State of Delaware
DELAWARE GEOLOGICAL SURVEY
Robert R. Jordan, State Geologist

REPORT OF INVESTIGATIONS NO. 48

GEOLOGIC AND HYDROLOGIC STUDIES OF THE OLIGOCENE – PLEISTOCENE SECTION NEAR LEWES, DELAWARE

Richard N. Benson, Editor

Contributions by

A. Scott Andres
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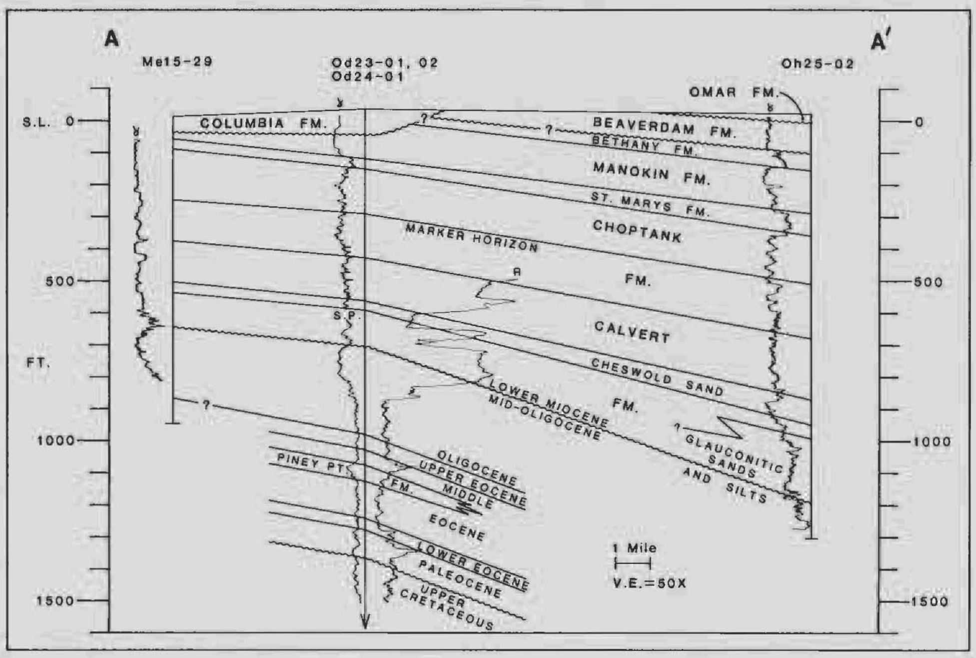

University of Delaware
Newark, Delaware

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GEOLOGIC AND HYDROLOGIC STUDIES OF THE OLIGOCENE – PLEISTOCENE SECTION NEAR LEWES, DELAWARE

Richard N. Benson, Editor

ABSTRACT

Borehole Oh25-02, located about 3 miles southwest of Lewes, Delaware, ends at a total depth of 1,337 ft in a mid-Oligocene glauconitic silt unit. It penetrated 317 ft of glauconitic sands and silts between the base of the Calvert Formation at a depth of 1,020 ft and total depth. A hiatus at 1,218 ft separates an outer neritic lower Miocene interval (*Globorotalia kugleri* Zone) above it from a deep upper bathyal mid-Oligocene (G. *opima opima* Zone) section below; the lower section is characterized by abundant large uvigerinid benthic foraminiferal species representing the transition from *Uvigerina tumeyensis* to *Tiptonina nodifera*. Similar uvigerinid assemblages identify the mid-Oligocene unit in boreholes near Bridgeville and Milford, Delaware; Cape May, New Jersey; and Ocean City, Maryland. Updip from these boreholes, the Calvert Formation, of latest Oligocene–middle Miocene age in Delaware, unconformably overlies middle Eocene glauconitic sands of the Piney Point Formation. The juxtaposition of the downdip mid-Oligocene rocks against the updip middle Eocene rocks can best be explained by a fault between the two regions.

Lower–middle Miocene silts and subordinate sands of the Calvert Formation are succeeded by middle–upper Miocene sands and subordinate silts of the Choptank Formation at the 710-ft depth in Oh25-02. Shell fragments are major components of the drill cuttings from both formations. The upper Miocene silts of the St. Marys Formation are in sharp contact with the Choptank Formation at 382 ft. Foraminifers from these three formations indicate primarily inner to middle neritic paleoenvironments. The upper Miocene sands of the Manokin formation overlie the St. Marys Formation at 310 ft. The predominantly silty Bethany formation is in sharp contact with the Manokin at 173 ft. The Bethany and overlying sands of the Beaverdam Formation (47–119 ft) are of late Miocene or early Pliocene age. Silty sands with scattered silt and silty clay beds of the Pleistocene Omar Formation unconformably overlie the Beaverdam at 47 ft in Oh25-02; 12 ft of erosional relief mark that contact as traced between boreholes Oh25-02, -04, and -05. The Manokin, Bethany, Beaverdam, and Omar formations were deposited in a variety of marginal marine to fluvial paleoenvironments.

Numerous hard-drilling streaks were encountered in nearly all units penetrated by borehole Oh25-02. Dolomite- and iron oxide-cemented sandstones and siltstones comprise most of these indurated layers.

Ground-water observation wells were completed in the upper Choptank Formation at a depth of 410 ft in Oh25-02 and in the Manokin aquifer at a depth of 240 ft in Oh25-03. Water from the Manokin is of good quality (chloride 14 mg/l), but that from the Choptank is high in dissolved solids (1,630 mg/l) and contains relatively high concentrations of chloride (600 mg/l), sodium (540 mg/l), and sulfate (290 mg/l). Hydrographs show that heads in the Manokin are higher and respond more rapidly to precipitation than those in the Choptank.

INTRODUCTION

Richard N. Benson

Coastal Sussex County is the site of the greatest thickness of the unconsolidated Mesozoic-Cenozoic sediments of the Atlantic Coastal Plain of Delaware. In this area, defined by Talley and Andres (1987) as lying between 75°15' W longitude on the west and the Atlantic shoreline on the east, depth to pre-Mesozoic basement (base of the Coastal Plain sediments) ranges from about 5,500–6,600 ft (1.7–2.0 km) on the north beneath the Delaware Bay shoreline to 6,600–10,500 ft (1.7–3.2 km) on the south at the Delaware-Maryland state boundary (Benson, 1984, 1990).

Until 1986, when Oh25-02, the subject of this report, was drilled, only three boreholes in the area reached depths of 1,000 ft or greater (Talley and Andres, 1987). Two holes penetrated the entire Chesapeake Group (in order of decreasing geologic age the Calvert, Choptank, St. Marys, Manokin, and Bethany formations [Andres, 1986]), but geophysical logs are available for only one, Ni31-07 at Lewes (Fig. 1). The deepest penetrations of other boreholes in coastal Sussex County were into the upper Choptank or the St. Marys formations (Andres, 1986). Also until 1986, there were no chemical analysis data on waters from aquifers below the Manokin in this area (Talley and Andres, 1987, Table 4).

Working with sufficient borehole data from stratigraphic units above the Choptank Formation, Andres (1986) interpreted and mapped depositional sequences of the upper Chesapeake Group, a wave- and fluvial-energy dominated delta complex. Groot et al. (1990) added their interpretations on the ages and depositional environments of the uppermost stratigraphic units present in coastal Sussex County, the Bethany, Beaverdam, and Omar formations.

In order to obtain samples for biostratigraphic and lithologic study and a suite of geophysical logs of the entire Chesapeake Group and younger units and the sediments below the Chesapeake Group, a deep stratigraphic test hole was needed. The best site for meeting these objectives was the northern part of coastal Sussex County where those stratigraphic units are the thinnest.

Results of study of data from a deep stratigraphic test hole would add to knowledge of the geologic framework of the U. S. Atlantic continental margin. Accordingly, a proposal was submitted to fund the drilling from the

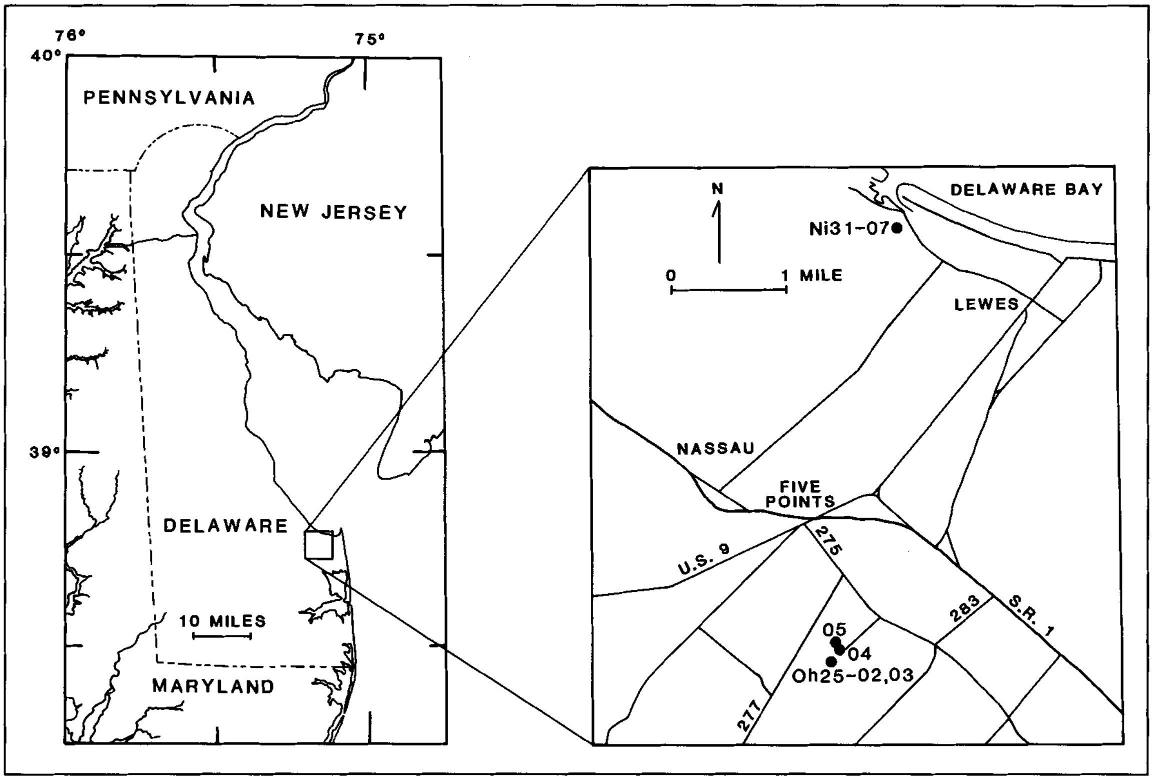

Figure 1. Map showing locations of Ni31-07 and Oh25-02 through -05, Lewes area.

Continental Margins Program supported by the Minerals Management Service of the U. S. Department of Interior through their cooperative agreement with the Association of American State Geologists. Funds from the third year of that program were granted to the Delaware Geological Survey (DGS) for drilling and logging the test hole.

In 1986, a site about 3 miles southwest of Lewes, Delaware, was selected for the borehole designated Oh25-02 (Fig. 1) under the DGS well-numbering system (Talley and Windish, 1984). The hole was drilled to a total depth of 1,337 ft. A major objective was to obtain drill cuttings and cores and to determine the age of glauconitic sediments expected to occur beneath the Calvert Formation, which contains little glauconite. In nearby borehole Ni31-07 at Lewes (Fig. 1, Table 1), glauconitic silts and silty sands were cored between 985 and 1,035 ft. At that time (1979), the first interpretation was that the glauconitic sediments were of the middle Eocene Piney Point Formation. However, rare foraminifers from the cores were later identified as lower Miocene species similar to those found in the overlying Calvert Formation. This discovery was unexpected because in boreholes to the north, the Calvert unconformably overlies glauconitic sands of the Piney Point, e.g., Nc13-03 near Greenwood, Delaware (Talley, 1975; Benson and Jordan, 1978). Benson et al. (1985) discovered that in borehole Je32-04 at the Dover Air Force Base, lowermost Calvert sediments are of uppermost Oligocene age and that cores from the upper 34 ft of the underlying glauconitic sands of the Piney Point contain latest Oligocene foraminifers. Benson et al. (1985) concluded that the upper 34 ft of the Piney Point in Je32-04 were reworked during a late Oligocene transgression.

TABLE 1
Borehole information

Borehole (DGS well number)	Latitude	Longitude	Altitude of ground surface (ft) (estimated)	*Total depth (ft)
Ni31-07	38°47'05"N	75°09'35"W	15	1,035
Oh25-02	38°43'50"N	75°10'14"W	20	1,337
Oh25-03	38°43'50"N	75°10'14"W	20	240
Oh25-04	38°43'53"N	75°10'11"W	25	61
Oh25-05	38°43'59"N	75°10'13"W	25	60

*All depths mentioned in this report are measured from ground surface.

A second objective of Oh25-02 was to determine the quality of water sampled from aquifers that elsewhere in coastal Delaware are important sources of fresh water. For this purpose an observation well was completed in the upper Choptank Formation at a depth of 410 ft in Oh25-02, and a second well, Oh25-03, was drilled and completed in the Manokin aquifer at a depth of 240 ft.

Results of lithostratigraphic, biostratigraphic, and hydrologic studies appear as separately authored chapters. Because Oh25-02 recovered mid-Oligocene sediments previously unknown to occur in the Delaware subsurface, samples from other boreholes in southern Delaware, New Jersey, and Maryland were also examined to determine if the unit is present elsewhere. A chapter on subsurface correlations presents the results of that study.

Samples from the upper 130 ft of Oh25-02 were sufficiently homogenized by the drilling process that the Omar and Beaverdam formations could not be differentiated by examination of drill cuttings alone. However, cores from two nearby boreholes, Oh25-04 and -05 (Fig. 1), plus exposures in a borrow pit at the site provided adequate samples for differentiation. A separate chapter reports the results of study of those samples.

Acknowledgments

In addition to the authors, well-site geologists included John H. Roberts and Kenneth D. Woodruff. Daniel Phelan and Anthony Tallman of the U. S. Geological Survey (USGS) participated in well development, water sample collection, and field analysis for water quality. Pierre Lacombe of the USGS graciously provided a copy of the gamma-ray log he recently ran of the upper 1,560 ft of the Dickinson No. 1 borehole, Cape May County, New Jersey. Kelvin W. Ramsey, William S. Schenck, and Robert Spring drafted the figures for this report. American Water Well Systems, Inc., of Seaford, Delaware, drilled Oh25-02 and -03 and completed the observation wells in those holes.

Robert R. Jordan, Nenad Spoljaric, and Kenneth D. Woodruff of the Delaware Geological Survey, Thomas G. Gibson of the U. S. Geological Survey, and Peter J. Sugarman of the New Jersey Geological Survey critically reviewed the manuscript and offered helpful suggestions for its improvement.

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OPERATIONAL SUMMARY, Oh25-02 AND -03

John H. Talley

The first attempt to drill Oh25-02 began October 27, 1986, and reached a depth of 413 ft., but because of problems with maintaining drilling mud circulation, the borehole was abandoned. The rig was moved 16 ft away and a new hole was drilled between October 28 and 31 to a total depth of 1,337 ft from land surface elevation of approximately 20 ft. Sediments penetrated range in age from Oligocene to Pleistocene.

The hole was drilled by hydraulic rotary method using a fresh-water bentonite mud as the circulating fluid. Delaware Geological Survey personnel collected drill cuttings at ten-foot intervals. Cuttings were circulated to the surface after drilling each ten-foot interval and before drilling the next interval. Under the DGS system, each sample was numbered in the 80,000 series for ditch (cuttings) samples from in-state boreholes. Geologist's and driller's descriptive logs were done on site.

Gamma-ray, dual-induction (including spherically focused log), caliper, and formation density logs were run by Schlumberger Well Services, Inc.; gamma-ray and differential single point resistivity logs were run by the DGS (Table 2). Sixteen sidewall cores were taken but were lost downhole during the latter part of the coring operation when the cable broke.

