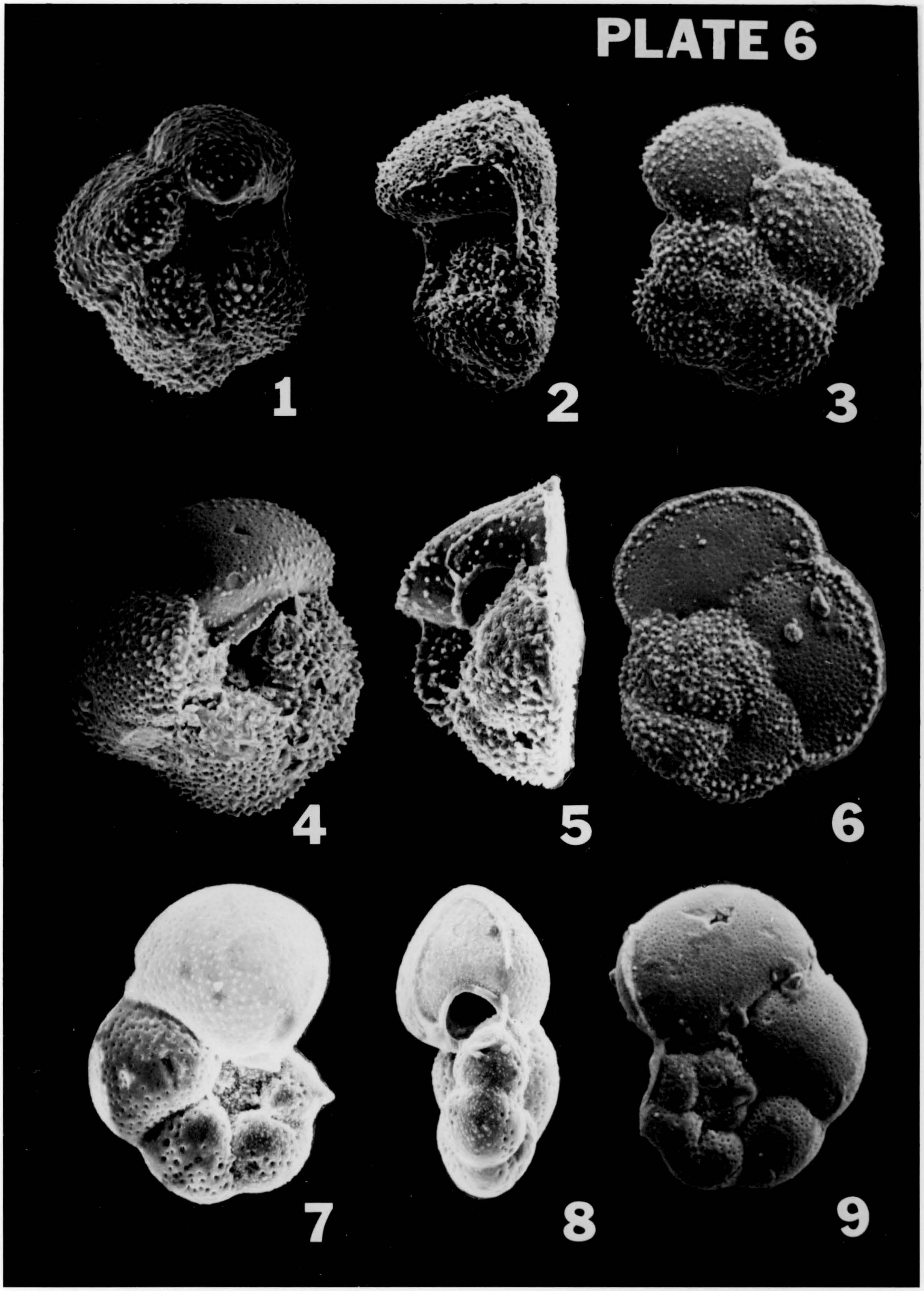
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All illustrations are SEM photographs.

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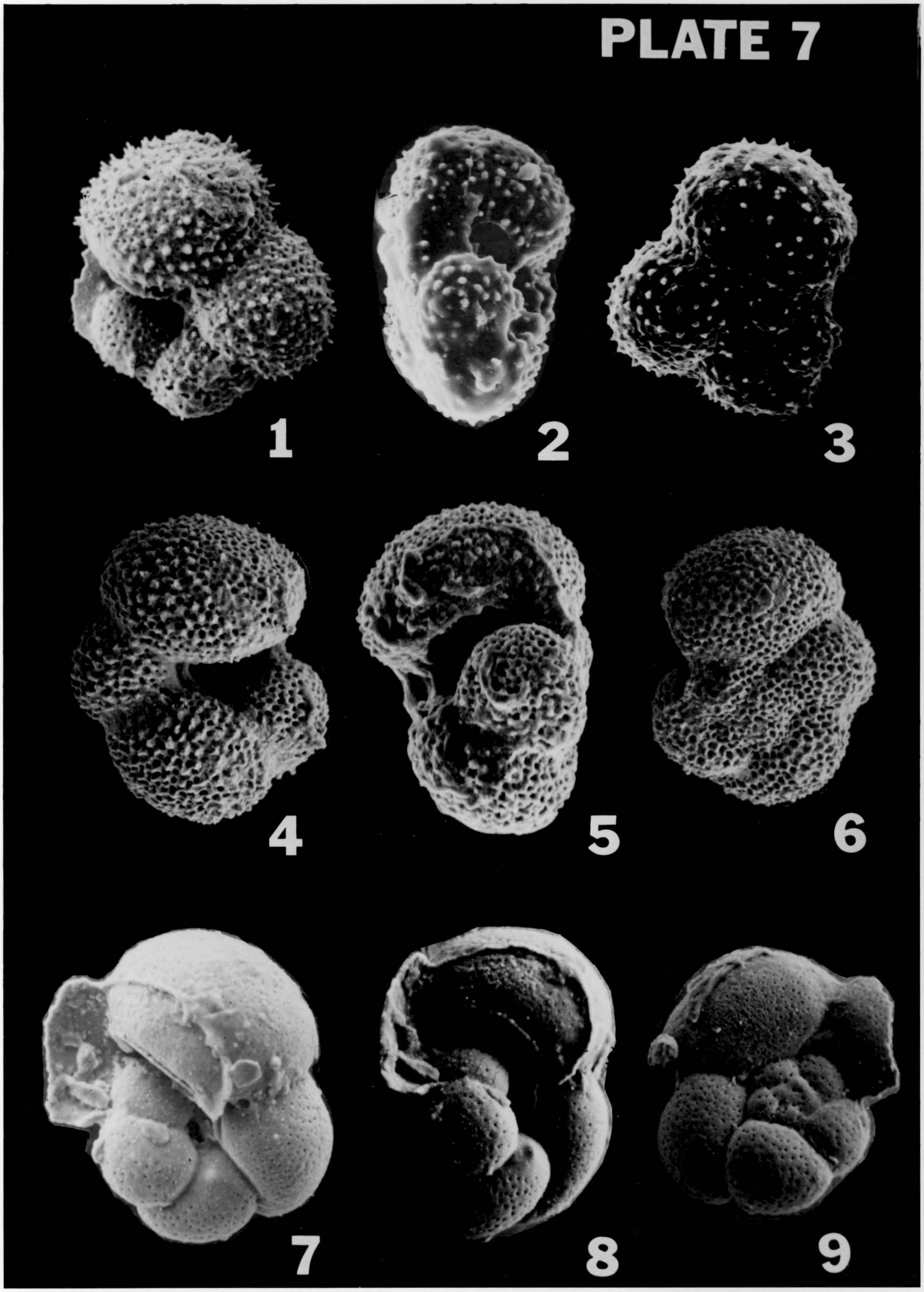
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PLATE 8

All illustrations are SEM photographs except those noted.