The borehole was completed as an observation well with the screen set at 390 to 410 ft in the first sand (uppermost Choptank sand) below the St. Marys Formation. A second observation well, Oh25-03, located approximately 30 ft from Oh25-02, was drilled to 240 ft and screened from 210 to 220 ft and 232 to 240 ft in the Manokin aquifer within the Manokin formation.

TABLE 2
Geophysical logging information, Oh25-02

Logger	Log type	Depth interval (ft)
Schlumberger	Dual Induction/ Gamma Ray	25–1,331
Schlumberger	Formation Density/ Gamma Ray/Caliper	22–252
Delaware Gelogical Survey	Single Point Resistivity	56–1,214
Delaware Gelogical Survey	Gamma Ray	5–1,220

Samples for water quality analyses were collected from wells Oh25-02 and Oh25-03. Field analyses were completed by the DGS and U. S. Geological Survey (USGS) Water Resources Division. Laboratory analyses were performed by the USGS.

LITHOSTRATIGRAPHY, Oh25-02

A. Scott Andres and John H. Talley

The lithologic analysis of Oh25-02 is based on evaluation of drill cuttings, thin sections, and geophysical log data (Plate 1, Appendix A). Lithostratigraphic units were defined, in part, by correlation with lithologic and geophysical log data from other boreholes.

Hard-drilling streaks were encountered in nearly all of the units penetrated by the borehole. Analyses of rock fragments picked from the cuttings samples of those intervals included examination by binocular microscope, petrographic microscope study of thin sections, and testing for carbonate minerals with 10% HCl.

Reconnaissance petrographic analysis of thin-sectioned rock chips revealed a complex assortment of cement types and textures indicating that a variety of diagenetic processes have affected the rocks. Further study will be required before all cements can be identified.

Omar and Beaverdam Formations (0–119 ft)

The Omar and Beaverdam formations cannot be differentiated on the basis of information provided by drill cuttings alone. The contact between the two formations at a depth of 47 ft is marked by the deflection of the gamma-ray log from the sandier Beaverdam to the siltier Omar above (Plate 1 and Ramsey, this report). Both formations comprise the regionally important Columbia aquifer which supplies water to wells and provides base flow to local streams.

Samples from 0 to 130 ft consist of gray and orange, fine to coarse quartz sand with trace amounts of pebbles; fine to medium gravel occurs in the 108- to 119-ft and 123- to 130-ft intervals. One thin (4 ft), dense, gray, silty and clayey bed is present from 80 to 84 ft. The Omar and Beaverdam interval is largely unconsolidated, although several thin (<1 ft) iron oxide-cemented layers were encountered between 50 and 60 ft. Fossil content is limited to very rare lignitized plant remains.

On the gamma-ray log, the contact between the Beaverdam and the underlying Bethany formation is interpreted at 119 ft, but the first samples from the Bethany were recovered from the 128- to 138-ft interval (sample no. 82611); the geologist on site detected the lithologic change in the lower half of that interval. Drilling-mud circulation problems and hole-diameter changes probably altered the mud velocity from its estimated value; therefore, the indicated depths for samples from this interval may deviate from their actual depths.

Bethany Formation (119–173 ft)

The Bethany formation is an informal lithostratigraphic unit (Andres, 1986) of late Miocene or early Pliocene age (Hansen, 1981; Groot et al., 1990). In Oh25-02 it consists of olive-gray, soft, sandy silt and clay with a few 4- to 10-ft thick silt and sand beds. Elsewhere in southeastern Sussex County, the Bethany is sandier and contains important water-bearing zones (e.g., the Pocomoke aquifer). The unit is unconsolidated. Fossils consist of lignitized and pyritized plant remains.

Manokin Formation (173–310 ft)

The Manokin formation, an informal lithostratigraphic unit (Andres, 1986) of late Miocene age (Hansen, 1981), consists of olive-gray, fine to medium, silty sand interbedded with sandy silt. Clean sand intervals from 186 to 215 ft and 231 to 240 ft comprise the Manokin aquifer, an important source of water for coastal Delaware. The formation is unconsolidated. Lignitized and pyritized plant remains, some as large as 1 to 2 inches in diameter, are significant constituents.

St. Marys Formation (310–382 ft)

The St. Marys Formation, of late Miocene age (Hansen, 1981; Benson, this report, p. 8), is a distinctively fine-grained unit of olive-gray, sandy (fine-grained) silt and clay, with minor amounts of shell fragments. It is an important regional subsurface lithologic marker. The unit is relatively impermeable and forms the base of coastal Delaware's fresh-water aquifer system. The formation is largely unconsolidated, although it is partially indurated near the base by dolomite cement.

Choptank Formation (382–710 ft)

The Choptank Formation, a lithologically complex unit of middle to late Miocene age (Benson, this report, p. 7-8), consists of interbedded brown to olive-gray, fine to coarse sand, shell, silt, and clay. The formation contains several relatively permeable zones; however, it is not used as a source of water in the Delaware coastal area.

Indurated layers are common and range in thickness from less than 1 ft to 17 ft. The cement is dolomitic micrite and microsparite and ranges in color from light to dark brown. Rock types range from nearly pure dolomite (wackestone) to grain-supported sandstones and siltstones. Clastic grains generally are of fine to medium quartz sand and silt with variable amounts of partially to wholly recrystallized allochems (mollusk, bryozoan, and sponge fragments; peloids).

Calvert Formation (710–1,020 ft)

Interbedded brown to olive-gray silt, fine to coarse sand, shell, and clay characterize the Calvert Formation of early to middle Miocene age (Benson, this report, p. 7). A thick, upward-coarsening, coarse-grained shell and sand section between 898 and 968 ft is correlative with the Cheswold sand which is an important regional aquifer supplying water to a number of communities located to the north in Kent and Sussex counties, Delaware. Geophysical logs of Oh25-02 indicate that the Cheswold contains salty water.

Indurated layers are common and range in thickness from less than 1 ft to 15 ft. Cement, textures and mineralogies are similar to those found in the Choptank Formation.

Unnamed Glauconitic Sand (1,020–Between 1,151 and 1,172 ft)

This upward coarsening, gray to olive-gray unit of early Miocene age (Benson, this report, p. 7), comprises glauconite (up to 50 percent of sand fraction) and fine to coarse quartz sand with silt and shell. The contact with the underlying glauconitic silt unit is gradational and occurs between 1,151 and 1,172 ft.

Thin, weakly indurated layers are common and are recognized as spikes of higher resistivity on the spherically focused log (Plate 1). Most rock types are grain-supported sandstones. Two types of cement are present. One is dolomite, with both microsparite and micrite textures; the other is a fine-grained, amorphous, non-calcareous material stained dark brown and containing inclusions of dolomite (microsparite) along with opaque euhedral grains and other opaque, possibly organic, material. The predominant cemented grains are of fine to medium glauconite, rimmed and embayed by dark brown to black material; shell and foraminiferal test fragments are also rimmed and embayed by the same material. Other grains include minor amounts of fine quartz sand and silt and rare, partially recrystallized allochems.

Unnamed Glauconitic Silt (1,172–1,337 ft)

The unnamed glauconitic silt unit includes a hiatus separating mid-Oligocene from early Miocene sediments (Benson, this report, p. 6). The predominant lithology is olive-gray silt with lesser amounts of glauconite (up to 30 percent of sand fraction) and quartz sand.

From 1,265 to 1,305 ft, the unit contains several thin (many less than 1 ft) indurated layers; thicker layers are recognized as more resistive zones on the spherically focused log. As in the overlying unit, there are two types of cement. Dominant is the fine-grained amorphous cement with dolomite present as inclusions and thin rims around some glauconite grains. Cement of some rock chips is entirely dolomite, with microsparite textures more common than micrite. Grain-supported and cement-supported textures are present in relatively equal proportions. Grains comprise fine to medium quartz, glauconite, and silt.

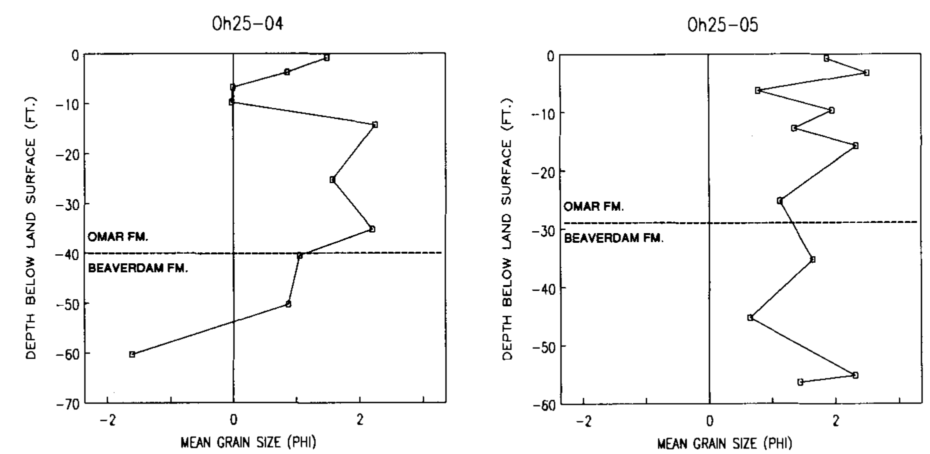
OMAR AND BEAVERDAM FORMATIONS, Oh25-04 AND -05

Kelvin W. Ramsey

The Omar and Beaverdam formations could not be differentiated on the basis of drill cuttings from Oh25-02. Analysis of split-spoon core samples from two nearby holes, Oh25-04 and -05 (Fig. 1, Table 1), confirmed the lithologic and formational break indicated on the gamma-ray log at the 47-ft depth in Oh25-02.

In Oh25-04, cores were taken continuously to a depth of 16.5 ft and then at 5-ft intervals to the total depth of 61 ft. In Oh25-05, core samples are continuous to a depth of 18 ft and then every 5 ft to total depth. Descriptive logs of the two holes are in Appendix A. Samples from the cores were wet-sieved to remove silt and clay; descriptions of the sand residues are in Appendix C. Figure 2 shows textural parameters derived from sieving at half-phi intervals of approximately 100-g splits of selected cores.

Beaverdam Formation that indicates an unconformity varying in altitude from -27 ft in Oh25-02, to -20 ft in Oh25-04, and -15 ft in Oh25-05. Sedimentary structures, such as fine sand-silt-clay laminae, burrows, and horizontal to low-angle cross-beds, and the fine-grained textures indicate that the lower fine sand was deposited in a back-barrier lagoon environment. Silty clay beds containing laminae of organic matter, including plant fragments, found in dredge spoil piles in a borrow pit at the site probably represent associated marsh deposits. The upper pebbly sand is 10 to 15 ft thick and forms a sharp contact with the underlying fine sand. Low- to high-angle cross-beds, laminae of coarse sand and pebbles, and abundant heavy mineral laminae present in the drill cores and adjacent exposures at the site indicate that the upper coarse sands are of dune, beach, overwash, and barrier spit origin. Thin silty clay beds are common within the sands. Pollen analysis of one of these clays indicates a cool-temperate fresh-water deposit with the palynoflora dominated by



SAMPLE #	DEPTH (FT.)	MEAN SIZE (PHI)	SORTING (PHI)	SKEWNESS
82953	0.75	1.49	1.10	-0.56
82955	3.75	0.86	1.13	-0.25
82957	6.75	-0.01	1.32	-0.13
82959	9.75	-0.03	1.33	-0.18
82963	14.25	2.25	1.29	-0.28
82966	25.25	1.57	0.83	-0.27
82968	35.25	2.20	0.93	-0.03
82970	40.50	1.05	1.28	-0.15
82972	50.25	0.87	1.62	-0.22
82974	60.25	-1.61	2.92	0.13

SAMPLE #	DEPTH (FT.)	MEAN SIZE (PHI)	SORTING (PHI)	SKEWNESS
82975	0.75	1.87	0.62	-0.19
82977	3.25	2.51	0.42	0.14
82979	6.25	0.78	1.17	0.31
82981	9.75	1.95	1.41	-0.27
82983	12.75	1.35	1.83	-0.35
82985	15.75	2.33	1.73	-0.33
82987	25.15	1.12	1.64	-0.14
82989	35.25	1.65	0.90	0.38
82991	45.15	0.65	0.73	-0.22
82993	55.15	2.31	1.54	-0.25
82994	56.25	1.44	1.10	0.32

Figure 2. Textural parameters (Lewis, 1984, p. 75) of samples from the Omar and Beaverdam formations, Oh25-04 and -05. Depths are mid-points of 1.5-ft split-spoon sample intervals.

Groot et al. (1990) reported on the ages, lithologies, and stratigraphic relationships of the Beaverdam and Omar formations. The Beaverdam Formation is a medium sand with discontinuous beds of fine to coarse sand, gravelly sand, and silty clay of late Miocene to late Pliocene age. The Omar Formation, of late Pliocene to Quaternary age, is a heterogeneous unit of fine to coarse sand, silty sand, clayey silt, and silty clay.

At the site of this investigation, the Omar Formation consists of medium to fine silty sands with scattered silt and silty clay beds overlain by a fine to coarse, cross-bedded, pebbly sand (Fig. 2). The lower medium to fine sands of the Omar fill an irregular surface cut into the underlying

pine with some spruce (J. J. Groot, pers. commun., 1990). These clays possibly represent small fresh-water ponds or marshes associated with a barrier spit complex. At the study site, the Omar represents a lagoonal environment transgressed by a beach-barrier-spit complex. The setting would have been similar to the modern Atlantic coast of Delaware.

The entire thickness of the Beaverdam Formation was not penetrated by Oh25-04 or Oh25-05. Beaverdam samples from these holes consist of a medium to coarse sand (Oh25-04, samples 82970, 82972; Oh25-05, samples 82991, 82994) with scattered fine sand (Oh25-05, sample 82993) to silty clay laminae. On the bases of its textures and gamma-ray log signatures, the Beaverdam penetrated by these drill holes is assigned to the upper Beaverdam of Groot et al. (1990). The formation can be distinguished mineralogically from the overlying Omar sands in that it contains more feldspar and has common to abundant grains of rounded and weathered glauconite (Appendix C). Groot et al. (1990) interpreted an estuarine origin for the upper Beaverdam.

BIOSTRATIGRAPHY, Oh25-02

Richard N. Benson

Microfossils were identified in sand fraction residues of drill cuttings samples (approximately 100 to 200 g) from Oh25-02. Because of the potential for contamination by cavings from higher in the drill hole, last appearances of species in geologic time, or "tops," are more reliable than first appearances. However, the drill cuttings from this borehole were collected by drilling ahead 10 ft and circulating the cuttings to the surface before resumption of drilling. This method provided samples that appear to be representative of each 10-ft interval. For this reason, first appearances in time of microfossil species are considered fairly reliable. Macrofossil fragments (mostly mollusks and barnacles) appear to be less representative of the drilled intervals. Coarse-grained sediments containing these larger fragments may be more susceptible to caving than the fine-grained lithologies that contain the majority of the microfossils.

Abundances of benthic foraminifers, planktic foraminifers, diatoms, radiolarians, and ostracodes in each sample are given in Appendix B. Macrofossil fragment abundances include mollusks, barnacles, and vertebrate remains (bone fragments and teeth). Abundances noted for the various fossil groups are based on visual percentage estimates made during microscope examination of the residue samples. Abundances of individual species were determined by number present per sample: <10 specimens = very rare, 10–30 = rare, 30–70 = common, >70 = abundant, and hundreds to significant percentage of the residue = flood.

Biozones, series, and stages are identified on the bases of only a few planktic and benthic foraminiferal marker species and one diatom species. Several intervals are unzoned because of the general paucity of planktic foraminifers, which are rare to very rare in nearly all samples examined. Only one diatom zone was identified; others were not investigated although they may be present. Radiolarians occur in most samples from marine units, but they are generally rare to very rare; although typical Miocene species are present, they are long-ranging forms that do not identify specific radiolarian biozones.

Results of this paleontological study are summarized in Plate 1. The time spans of the biozones and stages are not necessarily represented in their entirety by the drill-hole intervals assigned to them. The geochronometric ages in millions of years (Ma) before present given in Plate 1 and in the following discussion are from Berggren et al. (1985) and are each rounded to the nearest whole number. In the following, the drilled intervals assigned to each stage and biozone are identified, within parentheses, by DGS sample numbers followed by sample depths below ground level.

Mid-Oligocene
Upper Rupelian–Lower Chattian, 33–28 Ma
(82718–82728, 1,218–1,337 ft)

The oldest section drilled is of Oligocene age as defined by the *Globorotalia opima opima* foraminiferal zone. It is separated from the overlying unit of early Miocene age by a hiatus that is recognized by (1) the absence of the youngest Oligocene foraminiferal biozone, the *Globorotalia ciperoensis* Zone, and (2) the abrupt change from a deep upper bathyal paleoenvironment below the hiatus to an outer neritic one above it. Benthic foraminifers are persistently common to abundant or of flood proportions in the Oligocene section. Oligocene marker species (Lamb and Miller, 1984) include *Tiptonina nodifera* and *Uvigerina tumeyensis*. Benthic foraminifers generally considered indicative of Jackson age (late Eocene) (Cushman, 1935; Brown et al., 1972) that are found in the Oligocene section of Oh25-02 include *Anomalina bilateralis, Bulimina jacksonensis, Cibicides speciosus, Marginulina cooperensis, Nodosaria latejugata carolinensis,* and *Siphonina tenuicarinata.*

The bottom sample of the drill hole (82728, 1,328–1,337 ft) yielded a specimen of the planktic foraminifer *Pseudohastigerina micra* that ranges no higher than the lowermost Oligocene biozone, which bears its name. Also in the bottom sample is the only occurrence of *Chiloguembelina cubensis.* According to Berggren et al. (1985) the last occurrence of the genus *Chiloguembelina* marks the Rupelian/Chattian boundary at about 30 Ma. The presence of these two species indicates that sediments older than mid-Oligocene age may have been penetrated by Oh25-02. However, in sample 82728, the two species occur with the mid-Oligocene marker species *Tiptonina nodifera* (common to abundant) and *Globorotalia opima opima.* Whether the concurrence of these younger species with the two older ones is a result of downhole contamination of drill cuttings by the younger species or reworking of the older species into the younger Oligocene sediments cannot be resolved. In their study of an Atlantic slope core hole offshore from North Carolina, Stainforth and Lamb (1981) noted that tiny specimens of *P. micra* likely were reworked into younger Oligocene sediments.

Globorotalia opima opima *Zone, 33–28 Ma*
(82718–82728, 1,218–1,337 ft)

Marker species that identify this zone include *Globorotalia opima opima, G. opima nana, Globigerina angulisuturalis, G. ciperoensis,* and *Chiloguembelina cubensis.*

Lower Miocene
Aquitanian–Burdigalian, 24–17 Ma
(82678–82717, 808–1,218 ft)

The known lower Miocene section of Oh25-02 is identified by one diatom zone, *Actinoptychus heliopelta,* and two planktic foraminiferal zones, *Globorotalia kugleri* and *Globigerinatella insueta* (Plate 1).

The base of the lower Miocene section is the *Globorotalia kugleri* foraminiferal zone which is recognized in only one sample, 82717 (1,208–1,218 ft). The top of the known lower Miocene section is marked by the last occurrence of the diatom *Actinoptychus heliopelta* in sample 82678 at 808 ft. The actual lower/middle Miocene contact may be between the base of the middle Miocene *Globorotalia foshi peripheroronda* Zone(?) at 778 ft and the top of the A. *heliopelta* Zone at 808 ft (Plate 1).

Globorotalia kugleri *Zone, 24–22 Ma* *(82717, 1,208–1,218 ft)*

Globorotalia kugleri s.s. occurs only in sample 82717. Its total range in time identifies the *G. kugleri* Zone (Stainforth and Lamb, 1981). The species might occur higher in Oh25–02 in the unzoned (foraminiferal) interval from 898 to 1,208 ft (samples 82685–82716), but because it is rare, it was not found in that interval.

Actinoptychus heliopelta *Zone, 24–17 Ma* *(82678–82714, 808–1,188 ft)*

The last occurrence of the diatom *Actinoptychus heliopelta* marks the top of the *A. heliopelta* Zone (Abbott, 1978). Although the last appearance of the species occurs below the lower/middle Miocene boundary (Abbott, 1978; Andrews, 1988) its last occurrence in Oh25-02 is used as a marker for the top of the known lower Miocene section because no other marker species (diatom, radiolarian, or foraminiferal) that record that boundary were found. The species has not been reported from below the Miocene (Abbott, 1978). Its lowest occurrence in Oh25-02 is in sample 82714 (1,178–1,188 ft), above the *Globorotalia kugleri* Zone (Plate 1).

Globigerinatella insueta *Zone, 18–17 Ma* *(82680–82684, 838–898 ft)*

This planktic foraminiferal zone is a hybrid concurrent range zone because its identification depends, in part, on its relationship to a diatom zone. The *G. insueta* zone in Oh25-02 is identified on the bases of (1) the presence of *Globigerinoides sicanus* within the interval and (2) the occurrence of that interval below the top of the diatom *A. heliopelta*, therefore, within the lower Miocene section. *G. sicanus* first appears in the lower part of the *Globigerinatella insueta* Zone (Stainforth et al., 1975) which is the uppermost zone of the lower Miocene (Berggren et al., 1985). *Globigerinoides quadrilobatus altiapertura* is also present in the interval with *G. sicanus*; its last appearance is in the lower part of the *Globigerinatella insueta* Zone (Zone N7) according to Stainforth et al. (1975). However, Gibson (1983) indicates that *G. q. altiapertura* ranges into the middle Miocene (upper Zone N8 or lower Zone N9). The interval from 838 to 898 ft in Oh25-02, however, must represent the *Globigerinatella insueta* Zone because that interval is within the lower Miocene *Actinoptychus heliopelta* (diatom) Zone.

Lower–Middle Miocene Burdigalian(?), Langhian(?), 17(?)–15(?) Ma (82676–82677, 778–808 ft)

Planktic foraminiferal marker species are absent between 778 and 808 ft (samples 82676–82677). The contact between lower and middle Miocene rocks should occur somewhere within this interval.

Middle Miocene Langhian(?), Serravallian(?), 15(?)–12(?) Ma (82663–82677, 633–778 ft)

The known middle Miocene section of Oh25–02 is represented by the queried *Globorotalia foshi peripheroronda* Zone. The contact with the upper Miocene section probably occurs somewhere within the unzoned interval between 482 and 633 ft.

Globorotalia fohsi peripheroronda *Zone(?), 15(?)–12(?) Ma (82663–82675, 633–778 ft)*

The very rare occurrences of *Globorotalia fohsi peripheroronda* in samples 82663 and 82671, the only occurrence of *Globorotalia scitula scitula* in sample 82675, and the first appearance of *Orbulina suturalis* in sample 82666 identify the interval from 633–778 ft as no older than the *G. fohsi peripheroronda* Zone (Stainforth et al., 1975). Because all three species range above that zone and the nominal species ranges to within the *G. fohsi lobata/robusta* Zone (Stainforth et al., 1975), the interval could represent a biozone as young as the latter zone (about 12–13 Ma); therefore, the zonal assignment of the interval is queried.

Top of Calvert Formation *(82671, 713–723 ft)*

Prior to this paleontological investigation, the contact between the Calvert and Choptank formations was picked at about 710 ft on the gamma-ray log of Oh25-02. This was done by correlation with the gamma-ray log of Ni31-07 in Lewes, Delaware (Fig. 1), on which the contact was arbitrarily picked at 663 ft at the top of a "shale break" separating a predominantly sand section above (Choptank Formation) from an alternating sand and silt section below (Calvert Formation). This distinction is consistent with Shattuck's (1904) original lithologic descriptions of the two formations. Shattuck (1904) subdivided the formations of the Chesapeake Group (Calvert, Choptank, and St. Marys) into numbered zones that are characterized both by lithology and fossil content. Macrofossil content, therefore, can be used to identify the contacts between the Chesapeake Group formations, and Gardner (1948) did this by means of molluscan fossils from the Hammond well of the Eastern Shore of Maryland.

The tops of five Calvert Formation marker species (Shattuck, 1904; Gardner, 1948) occur in sample 82671, 713–723 ft in Oh25-02, thus corroborating the contact previously picked at 710 ft on the gamma-ray log. The markers include four molluscan species, *Astarte cuneiformis, A. vici-*

na, Chione alveata, Parvilucina prunus, and one bryozoan, *Lepralia maculata.*

Middle–Upper Miocene
Serravallian(?), Tortonian(?), 12(?)–10(?) Ma
(82648–82662, 482–633 ft)

Planktic foraminiferal marker species are absent between 482 and 633 ft (samples 82648–82662). The contact between the middle and upper Miocene sections should occur somewhere within this unzoned interval.

Upper Miocene
Tortonian–Messinian(?), 10(?)–5(?) Ma
(82615–82647, 173–482 ft)

The Tortonian is represented by the *Globorotalia acostaensis* Zone as described below. The unfossiliferous section above this to the base of the Bethany formation includes the upper St. Marys and Manokin formations. Hansen (1981) assigned the St. Marys and the equivalent rocks of the Manokin in Maryland to the upper Miocene on the basis of paleontological studies by others. By correlation with the Maryland section, therefore, the interval in Oh25-02 between the *G. acostaensis* Zone and the base of the Bethany formation would be of Tortonian and/or Messinian age.

Globorotalia acostaensis *Zone, 10(?) to 7–8 Ma*
(82634–82647, 354–482 ft)

The entire late Miocene is the time spanned by this zone as defined by Stainforth et al. (1975). The presence of *Globorotalia acostaensis, G. humerosa,* and *Sphaeroidinellopsis seminulina* in sample 82635 (364–374 ft) is evidence that the middle portion of the zone is represented; this is based on the first occurrence of *G. humerosa* and the last occurrence of *S. seminulina* at about this level (7–8 Ma), whereas the first occurrence of *G. acostaensis* defines the base of the zone (10 Ma) (Stainforth et al., 1975). The mid-zone level is equivalent to the middle of Zone N17 of Blow (1969) (Stainforth et al., 1975). Sample 82635 is from the St. Marys Formation. Hansen (1981) cited a foraminiferal study by R. K. Olsson of a drill core taken from the middle of that formation near Ocean City, Maryland, in which Olsson concluded that the fossil assemblage is associated with Zone N17. Berggren et al. (1985) place the Tortonian/Messinian boundary (6.4 Ma) at about the top of the lower third of Zone N17.

The first occurrence of *Globigerina bulloides apertura* in sample 82647 is used as the base of the *Globorotalia acostaensis* Zone in Oh25-02. Akers (1972, fig. 4) indicated the base of the range of this species at about the middle of Blow's (1969) Zone N16. The upper part of N16 is the basal part of the *G. acostaensis* Zone of Stainforth et al. (1975).

The top of the *G. acostaensis* Zone in Oh25-02 is the last occurrence ("top") of *G. humerosa* in sample 82634. No planktic foraminifers occur above this depth (354 ft) in Oh25-02.

Upper Miocene or Lower Pliocene
(82603–82647, 47–173 ft)

Although no diagnostic microfossils are present in the upper 354 ft of Oh25-02, results of palynological studies nearby can be applied to that sedimentary section. The interval from 47 to 173 ft includes the Beaverdam and Bethany formations (Andres and Talley, this report; Ramsey, this report). Groot et al. (1990) determined a late Miocene or early Pliocene age for the Bethany and lower Beaverdam and a Pliocene age for the upper Beaverdam.

Pleistocene, <0.5 Ma
(82598–82602, 0–47 ft)

The Omar Formation extends from 0 to 47 ft in Oh25-02 (Ramsey, this report). Groot et al. (1990) assigned a Pliocene age to the lower Omar and a Pleistocene age (<0.5 Ma) for the upper Omar. A palynoflora from a nearby outcrop of the Omar indicates a cool-temperate climate (Ramsey, this report) and a Pleistocene age is assumed; therefore, the upper Omar is represented in Oh25-02.

PALEOENVIRONMENTS, Oh25-02

Richard N. Benson

Three broadly defined paleoenvironmental realms were identified from study of the sand-size and coarser fractions of drill cuttings samples of Oh25-02 (Appendix B). Absence of macrofossils and microfossils indicates nonmarine or marginal marine environments for the upper 335-ft interval, which includes the uppermost St. Marys and Manokin through Omar formations (Table 3). Foraminifers, radiolarians, diatoms, and macrofossil shells and fragments

TABLE 3
Paleoenvironments, Oh25-02

Well depth interval (ft)	Paleoenvironment (water depth in ft)	Stratigraphic unit(s)
0–335	Marginal marine/fluvial	Omar, Beaverdam, Bethany, Manokin and uppermost St. Marys formations
335–673	Inner neritic (0–100)	St. Marys and Choptank formations
673–713	Shallow middle neritic (>100)	Lowermost part of Choptank Fm.
713–823	Inner neritic (0–100)	Uppermost Calvert Fm.
823–928	Middle neritic (100–300)	Calvert Fm.
928–958	Inner neritic (0–100)	Calvert Fm.
958–1,018	Middle neritic (100–300)	Lowermost Calvert Fm.
1,018–1,058	Outer neritic (>300)	Uppermost part of unnamed glauconitic sand unit
1,058–1,198	Middle neritic (100–300)	Lower glauconitic sand unit
1,198–1,217	Outer neritic (>300)	Uppermost glauconitic silt unit, including *G. kugleri* Zone
1,217–1,337 (TD)	Deep upper bathyal (1,000–1,200)	Glauconitic silt unit (*G. opima opima* Zone)

(mostly mollusks and barnacles) identify two marine realms –the neritic for the marine Miocene section and upper bathyal for the mid-Oligocene rocks.

The absence of fossils in cuttings samples from the Manokin, Bethany, Beaverdam, and Omar formations precludes direct determination of paleoenvironments for those units. Groot et al. (1990) indicated that (1) the Manokin represents a transition from the shallow marine, muddy shelf environment of the St. Marys Formation to a sandy deltaic system; (2) the Bethany sands and muds were deposited in a deltaic system; (3) the coarse lower Beaverdam is a fluvial deposit (Plate 1) grading upwards into silty sands deposited in an estuarine environment; and (4) the Omar was deposited in a wide variety of marginal marine environments including lagoon, estuary, barrier beach, marsh, and tidal flat, as well as fresh-water bog and swamp. In the vicinity of Oh25-02, Ramsey (this report) interpreted the Omar as lagoonal transgressed by a beach-barrier-spit complex. Groot et al. (1990) interpreted the upper Beaverdam as estuarine.

The entire section of Oh25-02 from 335 ft to total depth was deposited in an open marine environment. Benthic foraminifers occur throughout this interval, but they are rare to very rare (<1% of the sand-size fraction) in nearly 80 percent of the samples and are consistently common to abundant (1–5%) only from 1,200 ft to total depth. Planktic foraminifers are very rare (< 100 specimens per sample) throughout the marine section and are common (1–2%) in only a few samples. Siliceous microfossils (radiolarians and diatoms) are very rare except for a few samples in which they are common. Radiolarians are absent above 543 ft, and diatoms were not observed in the Oligocene section below 1,218 ft.