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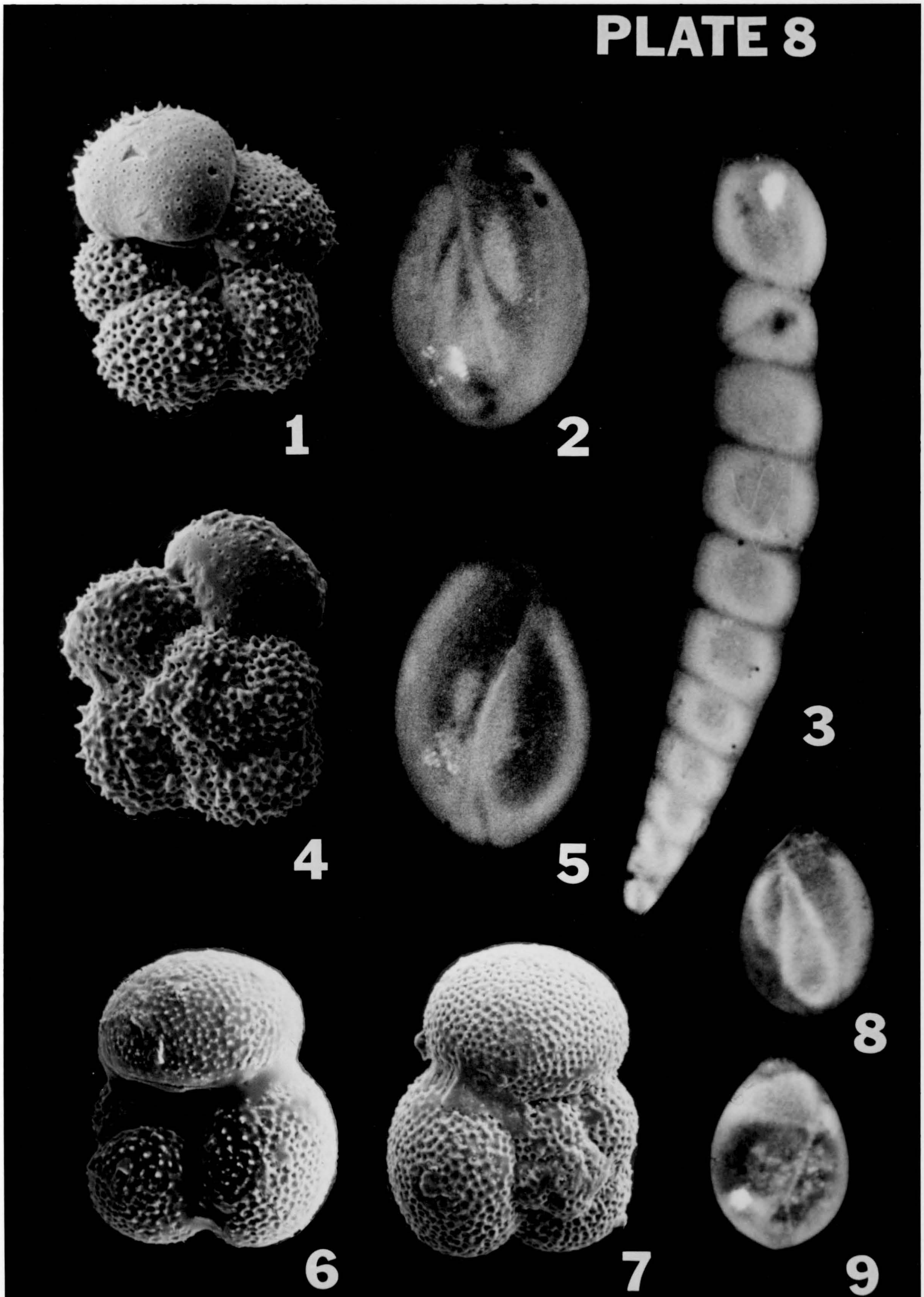
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PLATE 9

All illustrations are SEM photographs except those noted.

FIGURES		PAGE
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4,5.	<u>Marginulina</u> <u>toulmini</u> Cushman. 4, Edge view. 5, Umbilical view. x150	37
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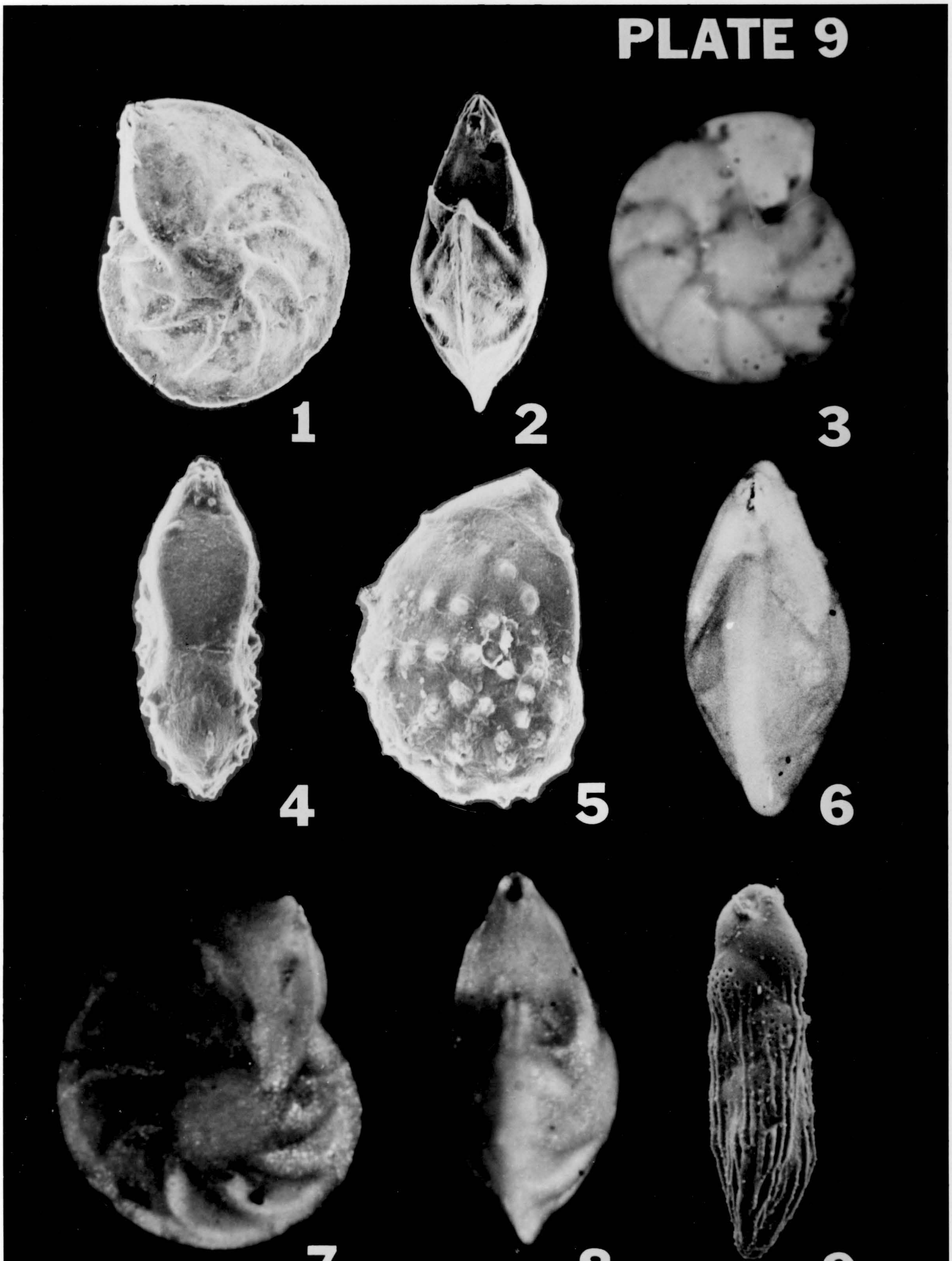
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PLATE 10

All illustrations are SEM photograps.

FIGURES		PAGE
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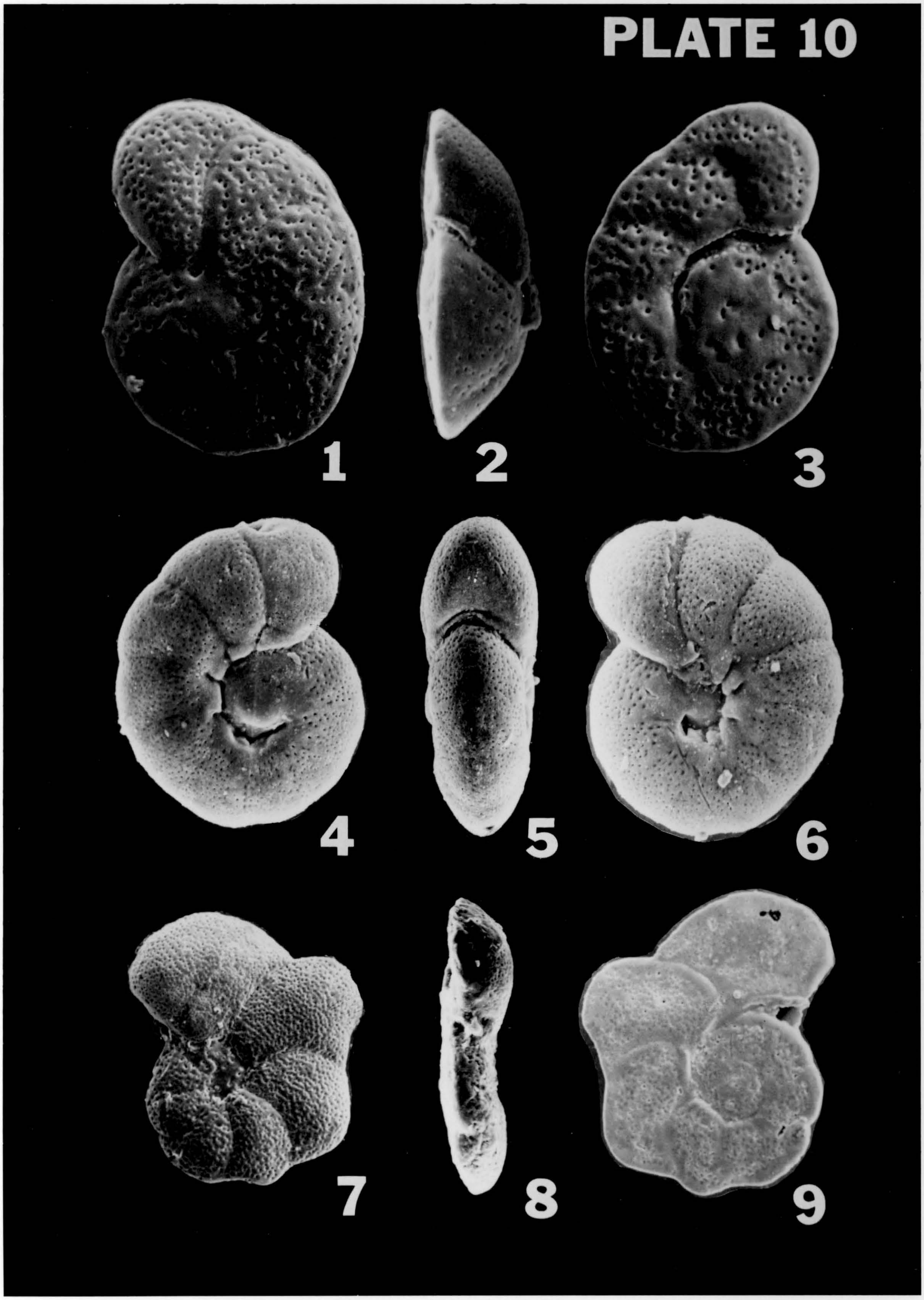
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PLATE 11

All illustrations are SEM photographs.

FIGURES		PAGE
1,2,3.	Cibicides praecursorius (Schwager) 1, Spiral view. 2, Edge view. 3, Umbilical view. x100	45
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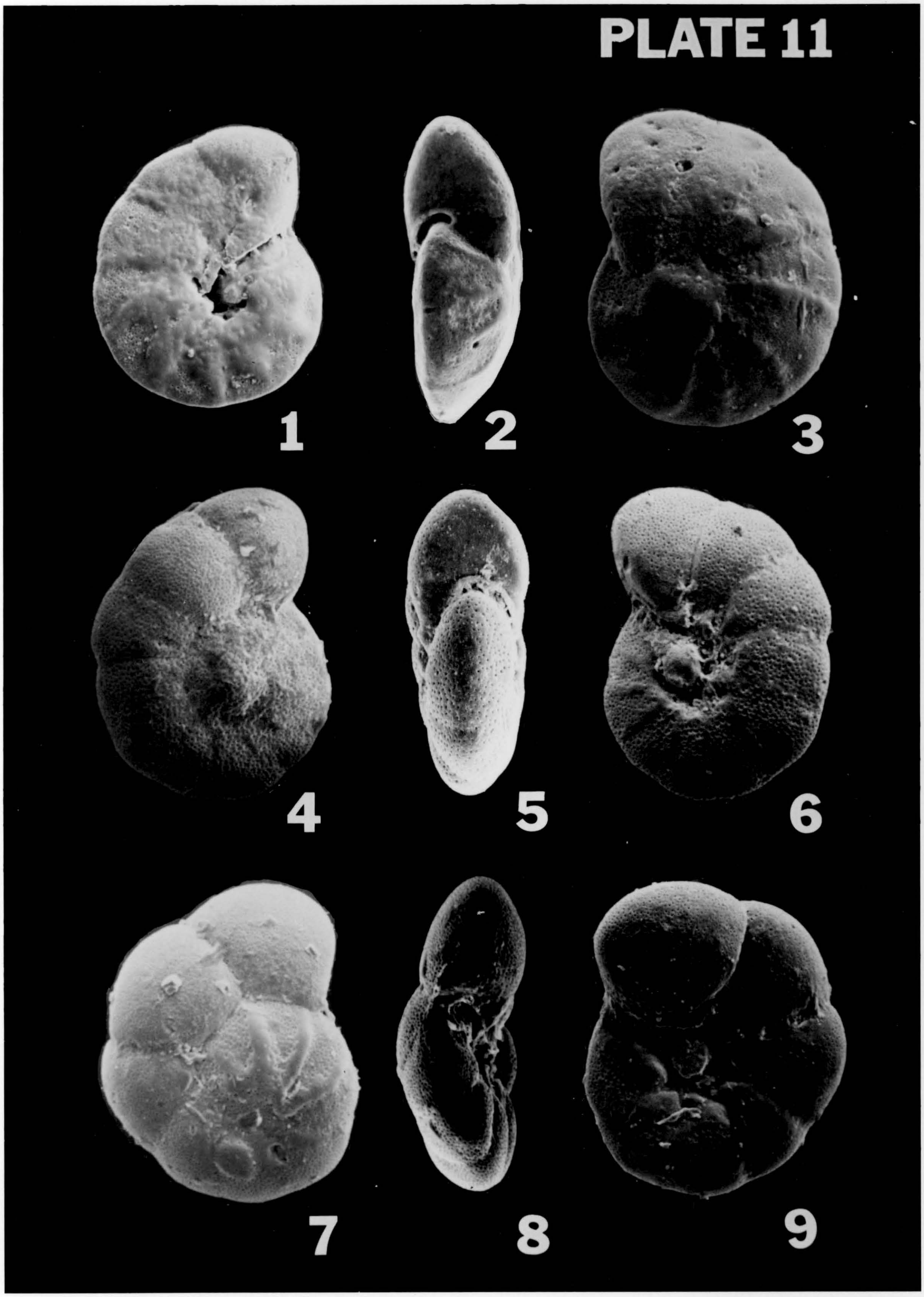
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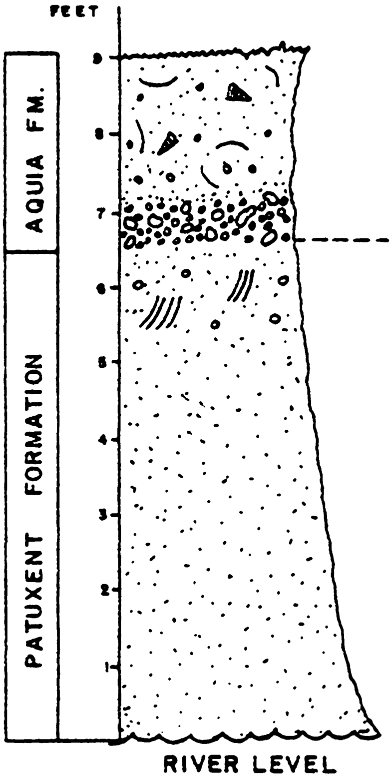
APPENDIX I