In Oh25-02, inner (water depth 0–100 ft) to middle (100–300 ft) neritic paleoenvironments are indicated for most of the marine Miocene (Table 3, Plate 1). Occurring in nearly every sample from this interval are, in order of decreasing abundance, *Florilus pizarrensis* (common to abundant in several samples), *Bulimina elongata, Hanzawaia concentrica, Buccella mansfieldi, Valvulineria floridana, Lenticulina americana, Bolivina paula, Uvigerina calvertensis, Buliminella elegantissima, Textularia gramen,* and *Spiroplectammina mississippiensis.* More sporadic and generally very rare to rare in occurrence are *Bolivina calvertensis, Cibicides lobatulus, Nonionella auris,* and *Lagena* spp. This assemblage is characteristic of inner (<30 m) to middle shelf (<60 m or <80 m) paleoenvironments interpreted for the Calvert, Choptank, and St. Marys formations in Maryland (Gernant, 1970; Gibson, 1983).

In Oh25-02, the estimated percentage of planktic foraminifers of the total foraminiferal assemblage per sample from the marine Miocene section is generally less than one. Along the Atlantic margin of the northeastern United States, Gibson (1989) showed that for most of the continental shelf area in water depths less than about 60–80 m, planktic foraminiferal percentages are less than one. Gibson (1983) also determined that for the Calvert, Choptank, and St. Marys formations near Calvert Cliffs, Maryland, planktic foraminifers are either absent or generally less than 2 percent of the total foraminiferal assemblage.

The inner, middle, and outer neritic paleoenvironments designated in Table 3 and illustrated by the curve in Plate 1 were determined on the bases of (1) abundance of shell fragments, (2) abundance and diversity (number of species per sample) of benthic foraminifers, and (3) abundance of planktic foraminifers, radiolarians, and diatoms. Intervals with abundant (2–5% of sand-size and coarser fraction) or flood (>5%) proportions of macrofossil fragments (primarily barnacles and mollusks) represent inner neritic environments. Decreased abundances (rare to very rare) of shell fragments if accompanied by decreased numbers of benthic foraminiferal species indicate restricted marine to marginal marine conditions (uppermost St. Marys Formation). Most decreases in shell fragments, however, occur where benthic foraminiferal diversity increases and thus indicate probable deeper water environments. Rare shell fragments and slight increases in abundances of planktic foraminifers and radiolarians and in benthic foraminiferal diversity indicate a shallow middle neritic environment between 673 and 713 ft. The middle neritic environment between 823 and 928 ft is marked by a decrease in shell fragments and a sharp increase in abundance and diversity of benthic foraminifers; planktic foraminifers exceed 5 percent of the total foraminiferal assemblage in sample 82679 at the top of this interval. In the deep middle neritic part of this interval, between 868 and 898 ft, *Bolivina marginata multicostata* is common to abundant, radiolarians are rare to common, and abundances of planktic foraminifers and diatoms increase slightly. The Miocene section below 958 ft represents middle or outer neritic paleoenvironments; shell fragments are rare to very rare below that depth. Between 1,018 and 1,058 ft, planktic foraminifers become common (30–40% of the total foraminiferal assemblage in sample 82699), and benthic foraminifers are abundant; a shallow outer neritic environment is indicated for this interval. Samples 82716 and 82717 at the base of the Miocene section also indicate outer neritic water depths; benthic foraminifers increase in abundance and diversity and planktic foraminifers become common and comprise 30 to 50 percent of the total foraminiferal assemblage.

Average benthic foraminiferal diversity for inner neritic intervals is 12 (general range is 8–16; range between extremes is 3–22), for middle neritic intervals it is 15 (general range 10–20; extreme range 10–29), and for the outer neritic intervals it is 22 (general range 17–27; extreme range 15–28).

The most abundant (common to abundant; flood in sample 82718) and diverse benthic foraminiferal assemblages occur in the mid-Oligocene section below the unconformity at 1,218 ft; they indicate a deep upper bathyal paleoenvironment. Diversity averages 36 and ranges generally between 30 and 43 (range between extremes is 24–46). Benthic foraminiferal species present only in this interval are, in order of decreasing abundance, *Tiptonina nodifera, Buliminella curta, Uvigerina glabrans*(?), *Bulimina ovata, Gyroidinoides soldanii, Gyroidina scalata, Uvigerina peregrina, Cassidulinoides* sp., *Bulimina jacksonensis, Cyclammina cancellata, Uvigerina tumeyensis, Melonis* sp., *Siphonina tenuicarinata, Pullenia eocenica, Anomalina bilateralis, Nodosaria latejugata carolinensis, Cibicides speciosus, Marginulina cooperensis,* and *Sphaeroidina bulloides.* Benthic species present that are also persistent in the overlying Miocene rocks include *Florilus pizarrensis* (common to abundant in several samples), *Bulimina elongata, Lenticulina americana, Bolivina paula, Hanzawaia concentrica,* and *Uvigerina calvertensis*. Shell fragments are rare to very rare and probably are downhole contaminants from the overlying Miocene rocks.

Although the Oligocene benthic foraminiferal assemblage indicates an upper bathyal paleoenvironment, planktic foraminifers are rare to very rare and only in one sample (82718, 1,218–1,228 ft) are they common (25–30% of the total foraminiferal assemblage). In upper bathyal water depths of the upper continental slope of the northeastern United States, Gibson (1989) determined that planktic foraminifers generally comprise 40 to 80 percent of the total foraminiferal assemblage. However, in comparable water depths in basins within the Gulf of Maine, relative abundances of planktic foraminifers greater than 20 percent are uncommon. Gibson (1989) attributed this to the lowered salinity and increased turbidity resulting from mixing of oceanic waters with coastal waters. During deposition of the Oligocene sediments of Oh25-02, the Salisbury Embayment of the U. S. mid-Atlantic Coastal Plain may have been a similar region of mixing of coastal and oceanic waters. Benthic foraminifers indicate the real water depths because they were not affected by the reduced salinity and increased turbidity of the surface waters.

NOTES ON SELECTED TAXA, Oh25-02

Richard N. Benson

Taxa illustrated in plates 2-4 and listed alphabetically below were selected on the bases of (1) their stratigraphic utility in this study or in studies by other authors (Brown et al., 1972; Lamb and Miller, 1984), (2) their being the dominant representatives of the benthic foraminiferal assemblages, and/or (3) their being indices to paleobathymetric zones. Original references are not given; those included are the ones used in identifying the taxa. Illustrated specimens are housed at the Delaware Geological Survey. Depths corresponding to sample numbers are given in Appendix B.

Diatom

Actinoptychus heliopelta Grunow

Plate 3, figure 9

Actinoptychus heliopelta Grunow, Andrews, 1988, p. 14, pl. 1, figs. 1,2; pl. 5, figs. 1,2.

This diatom species is used to identify lower Miocene rocks because key foraminiferal and radiolarian species that mark the top of the lower Miocene have not yet been found in Delaware borehole samples. Both Abbott (1978) and Andrews (1988) determined that the *A. heliopelta* zone does not occur at the top of the lower Miocene; therefore, the first downhole occurrence of the species indicates upper but not necessarily uppermost lower Miocene.

Foraminifers

Anomalina bilateralis Cushman

Plate 3, figure 5

Anomalina bilateralis Cushman, Cushman, 1935 p. 50, pl. 21, figs. 4, 5.

Individuals of this species are rare in the lower part of the Oligocene section of Oh25-02. Brown et al. (1972) included *A. bilateralis* as one of the species characteristic of the Jackson Stage (upper Eocene). Cushman (1935) reported that it is widely distributed in the lower Oligocene Vicksburg Group but also is present in much fewer numbers in the upper Eocene.

Bulimina elongata d'Orbigny

Plate 3, figure 4

Bulimina elongata d'Orbigny, Dorsey, 1948, p. 303, pl. 36, figs. 5, 6.

This species is present (common to abundant in many samples) throughout the marine Oligocene and Miocene sections of Oh25-02.

Bulimina jacksonensis Cushman

Plate 2, figure 17

Bulimina jacksonensis Cushman, Cushman, 1935, p. 35, pl. 13, figs. 7–9; 1948, p. 234, pl. 18, fig. 17; Morkhoven et al., 1986, p. 271, pl. 90.

Individuals of this species are rare in the Oligocene section of Oh25-02. Their presence extends the latest known occurrence of *B. jacksonensis* from early Oligocene (Morkhoven et al., 1986) to middle Oligocene. Although Brown et al. (1972) included *B. jacksonensis* as one of several benthic foraminiferal species characteristic of the Jackson Stage (upper Eocene), its range into mid-Oligocene rocks indicates it is not confined to the upper Eocene. Specimens from Oh25-02 have generally 10 to 12 longitudinal costae, as illustrated by Cushman (1948), rather than the usual six to eight described by Cushman (1935).

Buliminella curta Cushman

Plate 3, figure 1

Buliminella curta Cushman, Dorsey, 1948, p. 303, pl. 36, fig. 3.

This species occurs throughout the marine Oligocene–Miocene section of Oh25-02. Its presence along with *Bucella mansfieldi, Bulimina elongata, and Florilus pizarrensis* identifies marine units from the overlying marginal marine to nonmarine Manokin and younger stratigraphic units.

Chiloguembelina cubensis (Palmer)

Plate 2, figures 7–8

Chiloguembelina cubensis (Palmer), Beckman, 1957, p. 89; pl. 21, fig. 21; text-fig. 14, nos. 5–8.

The only occurrence of this species is in the bottom sample of Oh25-02 (82728, 1,328–1,337 ft). Berggren et al. (1985) noted that the last occurrence of the genus *Chiloguembelina* marks the lower/upper Oligocene (Rupelian/Chattian) boundary.

Cibicides speciosus Cushman and Cederstrom

Plate 3, figure 3

Cibicides speciosus Cushman and Cederstrom, Cushman, 1948, p. 244, pl. 20, fig. 13.

This species is present but rare in the Oligocene section of Oh25-02. It was originally described from the upper Eocene Chickahominy Formation of Virginia (Cushman, 1948). Brown et al. (1972) noted it as characteristic of the Jackson Stage (upper Eocene). Cushman (1948) identified this species in samples at 1,220–1,230 ft and 1,250–1,270 ft in the Hammond well near Salisbury, Maryland. Those samples are from the interval containing the same Oligocene-age platy-costate uvigerinid species as found in Oh25-02.

Cyclammina cancellata Brady

Plate 3, figure 6

Cyclammina cancellata Brady, Phleger and Parker, 1951, pt. II, p. 3, pl. 1, fig. 15.

In the northwest Gulf of Mexico, Phleger (1951) found *Cyclammina cancellata* in water depths ranging from 400 to 1,450 m; it occurred most common down to 1,000 m. In my petroleum industry experience with the Gulf Coast Oligocene to Miocene section, I used *C. cancellata* as a good index of the middle bathyal zone (1,500- to 3,000-ft water depth). The rare presence of this species along with common to abundant middle to upper bathyal indicators *Tiptonina nodifera* and *Uvigerina tumeyensis* in the Oligocene section of Oh25-02 indicates a deep upper bathyal paleoenvironment for those sediments.

Florilus pizarrensis (Berry)

Plate 3, figures 7, 8

Nonion pizarrense W. Berry, Dorsey, 1948, p. 300, pl. 35, figs. 6a-c.

Individuals assigned to this species are present in all samples from the marine Oligocene–Miocene section of Oh25-02. In many samples they are abundant and overwhelmingly dominate the foraminiferal assemblage. Other species of *Florilus* present in Oh25-02 and that resemble *F. pizarrensis* include *F. grateloupi* and *F. chesapeakensis.*

Globigerina angulisuturalis Bolli

Plate 2, figure 6

Globigerina angulisuturalis Bolli, Stainforth et al., 1975, p. 250, fig. 104.

This species is very rare in samples 82727 and 82728 (1,318–1,337 ft) from Oh25-02.

Globigerina bulloides apertura Cushman

Plate 4, figure 14

Globigerina bulloides apertura Cushman, Akers, 1972, p. 46, pl. 19, fig. l; pl. 21, fig. 3; pl. 30, fig. 1; pl. 31, fig. 1; pl. 37, fig. 1; pl. 42, fig. 1; pl. 47, fig. 3.

This species is very rare in the upper Choptank–lower St. Marys interval (samples 82635, 82637, 82645, and 82647).

Globigerina ciperoensis Bolli

Plate 2, figure 4

Globigerina ciperoensis Bolli, Stainforth et al., 1975, p. 263, fig. 111.

Very rare individuals of this species occur only in the bottom sample of Oh25-02 (82728, 1,328–1,337 ft)

Globigerinoides quadrilobatus altiapertura Bolli

Plate 4, figure 4

Globigerinoides quadrilobatus altiapertura Bolli, Stainforth et al., 1975, p. 305, fig. 135.

This species is very rare in samples 82682–82685 (868–908 ft).

Globigerinoides sicanus de Stefani

Plate 4, figures 5, 6

Globigerinoides sicanus de Stefani, Stainforth et al., 1975, p. 320, fig. 144.

Very rare individuals of this species occur between 838 and 898 ft (samples 82680, 82681, 82683, and 82684).

Globorotalia acostaensis Blow

Plate 4, figure 11

Globorotalia acostaensis Blow, Stainforth et al., 1975, p. 333, figs. 152–153.

This species is rare in sample 82635 and very rare in samples 82639, 82641, and 82643.

Globorotalia fohsi peripheroronda Blow and Banner

Plate 4, figures 8–10

Globorotalia fohsi peripheroronda Blow and Banner, Stainforth et al., 1975, p. 277, fig. 119.

Very rare occurrences of this species were noted in samples 82663 (633–643 ft) and 82671 (713–723 ft).

Globorotalia humerosa Takayanagi and Saito

Plate 4, figure 13

Globorotalia humerosa Takayanagi and Saito, Stainforth et al., 1975, p. 357, fig. 170.

This species is very rare in samples 82634, 82635, and 82639.

Globorotalia kugleri Bolli

Plate 4, figures 1–3

Globorotalia kugleri Bolli, Stainforth et al., 1975, p. 289, fig. 126.

Only a few specimens of this species were recovered from sample 82717. They show the typical recurved sutures on the spiral side, and the peripheral margin of the last formed chamber is smoothly rounded but asymmetrical with a subangular tendency.

Globorotalia opima nana Bolli

Plate 2, figure 5

Globorotalia opima nana Bolli, Stainforth et al., 1975, p. 297, fig. 131.

Very rare individuals of this species were found in the Oligocene section of Oh25-02 (samples 82718, 82726, and 82727).

Globorotalia opima opima Bolli

Plate 2, figures 1–3

Globorotalia opima opima Bolli, Stainforth et al., 1975, p. 300, fig. 132.

This mid-Oligocene species is very rare in samples 82718 and 82722–82726.

Orbulina suturalis Brönnimann

Plate 4, figure 7

Orbulina suturalis Brönnimann, Stainforth, et al., 1975, p. 325, fig. 147.

Very rare occurrences of this species were noted in samples 82634, 82635, 82638, 82644, 82646, and 82666.

Siphonina tenuicarinata Cushman

Plate 3, figure 2

Siphonina tenuicarinata Cushman, Cushman, 1948, p. 241, pl. 19, fig. 22; Morkhoven et al., 1986, p. 207, pl. 70.

This is one of the species Brown et al. (1972) listed as characteristic of the Jackson Stage (upper Eocene). It is present in the Oligocene section of Oh25-02. Morkhoven et al. (1986) reported that the species is a relatively common form in Oligocene and early Miocene bathyal deposits.

Sphaeroidinellopsis seminulina (Schwager)

Plate 4, figure 12

Sphaeroidinellopsis seminulina (Schwager), Stainforth et al., 1975, p. 317, fig. 142.

This species was found only in sample 82635 (364–374 ft).

Tiptonina nodifera (Cushman and Kleinpell)

Plate 2, figures 14–16

Tiptonina nodifera (Cushman and Kleinpell), Lamb and Miller, 1984, p. 10, pls.20–22, text-figs. 1, 2

Specimens assigned to this species are common to abundant in the Oligocene section of Oh25-02. They have mostly continuous, parallel to subparallel, longitudinal platelike costae, and later chambers that approach an irregular biserial mode. The bathymetric preference of *T. nodifera* is upper to middle bathyal (Lamb and Miller, 1984).