ADDITIONAL AQUIA OUTCROP "C"
EAST OF WICKHAM CROSSING*



Brown, medium-grained sand with scattered pebbles. Contains <u>Turritella</u>, <u>Cubitostrea</u>, <u>Crassatella</u> and <u>Dosinopsis</u> (No foraminifera recovered).

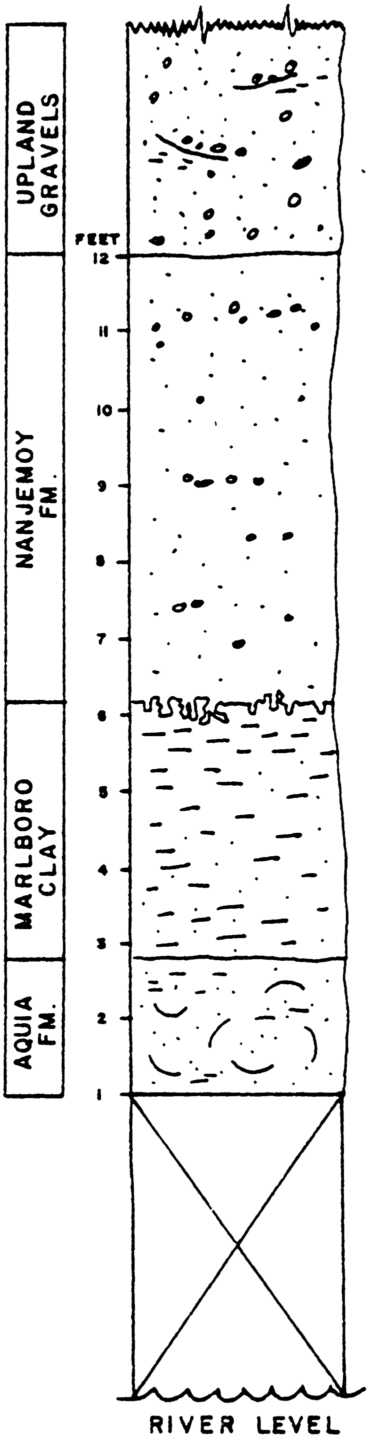
Pebble bed with brown, medium-grained sand matrix.

Unconformity, irregular contact ± 1 ft.

Light tan and green, medium-grained sand from river level to 5.5'. Sand contains cross-beds and scattered pebbles from 5.5' to 6.5'.

*See Figure I for map location.

APPENDIX 2
ADDITIONAL OUTCROP "D"



Oxidized quartz sands and gravels.

Sharp flat contact

Light gray sand with orange stains and quartz pebble horizons.

Burrowed contact

Light gray and blue clay grading into blue-gray clayey silt with bivalve molds (leached).

Gradational contact

Light green silty clay with orange oxidized bivalve molds (leached).

Covered by slumping

No foraminifera recovered from this outcrop.

APPENDIX 3

GEOLOGIC LOG, WATER WELL W-2158

Virginia Division of Mineral Recources
Robert H. Teifke, Geologist

OWNER:	Kiwanis Club of Richmond, Va.	VDMR:	2158
DRILLER:	Snyder Hydrodynamics, Inc.	WWCR:	94
COUNTY:	Caroline (Bowersville)	TOTAL DEPTH:	320'
LOCATION:	11,300' S3°W of Little Bethel School	ELEVATION:	185'

Depth in feet

COLUMBIA GROUP (0-50')

Depth in feet		
0-2	Sand -	abundant matrix of tan clay; very fine- to coarse-grained, poorly sorted, angular; very slightly feldspathic; trace of magnetite.
2-10	Sand -	abundant matrix of red clay; fine- to coarse-grained, poorly sorted, angular to subangular; very slightly feldspathic.
10-20	Sand -	abundant matrix of multi-colored clay; 10 percent very fine-grained quartz gravel; very fine- to very coarse-grained, poorly sorted, angular to subangular; very slightly feldspathic; a few schistose rock fragments.
20-30	Sand -	orange-brown (iron-stained); trace of clay; medium- to coarse-grained, fairly well-sorted, subangular to subrounded; slightly feldspathic and lithic in coarse fraction.
30-40	Sand -	orange-brown, very slightly clayey, 5 percent poorly rounded, quartzo-feldspathic granule gravel; fine- to coarse-grained, rather poorly sorted, angular to subrounded; slightly feldspathic; a few schistose rock fragments.
40-50	Sand -	orange-brown, very slightly clayey; bimodal, 50 per-

cent fine- to medium-grained, well-sorted, angular; 50 percent very coarse-grained, well-sorted, subrounded; coarser fraction is moderately feldspathic, slightly lithic; a few pebbles up to 15 mm.

CALVERT FORMATION (50-130')

50-60	Sand -	brownish gray, slightly clayey; fine-grained, well-sorted, angular to subangular; minor magnetite; traces of shell and plant material.
60-70	Sand -	gray, slightly clayey; fine-grained, very well sorted, angular to subangular; magnetite is an abundant accessory; a few small shell fragments.
70-80	Sand -	gray, slightly clayey; fine-grained, very well sorted angular to subangular; magnetite is an abundant accessory; a few small shell fragments.
80-90	Sand -	gray, slightly clayey; fine-grained, very well sorted, angular to subangular; magnetite is an abundant accessory; a few small shell fragments.
0-100	Sand -	gray, slightly clayey; fine-grained, very well sorted, angular to subangular; magnetite is an abundant accessory; a few small shell fragments.
100-110	Sand -	greenish gray, moderately clayey, 10 to 15 percent small pelecypod shell fragments, fine to very fine-grained, well sorted, angular; trace of magnetite; foraminifers rare.
110-120	Clay -	greenish gray, locally sandy, 10 percent small pelecypod shell fragments; sand is fine, well sorted, angular; quartz, with minor amount of bone phosphorite.
120-130	Sand and Clay -	greenish gray, about 50 percent clay, trace of shell fragments; sand is fine-grained, well sorted, angular; fragments of bone phosphorite common; traces of glauconite, muscovite, and kyanite.

NANJEMOY FORMATION (130-170')

130-140 Clay - greenish gray, locally orange-brown, very sandy, 5 percent shell fragments; sand is fine- to medium-grained, moderately sorted; 60 percent angular, clear to greenish quartz, 40 percent blackish green autochthonous glauconite (generally coarser than quartz); small amount of bone phosphorite; moderately micaceous; trace of pyrite; a few small foraminifers.