Uvigerina glabrans Cushman(?)

Plate 2, figures 12–13

?*Uvigerina glabrans* Cushman, 1935, p. 40, pl. 15, fig. 21.

This species occurs only in the Oligocene section of Oh25-02 where it is common to abundant. It is smaller than the platy-costate uvigerinids characteristic of that section, and most specimens are nearly smooth or have faint costae. Cushman (1935) noted that *Uvigerina glabrans* is the only smooth species of the Coastal Plain upper Eocene and that it is closely related to *U. cocoaensis*. The smooth uvigerinids from the Oligocene section of Oh25-02 may be representatives of *U. glabrans*.

Uvigerina jacksonensis Cushman(?)

Plate 2, figure 18

?*Uvigerina jacksonensis* Cushman, Lamb and Miller, 1984, p. 9, pl. 16, text-figs. 1, 2.

Rare platy-costate uvigerinids from the Oligocene section of Oh25-02 have predominantly discontinuous costae, restricted to individual chambers. These may be variants of *Uvigerina tumeyensis*, the putative descendant of *U. jacksonensis* (Lamb and Miller, 1984), rather than representatives of *U. jacksonensis* itself. The transition from *U. jacksonensis* to *U. tumeyensis* occurred during early middle Oligocene time before the transition from *U. tumeyensis* to *Tiptonina nodifera* (Lamb and Miller, 1984).

Uvigerina tumeyensis Lamb

Plate 2, figures 9-11

Uvigerina tumeyensis Lamb, Lamb and Miller, 1984, p. 10, pls. 17, 18, text–figs. 1, 2.

Specimens assigned to this species have both continuous and discontinuous, platelike costae. The concurrence of this species with its descendent species *Tiptonina nodifera* in the Oligocene section of Oh25-02 indicates that section is within the *Globorotalia opima opima* planktic foraminiferal zone (Lamb and Miller, 1984). This species is a good indicator of upper to middle bathyal water depths (Lamb and Miller, 1984).

PLATES 2–4

Scanning electron microscope photographs of selected foraminiferal and diatom taxa

PLATE 2

Figure

1-3. *Globorotalia opima opima* Bolli

1. Spiral view, X142, 1,308–1,318 ft, 82726 (DGS sample number), Oligocene.
2. Peripheral view of number 1, X142.
3. Umbilical view of number 1, X141.

4. *Globigerina ciperoensis* Bolli. Umbilical view, X141, 1,328–1,337 ft, 82728, Oligocene.

5. *Globorotalia opima nana* Bolli. Umbilical view, X140, 1,318–1,328 ft, 82727, Oligocene.

6. *Globigerina angulisuturalis* Bolli. Umbilical view, X142, 1,318–1,328 ft, 82727, Oligocene.

7–8. *Chiloguembelina cubensis* (Palmer).

7. Side view, X140, 1,328–1,337 ft, 82728, Oligocene.
8. Edge view of number 7 showing asymmetrical aperture, X141.

9–11. *Uvigerina tumeyensis* Lamb. All X60.9, 1,328–1,337 ft, 82728, Oligocene.

12–13. *Uvigerina glabrans* Cushman(?).

12. Less typical specimen with discontinuous costae present on all chambers, X60.9, 1,258–1,268 ft, 82722, Oligocene.
13. Typical specimen with nearly all chambers either smooth or with faint costae, X60.9, 1,258–1,268 ft, 82722, Oligocene.

14–16 *Tiptonina nodifera* (Cushman and Kleinpell). All X60.9, 1,218–1,228 ft, 82718, Oligocene. The three specimens illustrated show the variability in number of longitudinal costae, the degree to which the costae conform to the contours of the individual chambers, and the tendency for latest chambers to become uniserial.

17. *Bulimina jacksonensis* Cushman. X63.7, 1,298–1,308 ft, 82725, Oligocene.

18. *Uvigerina jacksonensis* Cushman(?). X60.9, 1,248–1,258 ft, 82721, Oligocene. Specimen with sparse costae that are generally restricted to individual chambers.

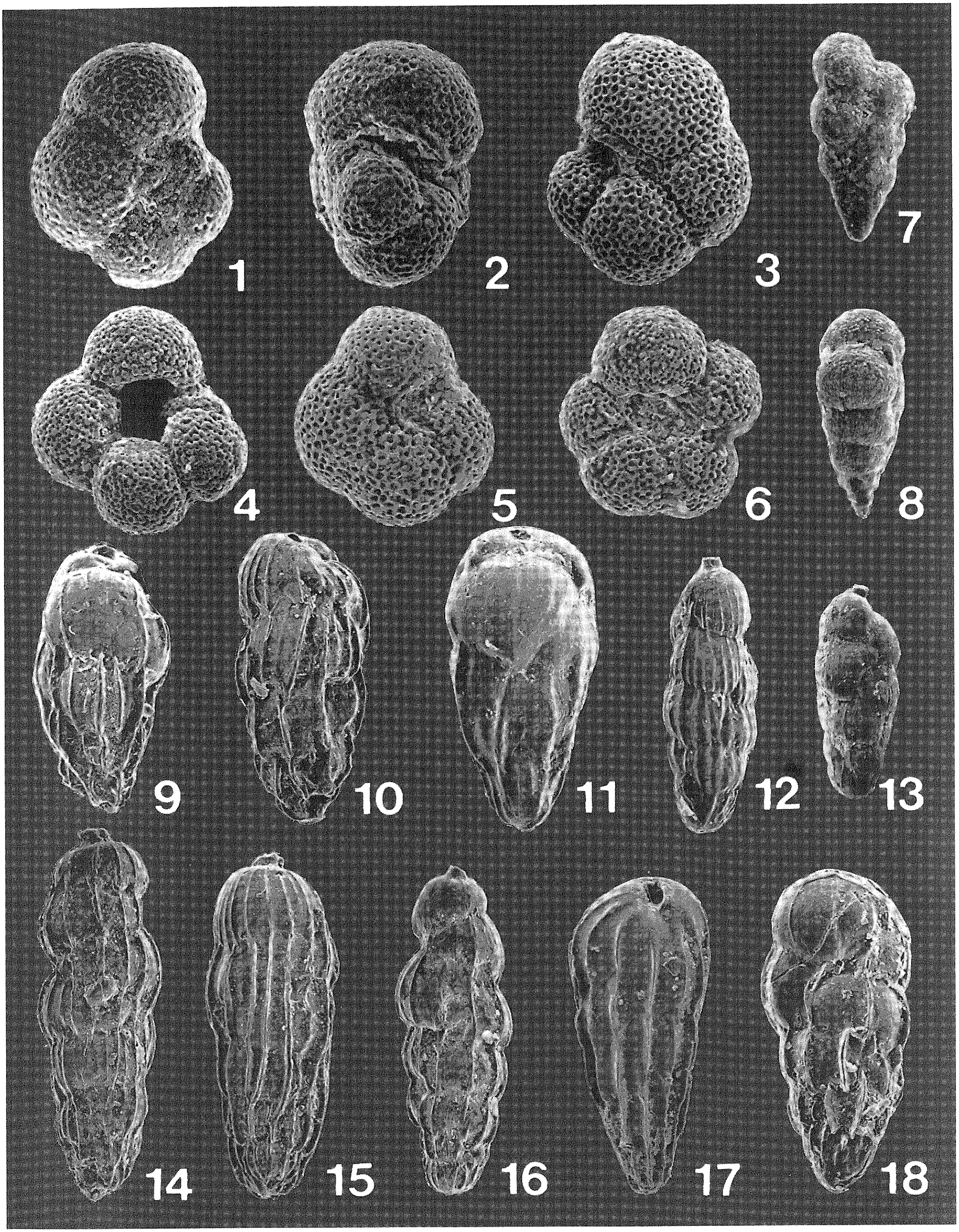

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PLATE 3

Figure

1. *Buliminella curta* Cushman. X141, 1,218–1,228 ft, 82718, Oligocene.

2. *Siphonina tenuicarinata* Cushman. Umbilical view, X141, 1,328–1,337 ft, 82728, Oligocene.

3. *Cibicides speciosus* Cushman and Cederstrom. Umbilical view, X124, 1,328–1,337 ft, 82728, Oligocene.

4. *Bulimina elongata* d'Orbigny. X99.4, 1,218–1,228 ft, 82718, Oligocene.

5. *Anomalina bilateralis* Cushman. X139, 1,328–1,337 ft, 82728, Oligocene.

6. *Cyclammina cancellata* Brady. X58.2, 1,218–1,228 ft, 82718, Oligocene.

7–8. *Florilus pizarrensis* (Berry).

   7. Side view, X86.9, 1,218–1,228 ft, 82718, Oligocene.

   8. Peripheral view, X84.7, 1,218–1,228 ft, 82718, Oligocene.

9. *Actinoptychus heliopelta* Grunow. X265, 853–868 ft, 82681, lower Miocene.

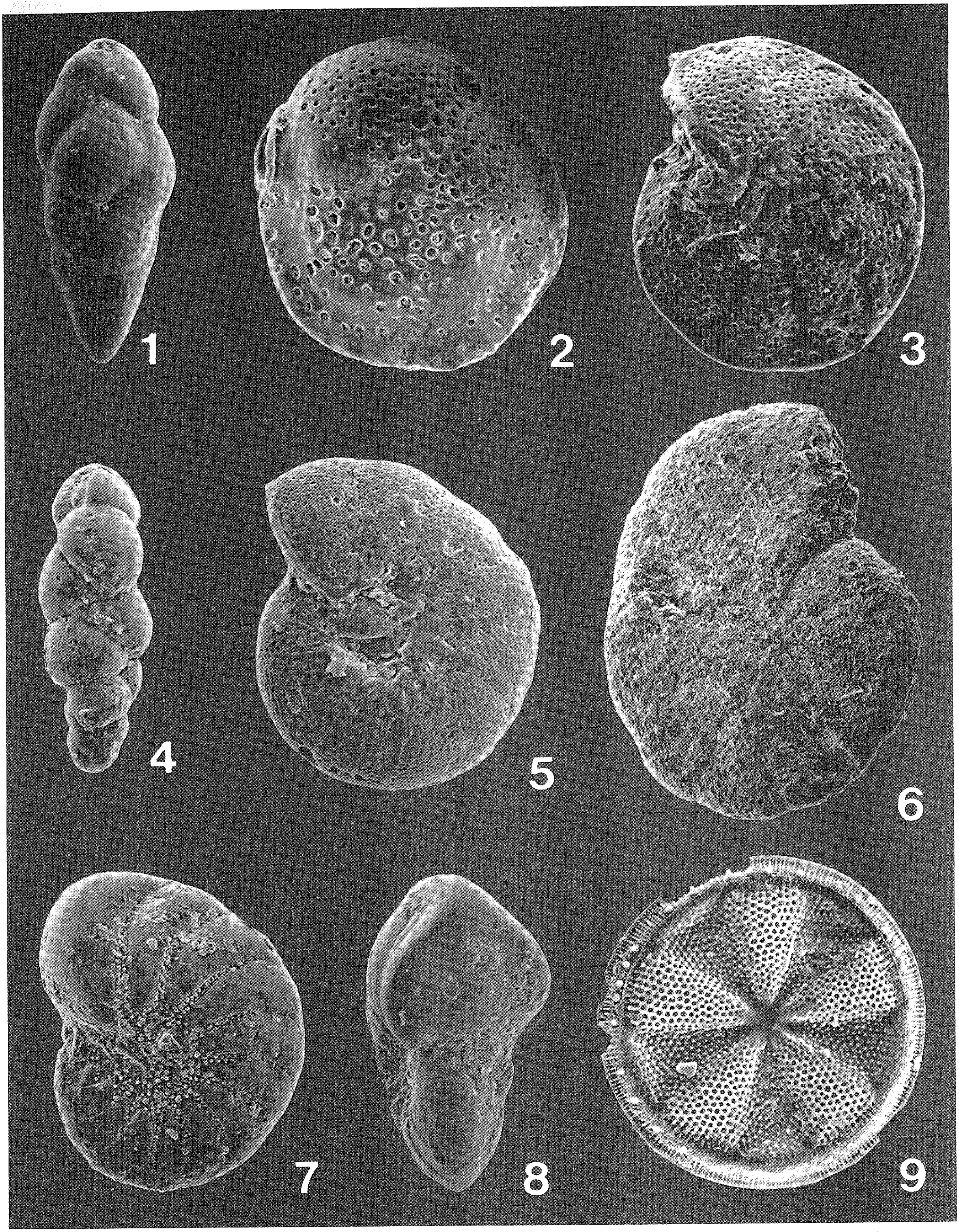
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PLATE 4

Figure

1–3. *Globorotalia kugleri* Bolli.

1. Spiral view of specimen with aberrant final chamber, X141, 1,208–1,218 ft, 82717, lower Miocene.
2. Peripheral view of number 1 showing aberrant final chamber; aperture concealed by sediment infilling, X141.
3. Umbilical view of number 1, X140.

4. *Globigerinoides quadrilobatus altiapertura* Bolli. Side view, X126, 868–878 ft, 82682, lower Miocene.

5–6. *Globigerinoides sicanus* de Stefani.

5. Umbilical view, X140, 838–853 ft, 82680, lower Miocene.
6. Side view of number 5, X141.

7. *Orbulina suturalis* Brönnimann. Side view showing nuclear coil of globigerine chambers below a single spherical chamber and enlarged pores along suture, X142, 663–673 ft, 82666, middle Miocene.

8–10. *Globorotalia fohsi peripheroronda* Blow and Banner.

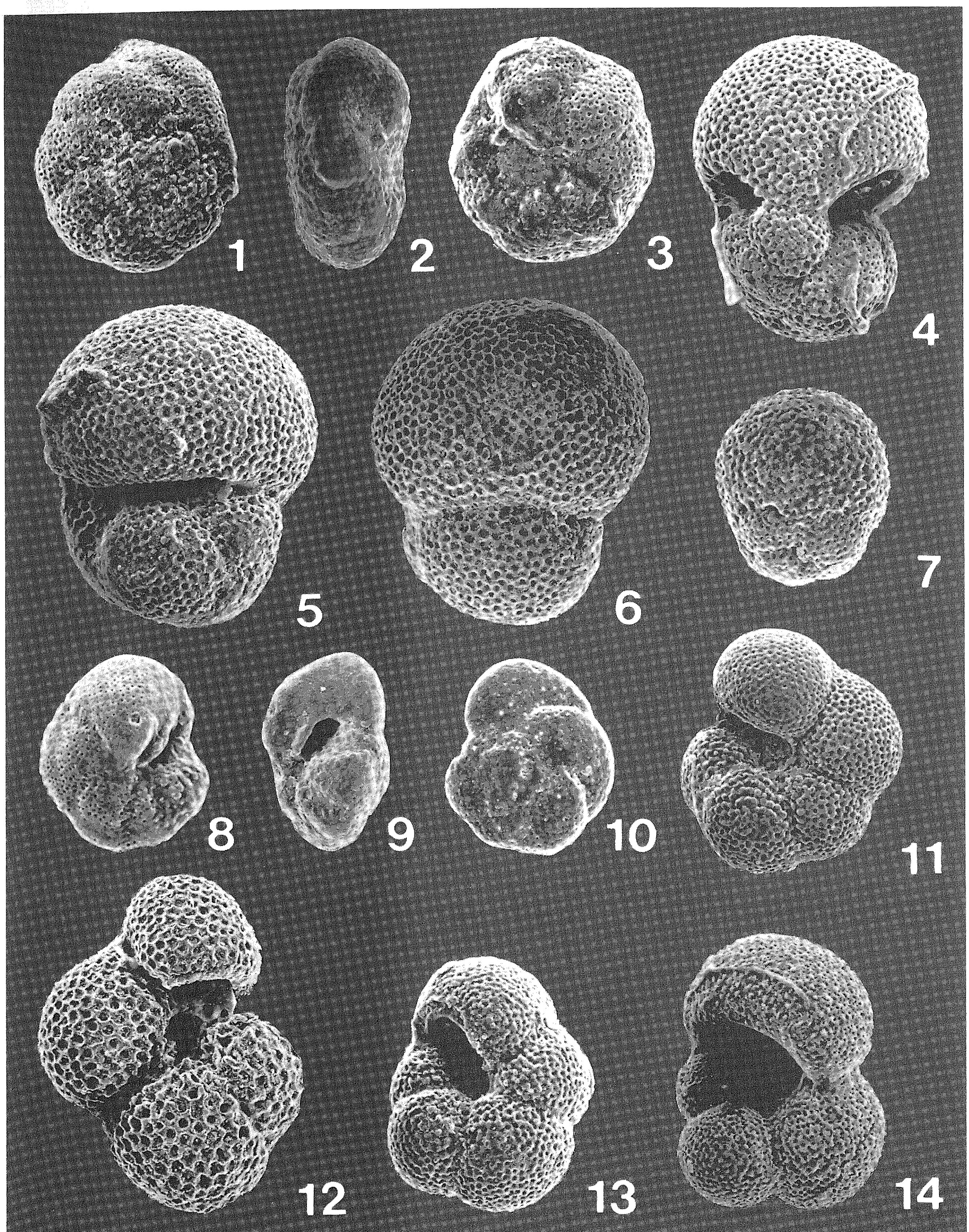
8. Umbilical view, X141, 633–643 ft, 82663, middle Miocene.
9. Peripheral view of number 8 showing aperture, X140.
10. Spiral view of number 8, X141.

11. *Globorotalia acostaensis* Blow. Umbilical view, X141, 364–374 ft, 82635, upper Miocene.

12. *Sphaeroidinellopsis seminulina* (Schwager). Umbilical view, X94.3, 364–374 ft, 82635, upper Miocene.

13. *Globorotalia humerosa* Takayanagi and Saito. Umbilical view, X141, 364–374 ft, 82635, upper Miocene

14. *Globigerina bulloides apertura* Cushman. Oblique umbilical view, X141, 472–482 ft, 82647, upper Miocene.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SUBSURFACE CORRELATION

Richard N. Benson

Subsurface correlations of stratigraphic units penetrated by Oh25-02 and other boreholes in southern Delaware and nearby New Jersey and Maryland (Fig. 3) are shown on cross sections A-A' and B-B' in figures 4 and 5, respectively.

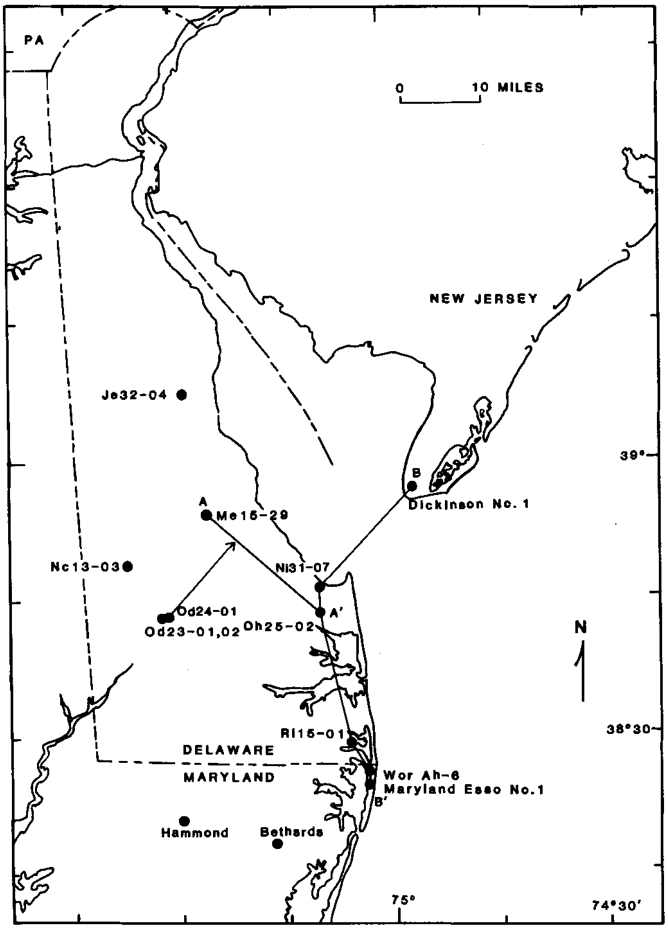

Figure 3. Map of borehole locations and cross sections A-A' and B-B'.

I identified the stratigraphic units on the geophysical logs (mostly gamma-ray logs) of the boreholes on the bases of published and unpublished information and my microscope examination of fossils and lithologies of the sand fractions of selected samples of drill cuttings and cores. Authors of reports providing stratigraphic information used in constructing A-A' and B-B' are Anderson (1948) for Maryland Esso No. 1; Andres (1986) for Ni31-07, Ri15-01, and WorAh-6; Brown et al. (1972) for Me15-29, Od23-01, Dickinson No. 1, and Maryland Esso No. 1; Olsson et al. (1980) for Dickinson No. 1; Overbeck (1948) for Maryland Esso No. 1; and Ulrich (1976) for Dickinson No. 1.

The platy-costate uvigerinid benthic foraminifers and planktic foraminiferal marker species from Oh25-02 are the evidence for the first recognition of mid-Oligocene rocks in the Delaware subsurface (Benson, 1989, and this report, p. 6). The planktic foraminiferal marker species are rare in Oh25-02 and were not observed in samples from the other boreholes. However, the mid-Oligocene uvigerinids and/or associated benthic foraminifers I identified from those boreholes plus the similarities in geophysical log signatures provided the means for recognition of the mid-Oligocene in Me15-29, Od23-01, Od23-02, Od24-01, and Dickinson No. 1.

In Maryland Esso No. 1, Anderson (1948) placed the top of the Eocene at a depth of 1,650 to 1,670 ft on the basis of J. A. Cushman's analysis of the benthic foraminifers. At that depth, Overbeck (1948, p. 432) noted the first downhole occurrence of significant amounts of glauconite and a distinct change in the microfossil assemblage from that of the overlying Calvert Formation,

> Forams, common; Siphogenerina, large
> Robulus, Marginulina?, 2 large Uvigerina?,
> many Bolivina, Bulimina.

Although not conclusive, this describes the mid-Oligocene assemblage of Oh25-02; the "Siphogenerina" and "2 large Uvigerina?" probably are representatives of the key platy-costate uvigerinids. As noted previously (Benson, this report, p. 6), Jacksonian (upper Eocene) sediments identified in

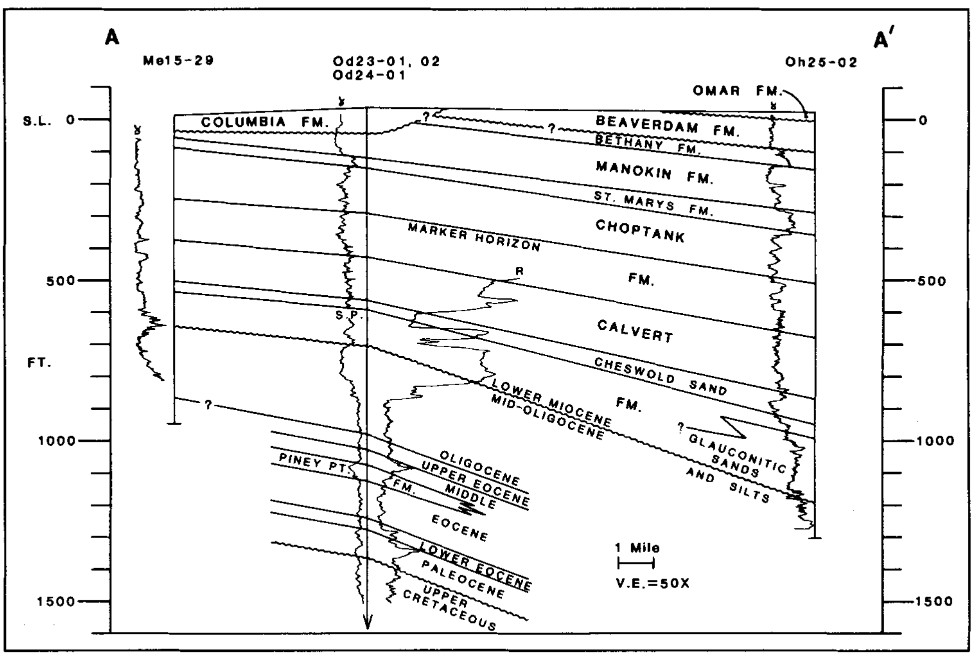

Figure 4. Cross section A-A'. γ = gamma-ray logs; gamma-ray log of Od24-01 to depth of 626 ft. SP = spontaneous potential log and R=resistivity log of Od23-01.

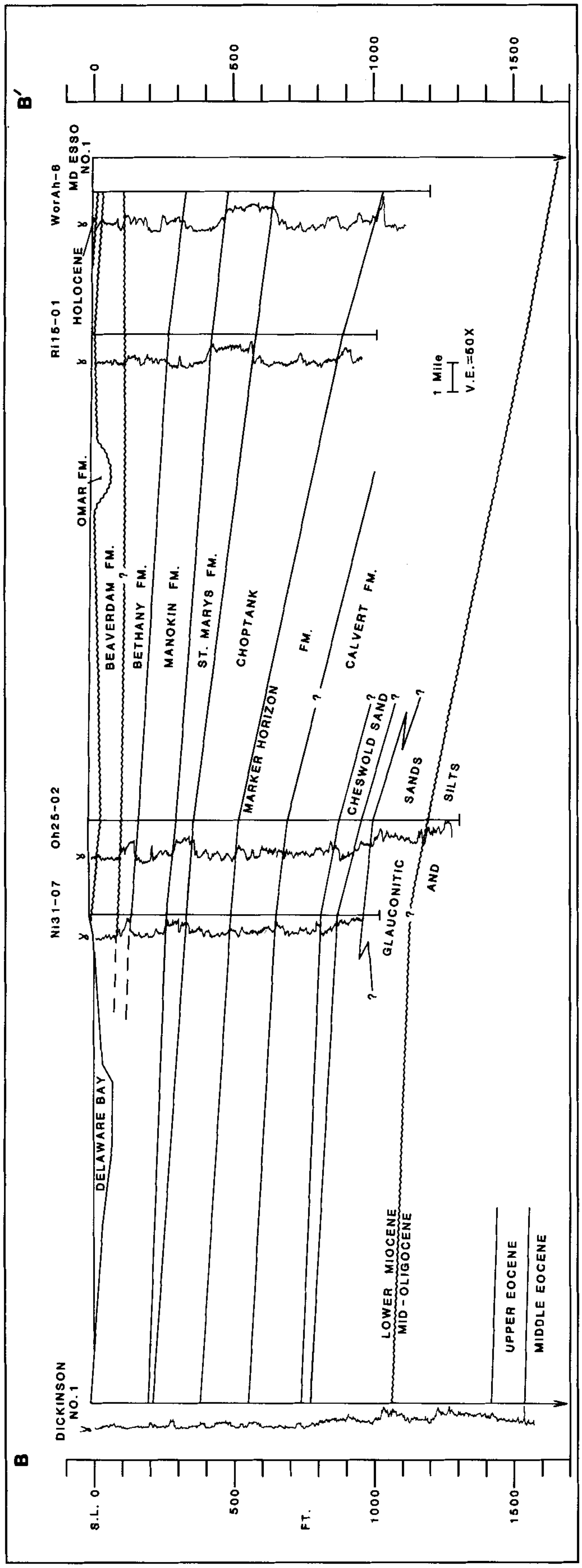

Figure 5. Cross section B-B'. γ = gamma-ray log. Gamma-ray log of Dickinson No. 1 provided by Pierre Lacombe; the lithostratigraphic units correlated from Delaware to that log are not recognized in New Jersey. Cut-and-fill relationship between the Omar and Beaverdam formations shown between Oh25-02 and Ri15-01 after Ramsey and Schenck (1990).

Delaware by Brown et al. (1972) instead are, at least in the upper part, of mid-Oligocene age. Brown et al. (1972) recognized the top of the Jacksonian interval at -1,652 ft (datum mean sea level) in Maryland Esso No. 1; I show that point on section B-B' (Fig. 5) as the top of the mid-Oligocene unit correlated from Oh25-02.

The mid-Oligocene assemblage is also present in the two other deep oil exploration wells in Maryland west of the Esso No. 1 (Fig. 3). In the Hammond well, I noted the first downhole occurrences of *Tiptonina nodifera*, *Uvigerina tumeyensis*, and *Globorotalia opima opima* in the core sample from 1,130 to 1,140 ft. Those and associated species are present in core samples to a depth of 1,250 ft; at 1,270 ft, middle Eocene foraminifers occur. Samples above 1,600 ft in the Bethards well are unavailable. In the drill cuttings sample from 1,600 to 1,610 ft in that well I identified *T. nodifera, U. tumeyensis*, and *G. opima opima* as well as other representatives of the mid-Oligocene foraminiferal assemblage. The sample also includes Miocene and Eocene species; therefore, the mid-Oligocene species are out of place at 1,600 ft. Anderson (1948, p. 85-86) noted that although samples from 1,110 to 1,270 ft in the Bethards well are missing, the sample from 1,100 to 1,110 ft is from the Miocene interval, and the 1,270- to 1,280-ft sample contains Jackson Eocene species, which are probably the mid-Oligocene species I observed in the sample from 1,600 to 1,610 ft.

In Delaware, upper Eocene to mid-Oligocene rocks do not extend updip to boreholes Je32-04 and Nc13-03 and beyond (Fig. 3). In Je32-04, the lower Calvert Formation sediments are of late Oligocene age (Benson et al., 1985). They overlie 34 ft of glauconitic sand of the same age derived from sedimentary reworking of the underlying Piney Point Formation of middle Eocene age (Benson et al., 1985). In Nc13-03, the Calvert unconformably overlies the Piney Point; there is no evidence for sedimentary reworking of the Piney Point during Oligocene(?)–early Miocene time (Talley, 1975; Benson and Jordan, 1978).

The juxtaposition of Oligocene and upper Eocene rocks downdip against middle Eocene rocks updip can best be explained by faulting (Benson, 1989). Upper Eocene to mid-Oligocene rocks are preserved in the downfaulted block but either were not deposited on or were eroded from the upthrown block prior to deposition of the Calvert Formation. The updip limit of the upper Eocene to mid-Oligocene rocks corresponds to the updip limit of Jacksonian rocks shown by Brown et al. (1972, pl. 18) for the Delmarva Peninsula. That limit may mark the approximate trace of the fault. A Vibroseis seismic reflection profile across southern Delaware and Eastern Shore Maryland shows a listric normal, down-to-the-basin fault that corresponds in position to and, therefore, is interpreted to be that fault (Benson, 1990).

The Piney Point Formation in Od23-01, -02, and Od24-01 (Fig. 4) is within the downthrown block with respect to its position in the upthrown block in Nc13-03. The formation is only 60 ft thick in Od23-01 but 293 ft thick in Nc13-03

(Talley, 1975), which indicates that it pinches out in a downdip direction. There are no geophysical log signatures of the Piney Point in the middle Eocene intervals of Dickinson No. 1 and Maryland Esso No. 1.

Downdip from the fault that offsets Oligocene and older rocks, and probably with a parallel trend, there is likely another, younger fault, probably a growth fault, of Miocene age. Between Oh25-02 and Ri15-01, there is a doubling of the thickness of the interval from the top of the St. Marys Formation to the marker horizon within the Choptank Formation (Fig. 5). This interval continues thickening between Ri15-01 and WorAh-6, and another growth fault might be present between those two boreholes. On nearby offshore seismic reflection profile DGS-2, the Miocene section thickens on the downthrown side of a fault indicated by Andres (1986) on that profile. That fault could be extended onshore as the growth fault(s) between the boreholes.