140-150 Clay - greenish gray, locally orange-brown, very sandy, 5 percent shell fragments; sand is fine- to medium-grained, moderately sorted; 60 percent angular, clear to greenish quartz, 40 percent blackish-green autochthonous glauconite (generally coarser then quartz); small amount of bone phosphorite; moderately micaceous; trace of pyrite; a few small foraminifers.

150-160 Clay - greenish gray, locally orange-brown, very sandy, 5 percent shell fragments; sand is fine- to medium-grained, moderately sorted; 60 percent angular, clear to greenish quartz, 40 percent blackish green autochthonous glauconite (generally coarser than quartz); small amount of bone phosphorite; moderately micaceous; trace of pyrite; a few small foraminifers. Sand fraction is well-sorted, 75 percent quartz, 25 percent glauconite.

160-170 Clay - gray, silty, moderately sandy, a few shell and plant fragments; sand is fine-to very fine-grained, very well sorted; 70 percent angular, clear to greenish quartz, 30 percent blackish green glauconite; micaceous and pyritic; a few fragments of bone phosphorite; a very few small foraminifers.

AQUIA FORMATION (170-240')

170-180 Clay - dark gray, very silty, slightly sandy, trace of granule gravel, sand is very fine- to coarse-grained, poorly sorted; 60 percent quartz, 40 percent dark-green glauconite; micaceous; minor pyrite and bone phosphorite; a few small shell fragments; plant fragments, ostracods and foraminifers (Robulus, Nodosaria).

180-190 Clay - dark gray, very silty, slightly sandy, trace of granule gravel, sand is very fine- to coarse-grained, poorly sorted; 60 percent qartz, 40 percent dark green glauconite; micaceous; minor pyrite and bone phosphorite; a few small shell fragments; plant fragments, ostracods and foraminifers (Robulus, Nodosaria).

190-200 Clay - dark gray, very silty, slightly sandy, trace of granule gravel, sand is very fine- to coarse-grained, poorly sorted; 60 percent quartz, 40 percent dark green glauconite; micaceous; minor pyrite and bone phosphorite; a few small shell fragments; plant fragments, ostracods and foraminifers (Robulus, Nodosaria).

200-210 Sand - dark gray, very silty, slightly sandy, trace of granule gravel, sand is very fine- to coarse-grained, poorly sorted; 60 percent quartz, 40 percent dark green glauconite; micaceous; minor pyrite and bone phosphorite; a few small shell fragments; plant fragments, ostracods and foraminifers (Robulus, Nodosaria).

210-220 Sand - dark gray, very silty, slightly sandy, trace of granule gravel, sand is very fine- to coarse-grained, poorly sorted; 60 percent quartz, 40 percent dark green glauconite; micaceous; minor pyrite and bone phosphorite; a few small shell fragments; plant fragments, ostracods and foraminifers (Robulus, Nodosaria); 5-10 percent shell fragments.

220-230 Sand and Shell - very little clay, 30 percent abraded polecypod shell fragments; 70 percent medium- to very coarse-grained, fairly well sorted (skewed coarse), sub-rounded sand (grades into granule gravel); sand is 15 percent medium- to coarse-grained glauconite, 5 percent nodular phosphorite, feldspathic; quartz and feldspar commonly stained yellow to green.

230-240 Sand and Shell - very little clay; 30 percent abraded polecypod shell fragments; 70 percent medium- to very coarse-grained, fairly well sorted (skewed coarse), sub-rounded sand (grades into granule gravel); sand is 15 percent medium- to coarse-grained glauconite, 5 percent nodular phosphorite, feldspathic; quartz and feldspar commonly stained yellow to green; 5 percent abraded pelecypod shell fragments

PATUXENT FORMATION (240-320')

240-250	Sand -	gray, clean, 5-10 percent granule gravel; coarse- to very coarse-grained, fairly well sorted, subrounded to rounded; 5 percent medium- to coarse-grained glauconite; very feldspathic; minor nodular phosphorite.
250-260	Sand -	gray, clean, 5-10 percent granule gravel; coarse- to very coarse-grained, fairly well sorted, subrounded to rounded; 5 percent medium- to coarse-grained glauconite; very feldspathic; minor nodular phosphorite. 15-20 percent granule gravel.
260-270	Sand -	gray, clean 5-10 percent granule gravel; coarse- to very coarse- grained, fairly well sorted, subrounded to rounded; 5 percent medium- to coarse-grained glauconite; very feldspathic; minor nodular phosphorite. 10 percent granule gravel.
270-280	Sand -	gray, clean, 5-10 percent granule gravel; coarse- to very coarse-grained, fairly well sorted, subrounded to rounded; 5 percent medium- to coarse-grained glauconite; very feldspathic; minor nodular phosphorite. 5 percent granule gravel.
280-290	Sand -	gray, clean, 5-10 percent granule gravel; coarse- to very coarse-grained, fairly well sorted, subrounded to rounded; 5 percent medium- to coarse-grained glauconite; very feldspathic; minor nodular phosphorite. 10 percent fine- to medium-grained glauconite; trace of granule gravel.
290-300	Sand -	gray, clean, traces of granule gravel and shell fragments; coarse- to very coarse-grained, fairly well sorted, subangular to subrounded; feldspathic; slightly glauconitic
300-310	Sand -	gray, clean traces of granule gravel and shell fragments; coarse- to very coarse-grained, fairly well

sorted, subangular to subrounded; feldspathic; slightly glauconitic.

310-320 Sand - gray, clean, traces of granule gravel and shell fragments; coarse- to very coarse-grained, fairly well sorted, subangular to subrounded; feldspathic; slightly glauconitic. 15 percent granule gravel.

GEOLOGIC SUMMARY

	Rock Unit	Age
0-50'	Columbia Group	Post-Miocene
50-130'	Calvert Formation	Miocene
130-170'	Nanjemoy Formation	Eocene
170-240'	Aquia Formation	Paleocene
240-320'	Patuxent Formation	Early Cretaceous

APPENDIX 4

GEOLOGIC LOG, WATER WELL W-1613

Virginia Division of Mineral Resources
Robert H. Teifke, Geologist

OWNER:	Barksdale Theater (D. S. Kilgore)	VDMR:	1613
DRILLER:	Sydnor Pump & Well Company, Inc.	WWCR:	95
COUNTY:	Hanover (Hanover Courthouse)	TOTAL DEPTH:	234'
LOCATION:	1300' N56^{o}W of Hanover Courthouse Building	ELEVATION:	100'

Depth
in
feet

COLUMBIA GROUP (0-10)

0-10 Sand and Gravel -orange-brown, very slightly argillaceous (orange-brown clay); 20-30% very fine gravel consisting of subrounded quartz and white feldspar up to 8 mm.; 70-80% fine- to very coarse-grained, poorly-sorted sand; slightly to to moderately arkosic; small amounts of muscovite, decomposed biotite, garnet, tourmaline, kyanite, magnetite, etc.

CALVERT FORMATION (10-60)

10-20 Sand - dull brown, argillaceous; fine- to very fine-grained, well sorted, angular to subangular, with a minor amount of coarser, poorly rounded sand; traces of brown garnet, carbonphosphatic material, glauconite and diatoms.

20-30 Sand - dull brown, argillaceous; fine- to very fine-grained, well sorted, angular to subangular, with a minor amount of coarser, poorly rounded sand; traces of brown garnet, carbonphosphatic material, glauconite and diatoms. Grayish brown.

30-40 Sand - dark gray, very argillaceous, a few granules and very small pebbles up to 6 mm.; fine- to very fine-grained, fairly well sorted, angular to subangular, with 10-20% admixture of much coarser sand; traces of brown epidote, glauconite, carbonophosphatic material, and diatoms.