The highly glauconitic lower Miocene sands and silts that underlie the Calvert Formation in Ni31-07 and Oh25-02 have not been found in the other boreholes mentioned in this report. Because the glauconitic unit does not appear to be widespread, it should probably be regarded as a localized facies of the Calvert. Likewise, the mid-Oligocene unit is highly glauconitic only in Oh25-02.

Correlations of the Calvert and younger formations within Delaware are fairly straightforward. Even gamma-ray log signatures of the Calvert, Choptank, and St. Marys formations in the Delaware boreholes can be correlated with similar signatures on the recently acquired gamma-ray log of the Miocene-age Kirkwood Formation in Dickinson No. 1 (Fig. 5). Above the St. Marys, however, the New Jersey and Delaware sections differ. The New Jersey Geological Survey does not recognize the Calvert, Choptank, and St. Marys formations in that state (Peter J. Sugarman, pers. commun., 1990). My correlation of the gamma-ray log signatures of those formations in Delaware to Dickinson No. 1 does not imply that those formations exist in New Jersey.

The stratigraphic relationships between the Columbia Formation and the Manokin, Bethany, and Beaverdam formations shown in Figure 4 reflect the recent work by Groot et al. (1990) and continuing studies by those authors.

HYDROLOGIC STUDIES, Oh25-02 AND -03

John H. Talley

Following drilling and geophysical logging operations, borehole Oh25-02 was backfilled with a bentonite clay slurry from 1,337 to 420 ft in the Choptank Formation immediately below the St. Marys Formation. The Choptank is lithologically a complex unit consisting of interbedded fine to coarse sand, shells, silt, and clay. Several intervals are indurated by dolomite cement. The St. Marys, which is a clayey confining unit, directly overlies the Choptank and generally occurs within the transition zone marking the salt/fresh water interface throughout southeastern Sussex County (Talley and Andres, 1987).

A 2-in diameter well was constructed in the Choptank Formation for the purposes of (1) determining water quality,

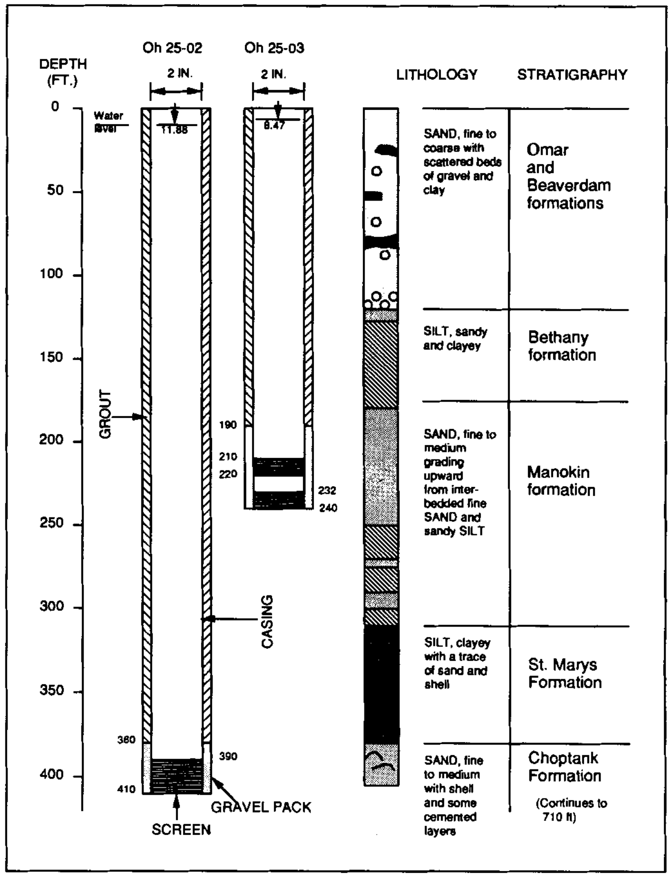

Figure 6. Well construction, Oh25-02 and -03.

especially concentrations of chloride; (2) estimating water-yielding capabilities; and (3) obtaining water levels and associated gradients. The well was cased from ground surface to 390 ft and screened from 390 to 410 ft (Fig. 6). It is one of the first wells completed in the Choptank in southeastern Sussex County and, therefore, provides an opportunity to obtain hydrologic baseline information.

A second well, Oh25-03, was constructed approximately 30 ft from Oh25-02. It is screened from 210 to 220 ft and 232 to 240 ft in the Manokin aquifer within the Manokin formation (Fig. 6). The Manokin aquifer is the first fresh-water-bearing sand above the St. Marys Formation. The aquifer is rated good to excellent in water-yielding characteristics and is used extensively by Delaware coastal towns for public water supplies. Yields from individual wells can exceed 300 to 400 gallons per minute (Talley, 1987). The water from the upper Choptank Formation (Oh25-02) is relatively hard (210 mg/l as $CaCO3$), high in dissolved solids (1,630 mg/l), and contains relatively high concentrations of chloride (600 mg/l), sodium (540 mg/l), and sulfate (290 mg/l) (Table 4 and Fig. 7). Although the screened interval is relatively sandy, water-bearing characteristics are not good, probably because porosity is decreased by dolomite cement.

The quality of water from the Manokin aquifer in Oh25-03 is good and is considerably better than that analyzed from wells completed in the aquifer closer to the coast (Talley, 1987). The results support Talley's (1987) conclusion that water quality is generally good in inland areas and becomes more mineralized with depth toward the Atlantic

TABLE 4

Quality of water from the upper Choptank Formation (Oh25-02) and the Manokin aquifer (Oh25-03)

Oh25-02 (Choptank)	Oh25-03 (Manokin)	Description
20.37	20.0	Elevation of land surface datum (LSD) (ft NGVD)
410	240	Depth of well, total (ft)
390	210	Depth to top of sample interval (ft below LSD)
410	240	Depth to bottom of sample interval (ft below LSD)
2.0	40.0	Flow rate, instantaneous (yield of well at time of sample in gal/min)
290	60	Pump or flow period prior to sampling (min)
19.5	15.0	Temperature, water (deg. C)
2890	95	Specific conductance (microsiemens/cm at 25 deg. C)
7.76	6.33	pH field (standard units)
7.90	6.40	pH, lab (standard units)
265	24	Alkalinity, water, whole, total, field, (mg/l as $CaCO_3$)
275	19	Alkalinity, titration of pH 4.5, laboratory (mg/l as $CaCO_3$)
-	24	Alkalinity, carbonate incremental titration, field (mg/l as $CaCO_3$)
320	29	Bicarbonate, water, whole, total, field (mg/l as HCO_3)
<0.100	0.100	Nitrogen, nitrite plus nitrate, dissolved (mg/l as N)
0.030	0.030	Phosphorus, orthophosphate, dissolved (mg/l as P)
210	11	Hardness, total (mg/l as $CaCO_3$)
43	2.1	Calcium, dissolved (mg/l as Ca)
25	1.4	Magnesium, dissolved (mg/l as Mg)
540	11	Sodium, dissolved (mg/l as Na)
17	1	Sodium adsorption ratio
13	2.4	Potassium, dissolved (mg/l as K)
600	14	Chloride, dissolved (mg/l as Cl)
290	9.6	Sulfate, dissolved (mg/l as SO_4)
0.40	0.10	Fluoride, dissolved (mg/l as F)
49	26	Silica, dissolved (mg/l as SiO_2)
20	1500	Iron, dissolved (g/l as Fe)
20	27	Manganese, dissolved (µg/l as Mn)
1630	69	Solids, residue on evaporation at 180 deg. C, dissolved (mg/l)

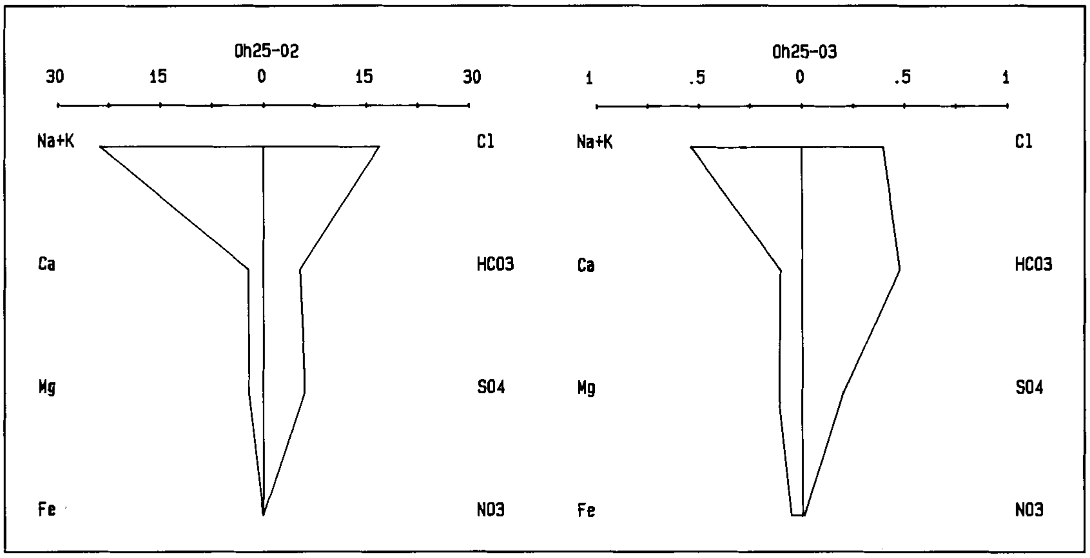

Figure 7. Stiff diagrams of water samples from the Choptank Formation (Oh25-02) and the Manokin aquifer (Oh25-03). Scales (note differences) are in milliequivalents per liter.

coast. Chloride concentrations are relatively low (14 mg/l) as are concentrations of other elements. Iron concentration (1.5 mg/l), although exceeding the secondary standard of 0.3 mg/l, is lower than in many other wells completed in the Manokin aquifer.

Stiff diagrams (Fig. 7) portray the sharp differences in major ion composition between the waters from the two wells. Water in the Manokin aquifer meets the secondary standards of the U. S. Environmental Protection Agency whereas water in the Choptank Formation does not.

Water levels in the two wells were recorded approximately every month from December 1986 through April 1990 (Fig. 8). The heads in the Manokin aquifer (Oh25-03) are 7 ft higher than those in the underlying Choptank Formation (Oh25-02). The Manokin aquifer responded quickly to precipitation, with trends similar to those observed in shallow water-table observation wells. Levels generally rose during late fall and winter and declined during late spring, summer, and early fall. The relatively sharp rise in water levels from March 1989 to October 1989 is attributed to above normal precipitation recorded during those months.

The range of water levels from 1986 to 1990 in Oh25-02 is small (1.22 ft) compared to the range in Oh25-03 (5.92 ft) during the corresponding period.

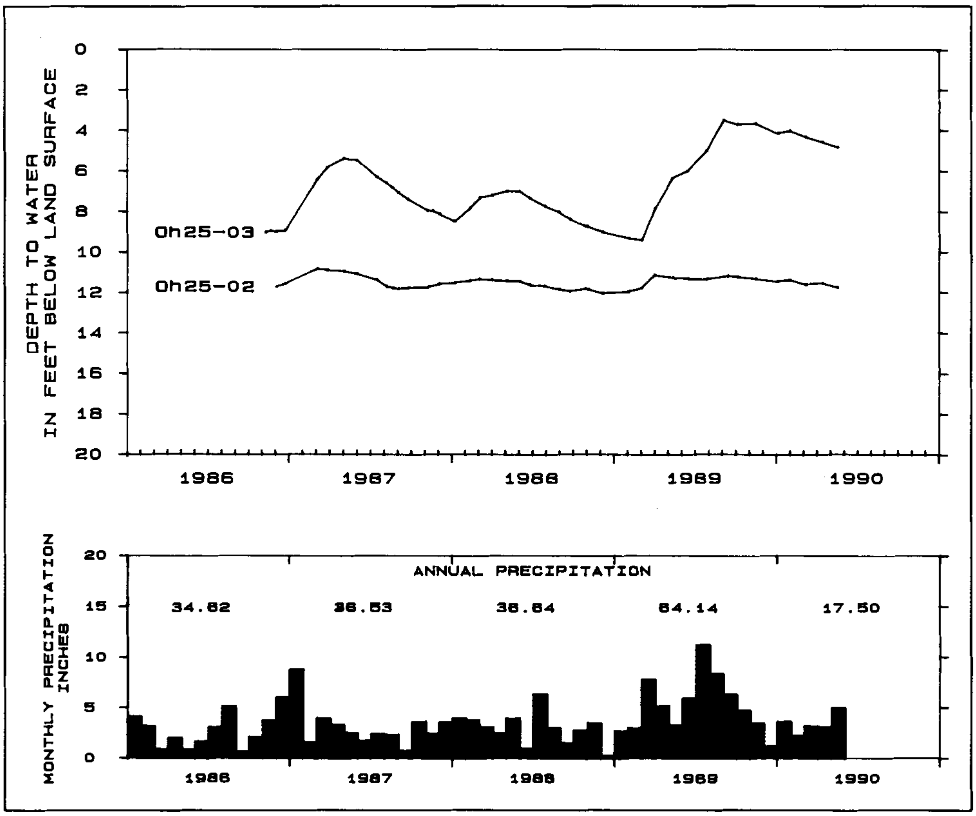

Figure 8. Hydrographs of wells Oh25-02 and -03 and precipitation at Lewes.

SUMMARY AND CONCLUSIONS

Richard N. Benson

The abstract (p. 1) and Plate 1 summarize this report. The following are the significant findings by the contributing authors.

(1) A glauconite-rich sand and silt section occurs below the Calvert Formation from 1,020 ft to total depth of Oh25-02 at 1,337 ft. Its age is mid-Oligocene (*Globoratalia opima opima* Zone) and paleoenvironment deep upper bathyal below a major hiatus at 1,218 ft; above the hiatus it is early Miocene (*G. kugleri* Zone) and its paleoenvironment is outer to middle neritic. Only the upper 50 ft of the glauconitic lower Miocene section was previously known from borehole Ni31-07 at Lewes, Delaware.

(2) The mid-Oligocene section is also identified by large, platy-costate uvigerinid species representing the transition from *Uvigerina tumeyensis* to *Tiptonina nodifera*. That transition occurred in the middle of the *G. opima opima* Zone. The same uvigerinid species identify mid-Oligocene sediments, although not as glauconite-rich as in Oh25-02, in boreholes Me15-29, Milford, Delaware; Od23-01, -02, and Od24-01 near Bridgeville, Delaware; Dickinson No. 1, Cape May, New Jersey; and in the Maryland Esso No. 1, Hammond, and Bethards oil exploration wells in Maryland. The mid-Oligocene section is absent updip from these boreholes and may owe its presence in the downdip region to preservation in a downfaulted block.

(3) Benthic foraminifers and fragments of mollusks and barnacles from Oh25-02 indicate predominantly shallow marine (inner neritic, water depths <100 ft) environments of deposition for the Calvert, Choptank, and St. Marys formations, the lower

three formations of the Chesapeake Group. Because planktic foraminifers are rare in these formations, only three, noncontiguous planktic foraminiferal zones were identified: *Globigerinatella insueta* Zone (mid-Calvert), *Globoratalia fohsi peripheroronda*(?) Zone (upper Calvert/lower Choptank), and *Globorotalia acostaensis* Zone (upper Choptank/ lower St. Marys).

(4) Growth faulting may account for the near doubling of thickness of the upper Choptank and St. Marys formations between Oh25-02 on the north to WorAh-6 in Maryland on the south.

(5) The absence of fossils in the Manokin and Bethany formations, the upper two formations of the Chesapeake Group, indicates marginal marine to possibly nonmarine environments of deposition for those units.