40-50 Sand - dark gray, very argillaceous, a few granules and very small pebbles up to 6 mm.; fine- to very fine-grained, fairly well sorted, angular to subangular, with 10-20% admixture of much coarser sand; traces of brown epidote, glauconite, carbonophosphatic material, and diatoms.

NANJEMOY FORMATION - MARLBORO CLAY (?) (50 - 60) *

50-60 Sand - medium gray, slightly to moderately argillaceous; fine- to very fine-grained, well sorted, angular to subangular; minor amount of very finely-divided, black, carbonophosphatic material trace of glauconite.

AQUIA FORMATION (60 - 100)

60-70 Sand - dark gray, argillacous; fine- to very fine-grained, very well sorted (skewed fine), angular; about 65% clear to green tinted quartz, 25-30% fresh glauconite, and 5-10% chalky shell fragments; minor amounts of mica and nodular and platy phosphorite; a small number of large Aquia foraminifers.

70-80 Sand - dark gray, argillaceous; fine- to very fine-grained, very well sorted (skewed fine), angular; about 65% clear to green tinted quartz, 25-30% fresh glauconite, and 5-10% chalky shell fragments; minor amounts of mica and nodular and platy phosphorite; a small number of large Aquia foraminifers. Foraminifers moderately abundant.

80-90 Sand - dark gray; argillaceous; fine- to very fine-grained, very well sorted (skewed fine), angular; about 65% clear quartz, and 35% fresh glauconite; small amounts of pyrite and phosphorite; a few shell fragments, fish teeth, and foraminifers.

90-100 Sand - dark gray, argillaceous; very fine- to medium-grained well sorted; 35% fine- to very fine-grained, angular, clear to green tinted quartz, 45% very fine- to medium-grained, fresh glauconite, and 20% chalky abraded molluscan shell fragments; a very few foraminifers.

POTOMAC GROUP (100 - 230)

100-110 Sand and Gravel - gray, argillaceous; sand (30%) is coarse- to very coarse-grained, well sorted (skewed coarse),

*Authors Interpretation

subrounded to rounded; gravel (70%) is fine (2-10 mm), well sorted, subrounded to rounded; both fractions are arkosic and contain abundant stained quartz and feldspar; some pebbles of quartzite are present in gravel fraction; small amount of glauconite and chalky shell debris.

110-120 Sand and Gravel - gray, argillaceous; sand (30%) is coarse- to coarse-grained, well sorted (skewed coarse), subrounded to rounded; gravel (70%) is fine (2-10 mm), well sorted, subrounded to rounded; both fractions are arkosic and contain abundant stained quartz and feldspar; some pebbles of quartzite are present in gravel fraction; small amount of glauconite and chalky shell debris.

120-130 Sand and Gravel - gray, argillaceous; sand (30%) is coarse- to very coarse-grained, well sorted (skewed coarse), subrounded to rounded; gravel (70%) is fine (2-10 mm), well sorted, subrounded to rounded; both fractions are arkosic and contain abundant stained quartz and feldspar; some pebbles of quartzite are present in gravel fraction; small amount of glauconite and chalky shell debris. Gravel is finer (2-6 mm) and better sorted.

130-140 Sand, Clay, and Gravel - grayish brown; sand (70%) is poorly sorted, variably rounded, arkosic and slightly glauconitic. Gravel (10%) consists of rounded quartz granules and small pebbles up to 10 mm.

140-150 Sand, Clay, and Gravel - grayish brown; sand (70%) is poorly sorted, variably rounded, arkosic and slightly glauconitic. Gravel (10%) consists of rounded quartz granules and small pebbles up to 10 mm. Clay is mottled, more abundant (about 30%).

150-160 Sand, Clay, and Gravel - grayish brown; sand (70%) is poorly sorted, variably rounded, arkosic and slighly glauconitic. Gravel (10%) consists of rounded quartz granules and small pebbles up to 10 mm. Clay is mottled, most abundant (about 30%).

160-170 Sand, Clay, and Gravel - grayish brown; sand (70%) is poorly sorted, variably rounded, arkosic and slightly glauconitic. Gravel (10%) consists of rounded quartz granules and small pebbles up to 10 mm. 50% gravel, 40% sand, 10% clay.

170-180 Sand, Clay, and Gravel - grayish brown; sand (70%) is poorly sorted, variably rounded, arkosic and slightly glauconitic. Gravel (10%) consists of rounded quartz granules and small pebbles up to 10 mm. 40% gravel, 60% sand.

180-190 Sand - drab brown, moderately argillaceous and silty; medium- to coarse-grained, moderately sorted, subangular to subrounded; moderately arkosic and slightly glauconitic.

190-200 Sand - drab brown, moderately argillaceous and silty; medium- to coarse-grained, moderately sorted, subangular to subrounded; moderately arkosic and slightly glauconitic. Argillaceous.

200-210 Sand - drab brown, moderately argillaceous and silty; medium- to coarse-grained, moderately sorted, subangular to subrounded; moderately arkosic and slightly glauconitic. Moderately argillaceous (gray clay), with a few small pebbles.

210-220 Sand - drab brown, moderately argillaceous and silty; medium- to coarse-grained, moderately sorted, subangular to subrounded; moderately arkosic and slightly glauconitic. Moderately argillaceous (gray clay), with a few small pebbles.

220-230 Sand - drab brown, moderately argillaceous and silty; medium- to coarse-grained, moderately sorted, subangular to subrounded; moderately arkosic and slightly glauconitic. Moderately argillaceous (gray clay), with a few small pebbles.

230-240 No sample.

APPENDIX 5

Locations of Sample Localities and Additional Outcrops

On Ashland, Virginia 7½ USGS Topographic Map

Sample Locality	Location
1	2800' S80°E of Wickham Crossing, south bank of Pamunkey River. (Witmer, 1975 Locality 1).
Additional Outcrop	
A	8200' N24°E of Wickham Crossing, east bank of Pamunkey River.
B	4800' N31°E of Wickham Crossing, southwest bank of Pamunkey River.
C	1000' N74°E of Wickham Crossing, south bank of Pamunkey River.

On Hanover, Virginia 7½" USGS Topographic Map

Sample Locality	Location
2	4700' S15° of intersection of Pamunkey River and Route 301, southeast bank of river. (Witmer, 1975 Locality 2).
3	1300' N58°E of intersection of Pamunkey River and Route 301, west bank of river.
4	5600' N69°E of intersection of Pamunkey River and Route 301, northeast bank of river.
Additional Outcrop	
D	4400' S13°E of intersection of Pamunkey River and Route 301, southeast bank of river. (Witmer, 1975 Locality 3).
E	4100' N33°E of intersection of Pamunkey River and Route 301, on north bank of river.

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FORAMINIFERAL BIOSTRATIGRAPHY AND PALEOECOLOGY OF THE AQUIA FORMATION NEAR HANOVER, VIRGINIA

by

William Joseph Seaton

(ABSTRACT)

Foraminifera of the Paleocene Aquia Formation outcropping near Hanover, Virginia were studied in terms of their taxonomy, stratigraphic distribution and abundance. A total of seventy-nine species were described, eight of which have never been reported in the Aquia. Twenty species of planktonic foraminifera were recovered.

The basal seven feet of Aquia contains only long ranging Paleocene Foraminifera. In the next two feet of Aquia occurred *Globigerina triloculinoides* and *Globorotalia acuta* which overlap in the Middle Paleocene *Globorotalia pusilla pusilla* Zone and the Late Paleocene *Globorotalia pseudomenardii* Zone. The next section of Aquia, from nine feet above its base to six feet below the overlying Marlboro Clay, is referred to the *Globorotalia pseudomenardii* Zone based on the occurrence of *Globorotalia aequa* and *Globigerina triloculinoides*. The top six feet of the Aquia and basal one foot of Marlboro Clay contain *Globorotalia subbotinae* and *Globorotalia occlusa* placing this section in the Late Paleocene *Globorotalia velascoensis* Zone.

The basal Aquia foraminiferal fauna is characterized by low species diversity, high morphologic variability in dominant species and large populations suggesting an unstable, marginal marine environment. The upper sections of the Aquia Formation contain faunal associations with higher species diversity, lower dominance and smaller populations indicating a somewhat deeper water, more stable environ-

ment. The associated macrofossil communities and local lithologies support these conclusions.

A cross-section through the study area reveals offsets in formational boundaries and unusual downdip thickening of the Tertiary section. Accompanying these anomalies are abrupt changes in the course of the Pamunkey River. These data suggests faulting in the study area analogous to the faulted Coastal Plain strata near Fredericksburg, Virginia (Mixon and Newell, 1978).

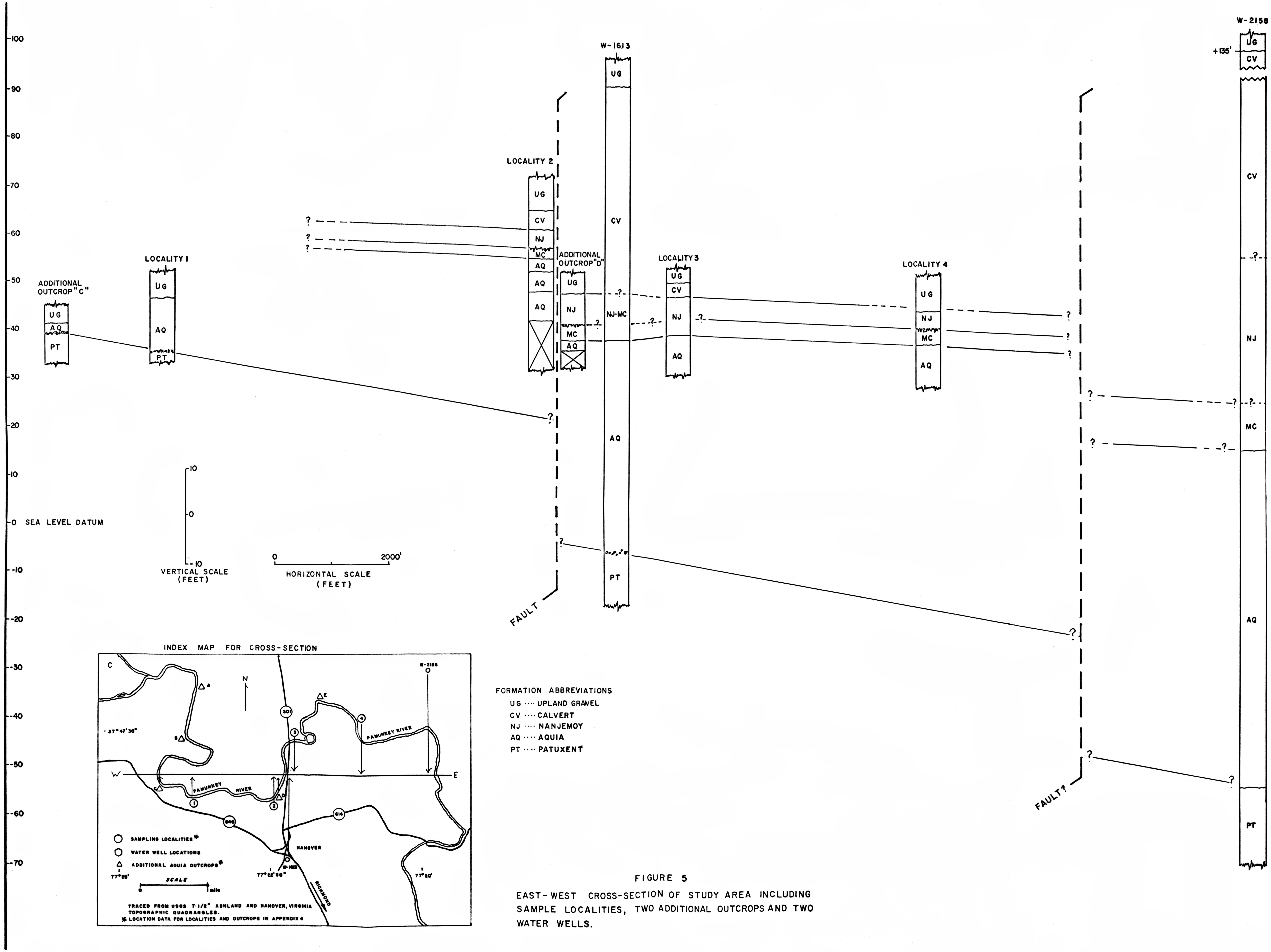

FIGURE 5

EAST-WEST CROSS-SECTION OF STUDY AREA INCLUDING SAMPLE LOCALITIES, TWO ADDITIONAL OUTCROPS AND TWO WATER WELLS.

See figures 2, 3 and Appendix fr detailed description of localities and wells.

Locality	Percent Planktonic Species	Benthic Foram Variability Ratio *	Number of Specimens	Sample Number	Anomalinoides midwayensis	Haplophragmoides aquiensis	Spiroplectammina wilcoxensis	Cibicides praecursorius	Globulina gibba	Sigmomorphina terquemiana	Guttulina irregularis	Epistominella minuta	Lagena adepta	Buliminella marylandica	Eponides lotus	Alabamina wilcoxensis	Lagena rancocasensis	Guttulina problema	Dentalina colei	Cibicides irenae
LOCALITY 4	5.6	PL 7	89	10			11		2	1	1				11	1			3	
LOCALITY 4	3.6	12	465	9			102	26	12	4	4	2	1		29	3			16	19
LOCALITY 4	3.3	PL 12	150	8			14	35	3			1			5	4			6	3
LOCALITY 4	2.7	9	448	7			64	60	21			1			18	2			21	11
LOCALITY 4	1.2	8	500	6			26	90	23	1		8			31	3			6	6
LOCALITY 4	1.6	5	430	5			14	109	12	2					50				13	
LOCALITY 4	1.5	6	471	4			25	145	7	2					20				7	4
LOCALITY 4	5.0	8	436	3			32	148	12	2	5	4			12	5			7	2
LOCALITY 4	2.9	4	486	2			5	213	1	3	1		1	2	5	3			3	1
LOCALITY 4	.6	6	496	1			11	186	6	7					11	4			6	1
LOCALITY 2 (Lowest 6 Feet)	1.7	12	474	6		1	30	72	14	7					22	17			15	8
LOCALITY 2 (Lowest 6 Feet)	3.2	8	475	5			42	78	15	7	2				14	7			7	12
LOCALITY 2 (Lowest 6 Feet)	.33	5	603	4			15	126	5	6					13	3			15	2
LOCALITY 2 (Lowest 6 Feet)	.19	5	529	3			4	156	6	3		1			13	6			12	2
LOCALITY 2 (Lowest 6 Feet)	7.2	7	502	2			6	175	13	4		3			12	8			25	4
LOCALITY 2 (Lowest 6 Feet)	1.7	9	481	1		1	10	154	14	12		2			5	12			10	5
LOCALITY 3	0	5	467	9			6	215	8	4					1	11			11	1
LOCALITY 3	.43	9	462	8			4	193							4	14			9	
LOCALITY 3	.68	9	296	7			6	125	9	4	2	2	1		1	11			3	
LOCALITY 3		L		6																
LOCALITY 3		L		5																
LOCALITY 3		L		4																
LOCALITY 3		L		3																
LOCALITY 3		L		2																
LOCALITY 3	.68	9	441	1		1	3	65	23	4		4				4	2		8	9
LOCALITY 1	7.2	5	474	13	395	1	9	33	9	10		1				5	2			
LOCALITY 1	3.4	3	441	12	401		6			8		1				1		2		
LOCALITY 1	2.9	3	479	11	442		7	6	1	10	3					1	1			
LOCALITY 1	2.9	1	490	10	469		1	5	11				1					2	1	
LOCALITY 1	2.0	1	447	9	424	3			8	4						3				1
LOCALITY 1	2.1	1	476	8	458		1		6	7				1				1		1
LOCALITY 1	.21	1	478	7	473		1		1								1	1	1	
LOCALITY 1	1.22	1	490	6	469				11	3					5	2				
LOCALITY 1	10	5	60	5	5		3	43	1	3	1	1	1	2						
LOCALITY 1	18	4	33	4	3		2	23	3	2										
LOCALITY 1	0	3	8	3	6	1	1													
LOCALITY 1		L		2																
LOCALITY 1		L		1																
			12,577	TOTAL SPECIMENS																

Locality	Sample Number	Ammobaculites sp.	Chilostomella ovoidea	Karreria cervicula	Nonionella aquiensis	Gaudryina sp.	Cibicides howelli	Lamarkina marylandica	Oolina virginiana	Nonion mauricense	Cibicidoides hilgardi	Ceratobulimina perplexa	Lagenammina pseudodifflugiformis	Bulimina cacumenata		Bulimina ovata
LOCALITY 4	10				1											
LOCALITY 4	9										2	1				
LOCALITY 4	8										10	1				
LOCALITY 4	7										8	1				
LOCALITY 4	6										2					
LOCALITY 4	5															
LOCALITY 4	4										1					
LOCALITY 4	3				1											
LOCALITY 4	2										3					
LOCALITY 4	1															
LOCALITY 2 (Lowest 6 Feet)	6										6	2				
LOCALITY 2 (Lowest 6 Feet)	5										2					
LOCALITY 2 (Lowest 6 Feet)	4										2					
LOCALITY 2 (Lowest 6 Feet)	3															
LOCALITY 2 (Lowest 6 Feet)	2											1				
LOCALITY 2 (Lowest 6 Feet)	1						1			1	1					
LOCALITY 3	9															
LOCALITY 3	8							1			1					2
LOCALITY 3	7			1				1			3					1
LOCALITY 3	6															
LOCALITY 3	5															
LOCALITY 3	4															
LOCALITY 3	3															
LOCALITY 3	2															
LOCALITY 3	1										3	2				224
LOCALITY 1	13						1			4		2	1	1		
LOCALITY 1	12						10			7	2	2	1			
LOCALITY 1	11			1				3	1	3						
LOCALITY 1	10															
LOCALITY 1	9		1	1	1	1										
LOCALITY 1	8	1														
LOCALITY 1	7															
LOCALITY 1	6															
LOCALITY 1	5															
LOCALITY 1	4															
LOCALITY 1	3															
LOCALITY 1	2															
LOCALITY 1	1															

Locality	Sample Number	Lenticulina midwayensis	Trifarina wilcoxensis	Nodosaria latejugata carolinensis	Dentalina wilcoxensis	Polymorphina subrhombica	Rectoglandulina aquiensis	Polymorphina sp.	Lagena pseudocostata	Gyroidinoides octocameratus	Lagena distincta		Fursenkoina wilcoxensis	Neoconorbina humilis	Cibicides marylandicus	Turrilina robertsi	Dentalina cocoaensis	Pulsiphonina prima
LOCALITY 4	10	53																
LOCALITY 4	9	213			2		1		1	6			5				3	5
LOCALITY 4	8	52		2						5			1					3
LOCALITY 4	7	207								4			3				1	16
LOCALITY 4	6	276		1						2			2				1	10
LOCALITY 4	5	219								3			1					4
LOCALITY 4	4	244		1					3	2							2	7
LOCALITY 4	3	192							1				6					2
LOCALITY 4	2	238	1						1	2			1			1		
LOCALITY 4	1	251		1						1			7					3
LOCALITY 2 (Lowest 6 Feet)	6	241		5					3	1					1		5	11
LOCALITY 2 (Lowest 6 Feet)	5	273								4								8
LOCALITY 2 (Lowest 6 Feet)	4	404								1							1	9
LOCALITY 2 (Lowest 6 Feet)	3	316		4	1		1											4
LOCALITY 2 (Lowest 6 Feet)	2	236							3	3								5
LOCALITY 2 (Lowest 6 Feet)	1	232			1			4	6	2						1	1	1
LOCALITY 3	9	201		2					2							1	2	2
LOCALITY 3	8	225		3		1			1	2				1	1			
LOCALITY 3	7	119	1	2		1					1		2					
LOCALITY 3	6																	
LOCALITY 3	5																	
LOCALITY 3	4																	
LOCALITY 3	3																	
LOCALITY 3	2																	
LOCALITY 3	1	70	1	1	2	1	1	1	1	11								
LOCALITY 1	13																	
LOCALITY 1	12																	
LOCALITY 1	11																	
LOCALITY 1	10																	
LOCALITY 1	9																	
LOCALITY 1	8																	
LOCALITY 1	7																	
LOCALITY 1	6																	
LOCALITY 1	5																	
LOCALITY 1	4																	
LOCALITY 1	3																	
LOCALITY 1	2																	
LOCALITY 1	1																	

FIGURE 6A

PL - Partially leached
L - Leached
*Benthonic Foram Variability Ratio = number of benthonic species comprising 95% of number of specimens in sample

Locality	SAMPLE NUMBER	Dentalina virginiana	Bullopora sp.	Bulimina virginiana	Trochammina howei	Marginulina toulmini	Chiloguembelina crinita	Robertina wilcoxensis	Caucasina marylandica	Saccamina sp.	Rectoglandulina tenuistriata		Pseudouvigerina triangularis	Anomalinoides pseudowelleri	Cibicides neelyi		Globorotalia perclara	Globorotalia reissi	Globorotalia aquiensis	Globigerina triloculinoides	Globorotalia acuta	Globorotalia tribulosa	Globorotalia aequa	Globorotalia imitata	Globorotalia stabocella	Globorotalia esnaensis	Globigerina linaperta	Globorotalia wilcoxensis	Globorotalia occlusa	Globorotalia subbotinae	Globorotalia apanthesma	Globorotalia pseudotopilensis	Globigerina primitiva	Globorotalia chapmani	Globigerina soldadoensis soldadoensis	Globorotalia hispidicidaris
LOCALITY 4.	10													5													1	1						1		1
	9	1		1		1	1			3	1			25							2	2	3	1			5	13	1	1					1	
	8					3								2							1		1					1								
	7	1				3				1				5				3			1	1					3	1								
	6		2	4		1			1	3					1			5									1	1						1		
	5					1								2				1			1							1					1			
	4	1																			1	1	1				1	3				1				
	3	1								3			1				1	5			3		4				1	2	1	1	1					
	2									1			1					12							1											
	1	1																3																		
LOCALITY 2 (Lowest 6 Feet)	6					2	2	1	2	5	1									1	1		3													
	5	1			2	1														2		2	4	1												
	4	1																					1													
	3																					1														
	2	2		2														1		1			2													
	1	4	1															1		3		4				1										
LOCALITY 3	9																																			
	8																						1													
	7																						1		1											
	6																																			
	5																																			
	4																																			
	3																																			
	2																																			
	1																			1			1													
LOCALITY 1	13																23			2		1	5													
	12																9						4													
	11																8		1		2	1														
	10																9		1	2	2															
	9																8	1	1																	
	8																8		1	1																
	7																1																			
	6																5		1																	
	5																2	1																		
	4																4																			
	3																																			
	2																																			
	1																																			

FIGURE 6B