(6) Numerous hard-drilling streaks correlated with layers indurated by dolomite, iron oxide, or other unknown cements were encountered in all stratigraphic units below the Bethany formation. Additional studies will be needed to understand the diagenetic processes responsible for the induration.

(7) Analyses of core samples from Oh25-04 and -05 confirm the lithologic and formational break between the Omar and Beaverdam formations indicated on the gamma-ray log at the 47-ft depth in Oh25-02. The contact traced between the three boreholes shows 12 ft of erosional relief. Study of the cores and outcrops at the borehole sites indicate that the Omar was deposited in a lagoonal environment transgressed by a beach-barrier-spit complex.

(8) Water-bearing characteristics of the relatively sandy screened interval of the upper Choptank Formation in Oh25-02 are not good probably because porosity is decreased by dolomite cement. Water from the interval is relatively hard (210 mg/l), high in dissolved solids (1,630 mg/l), and contains relatively high concentrations of chloride (600 mg/l), sodium (540 mg/l), and sulfate (290 mg/l).

(9) The Manokin aquifer, screened in well Oh25-03, yielded good quality water, considerably better than that from wells completed in the aquifer closer to the coast. Chloride concentrations are relatively low (14 mg/l) as are concentrations of other elements. Iron concentration (1.5 mg/l), although exceeding the secondary standard of 0.3 mg/l, is lower than in many other wells in the Manokin.

(10) Heads in the Manokin aquifer are 7 ft higher than those in the Choptank Formation. The Manokin responded rapidly to precipitation, with trends similar to those observed in shallow water-table observation wells.

The findings testify to the value of the information derived from deep stratigraphic test holes. These important data points are few and far between in the entire Atlantic Coastal Plain and are particularly rare in Delaware. New insight gained from study of just this one borehole, Oh25-02, has added significantly to our understanding of the subsurface stratigraphy, hydrology, and geologic framework of coastal Delaware.

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APPENDIX A

Descriptive Logs, Oh25-02, -04, and -05,

Oh25-02

This log was compiled from descriptions of the ditch samples (ignoring down-hole contamination) and interpretations of geophysical logs.

Depth interval (feet below ground surface)	Description
	Omar and Beaverdam formations (undifferentiated)
0– 22	SAND, medium to coarse, trace of silt and small pebbles, light orangish-gray
22– 26	SAND, coarse to fine, silty, trace of pebbles and clay, light brownish-gray
26– 35	SAND, coarse to medium, small pebbles, trace of silt, light brownish-gray
35– 39	SAND, medium to coarse, silty, trace of pebbles and clay, light brownish-gray
39– 47	SAND, coarse to medium, trace of small pebbles, silt and clay, light brownish-gray
47– 60	SAND, coarse to fine, trace of small pebbles, and silt, light brownish-gray; ironstone
60– 66	SAND, medium to coarse, trace of silt and small pebbles, light gray; lignite
66– 80	SAND, medium to coarse, trace of small pebbles, and silt, light brownish-gray
80– 84	SAND, fine to medium, clayey and silty, gray
84– 108	SAND, coarse to medium, trace of small pebbles, and silt, light brownish-gray
108– 119	GRAVEL, fine to medium, sandy, coarse to medium, light grayish-brown
	Bethany formation
119– 123	SAND, fine to medium, silty and clayey, light brownish-gray
123– 130	SAND, coarse to medium, and GRAVEL, fine to medium, trace of silt, orangish- brown
130– 136	SAND, fine to medium, silty, clayey, light brownish-gray
136– 140	SAND, fine to medium, trace of silt, light olive-gray
140– 152	SAND, fine, and SILT, light olive-gray
152– 160	SILT, sandy, fine, clayey, interbedded with SILT and SAND, fine, olive gray
160– 173	SILT and CLAY, sandy, fine, olive gray
	Manokin formation
173– 186	SAND, fine, silty, olive gray
186– 215	SAND, fine to coarse, trace of silt, olive gray; lignite, few indurated layers
215– 223	SAND, fine to medium, silty, olive gray; lignite
223– 231	SAND, fine, and SILT, dark olive-gray; lignite particles (1–2 in)
231– 240	SAND, fine to coarse, trace of silt, olive gray; lignite
240– 250	SAND, fine, and SILT, clayey, olive gray; lignite
250– 267	SILT, sandy, fine, and clayey, dark olive-gray; lignite
267– 273	SAND, fine to medium, silty and clayey, olive gray; trace of lignite
273– 291	SILT, sandy, fine, clayey, dark olive-gray; trace

of lignite

291–298 SAND, fine to medium, silty and clayey, olive gray; trace of lignite

298–310 SILT, sandy, fine, and clayey, dark olive-gray; mica

St. Marys Formation

310–322 SILT, clayey, trace of sand, fine, dark olive-gray to dark brownish-gray

322–340 SILT, shelly and clayey, trace of sand and gravel, fine, dark olive-gray; chert pebbles

340–346 SILT, clayey, trace of sand, fine, dark olive-gray

346–356 SILT, clayey and sandy, fine, dark olive-gray

356–363 SILT, clayey, trace of sand, fine, dark olive-gray

363–382 SAND, fine, silty and clayey, dark olive-gray; thin indurated layers from 363 to 374 ft, dolomite cement

Choptank Formation

382–392 SAND, fine, silty, trace of shells and small pebbles, dark olive-gray; indurated layers 386 ft, 389 to 392 ft, dolomite cement

392–402 SAND, fine to medium, shelly, silty, dark olive-gray; indurated layers 395 to 396 ft, 399 to 402 ft, dolomite cement

402–418 SANDSTONE, fine to coarse, silty and shelly, dark olive-gray; dolomite cement; phosphatic particles

418–430 SAND, fine, and SILT, shelly, clayey, dark olive-gray

430–453 SAND, fine to medium, and SHELL, trace of silt, dark olive-gray; indurated 436 to 439 ft, dolomite cement

453–467 SHELL, silty and sandy, fine, dark olive-gray

467–472 SILTSTONE, shelly and sandy, fine, olive gray; dolomite cement

472–480 SHELL, sandy, fine, trace of silt, dark olive-gray

480–488 SAND, fine to medium, shelly, trace of silt, dark olive-gray

488–498 SANDSTONE, shelly, trace of silt, dark olive-gray; dolomite cement

498–503 SAND, fine to medium, silty and shelly, dark olive-gray

503–511 SHELL, sandy, fine to medium, and silty, dark olive-gray; indurated 508 to 511 ft, dolomite cement

511–525 SHELL and SAND, fine, silty, dark olive-gray

525–534 SAND, fine to medium, trace of silt and shell, dark olive-gray

534–544 SAND, fine, and SILT, trace of shell, brown

544–563 SAND, fine, silty, trace of shell, brown

563–570 SAND, fine, and SILT, shelly, brown; indurated 563 to 565 ft

570–586 SAND, fine, and SHELL, trace of silt, brown; indurated 583 to 586 ft

586–594 SILTSTONE, sandy, fine to medium, and shelly, brown; dolomite cement

594–603 SAND, medium to fine, and SHELL, brown; indurated, dolomite cement

603–620 SHELL and SAND, medium to fine, brown; thin indurated layers, dolomite cement

620–642 SILT and CLAY, sandy, fine, shelly, brown

642–679 SAND, fine to medium, silty, clayey, and shelly, brown; indurated 655 to 657 ft

679–701 SILT and CLAY, sandy, fine, trace of shell, brown; lignite; indurated 679 to 683 ft

701–710 SAND, fine to medium, silty, shelly, trace of lignite and small pebbles, brown

Calvert Formation

710–733 SAND, fine to medium, SILT and CLAY, shelly, brown to grayish brown; trace of glauconite

733–748 SANDSTONE, SILTSTONE, and SHELL, brown to grayish brown; dolomite cement

748–784 SILT, sandy, fine, clayey, shelly, trace of small pebbles, brown to grayish brown

784–793 SILT and SAND, fine, shelly, trace of small pebbles, gray

793–806 SANDSTONE, fine to coarse, shelly, silty, very hard, gray; dolomite cement

806–826 SILT, sandy, fine, clayey, trace of shell, gray

826–834 CLAY, silty, sandy, fine, grayish brown

834–863 SILT, sandy, fine, shelly, grayish brown

863–898 SILT, CLAY, AND SHELL, sandy, fine, grayish brown; hydrogen sulfide odor

898–925 SHELL, sandy, coarse to fine, trace of silt, grayish brown; indurated 896 to 898 ft, 907 to 908 ft, dolomite cement; hydrogen sulfide odor

925–968 SHELL, silty, and sandy, fine to medium, grayish brown; indurated 929 to 934, 938 to 943 ft, dolomite cement

968–981 SILT, clayey, sandy, fine, trace of shell, gray to olive-gray; thin indurated layers, dolomite cement

981–1020 SILT, sandy, fine to medium, trace of shell and small pebbles, gray to olive-gray; thin indurated layers, dolomite cement

Unnamed glauconitic sand

1020–1036 SILT, and SAND, fine to medium, trace of shell and small pebbles, grayish olive; glauconite(?) (from gamma log)

1036–1048 SAND, fine to coarse, silty, trace of shell and small pebbles, grayish olive; first significant glauconite in samples

1048–1066 SAND, fine to coarse, trace of shell, silt, and small pebbles, grayish olive; glauconite; indurated 1,063 ft

1066–1080 SAND, fine to coarse, shelly, silty, trace of small pebbles, grayish olive, glauconite

1080–1112 SAND, fine to coarse, silty, trace of small pebbles and shell, grayish olive; glauconite

1112–1151 SILT, sandy, fine to coarse, trace of small pebbles and shell, grayish olive; glauconite

1151–1172 SAND, fine to coarse, trace of silt, shell, and small pebbles, grayish olive; glauconite; indurated 1,152 to 1,154 ft, 1,163 to 1,165 ft, dolomite and unknown cements

Unnamed glauconitic silt

1172–1194 SILT and SAND, fine to coarse, grayish brown to olive gray; glauconite

1194–1206 SILT and SAND, fine to coarse, trace of shell, olive gray; glauconite; indurated 1,200 to 1,201 ft, dolomite and unknown cements

1206–1220 SILT, sandy, fine to coarse, trace of shell, olive gray; glauconite; indurated 1,208 to 1,213 ft, dolomite and unknown cements

1220–1235 SILT and CLAY, sandy, fine to coarse, trace of shell, olive gray; glauconite; thin indurated layers, dolomite and unknown cements

1235–1265 SILT, clayey, sandy, fine to medium, trace of shell, olive gray; glauconite; thin indurated layers, dolomite and unknown cements

1265–1305 SILTSTONE, trace of sand, fine, and shell, olive gray; glauconite; dolomite and unknown cements

1305–1337 SILT AND CLAY, trace of sand, fine, and shell, olive gray; glauconite; thin indurated layers, dolomite and unknown cements

Oh25-04

Hole starts in borrow pit approximately 4 ft below original land surface. Upper 4 ft in adjacent cut contains medium to coarse, cross-bedded sand with subordinate reddish-brown, coarse, sandy gravel, abundant 1- to 2-cm pebbles.

Depth interval (feet below ground surface)	Description
	Omar Formation
0– 0.5	SAND, fine to medium, gravelly, yellowish brown, 1- to 2-cm pebbles abundant
0.5– 1.5	SAND, fine to medium, loose, scattered pebbles (1- to 2-cm), yellowish brown; few dark-brown clayey laminae (secondary)
1.5– 3.0	SAND, medium to coarse, grading down to granule gravel, white to yellowish brown; cross-bedded; heavy minerals common
3.0– 4.5	SAND, coarse, white to tan, scattered pebbles; cross-bedded
4.5– 6.0	same; coarse to granule, very abundant small pebbles (<0.5 cm)
6.0– 7.5	same
7.5– 9.0	same
9.0–10.5	same; water table
10.5–11.75	same
11.75–12.0	SAND, very fine, very clayey, gray; abundant heavy minerals
12.0–13.5	SAND, very fine to silt, slightly clayey, gray; heavy mineral laminae common; 1-inch thick beds of medium to coarse sand and gravel, brown, cross-bedded(?); vertical thin-diameter (2 mm) brown stains (=rootlets? or burrows?)
13.5–15.0	same, scattered laminae of medium to coarse sand
15.0–16.5	SAND, fine to medium, gray, slightly clayey; scattered heavy mineral laminae
16.5–19.5	Not sampled
19.5–21.0	Poor recovery, same as 15–16.5 ft
21.0–24.5	Not sampled
24.5–26.0	SAND, medium to coarse, gray; opaque heavy minerals common; scattered laminae of coarse to very coarse sand; scattered pebbles
26.0–29.5	Not sampled
29.5–31.0	CLAY, silty, gray; laminae of fine to very fine sand and silt, yellowish brown; some opaque heavy mineral laminae; micaceous; rare organic-rich(?) layers
31.0–34.5	Not sampled
34.5–34.75	Same as 29.5–31.0 ft
34.75–36.0	SAND, fine, gray to yellowish brown; sample may contain wash
36.0–39.5	Not sampled
39.5–39.75	CLAY, gray to brown; laminae of fine sand, brown
39.75–40.0	SAND, very coarse to gravel, yellowish brown; iron oxide stains at base
	Beaverdam Formation
40.0–41.0	SAND, coarse, gray to white, feldspathic; cross-bedded; heavy mineral laminae common
41.0–44.5	Not sampled
44.5–46.0	SAND, very coarse to granule, gray to white; scattered pebbles; opaque heavy minerals common; cross-bedded (silty white stains on hands from water)
46.0–49.5	Not sampled
49.5–51.0	SAND, coarse, gray to reddish brown; cross-bedded; scattered pebbles; reddish-brown stains on pebbles
51.0–54.5	Not sampled
54.5–56.0	SAND, coarse, gray to brown; scattered pebbles; cross-bedded; sample may be partly wash
56.0–59.5	Not sampled
59.5–61.0	Gravel, sandy, coarse to granule; poor recovery

Oh25-05

Hole drilled in borrow pit approximately 5 ft below land surface. Upper 5 ft is pebbly, medium to coarse sand to gravel and is yellowish brown with reddish-brown oxidation laminae. The pebbles are small, most less than 1 cm diameter.

Depth interval (feet below ground surface)	Description
	Omar Formation
0– 1.5	SAND, fine to medium, yellowish brown; silty, dark reddish-brown oxidation laminae common; structureless; loose
1.5– 3.0	Same, cross-bedded; laminae of coarse sand
3.0– 4.5	same
4.5– 5.5	same; heavy mineral laminae common
5.5– 6.0	SAND, very coarse to granule; tan to reddish brown
6.0– 7.5	same
7.5– 9.0	SAND, medium to coarse; reddish brown to gray; scattered granules
9.0–9.75	same
9.75–10.5	SAND, very fine; laminae of clayey silt to silty clay and medium to coarse sand; water table
10.5–12.0	SAND, medium to coarse, interlaminated with clay and clayey sand, very fine to silt; granules and very small pebbles common; reddish brown
12.0–13.5	SAND, medium to coarse, dark reddish-brown to yellowish brown; scattered small pebbles; cross-bedded(?)
13.5–14.5	same
14.5–15.0	SAND, fine, gray, with scattered reddish-brown clay laminae
15.0–16.5	SAND, fine, slightly clayey; poor recovery; very low blow counts
16.5–18.0	SAND, fine, gray, scattered heavy mineral laminae; rare clay laminae at 16.5 feet; burrowed
18.0–24.4	Not sampled. No recovery at 20 ft
24.4–25.9	SAND, coarse, dark gray, abundant pebbles; opaque heavy minerals common with heavy mineral laminae at top
25.9–29.4	Not sampled
	Beaverdam formation
29.4–30.9	SAND, coarse to very coarse, yellowish brown; rare laminae of fine clayey sand; abundant granules; scattered small pebbles
30.9–34.4	Not sampled
34.4–35.9	SAND, coarse to very coarse, gray to yellowish brown; abundant granules; scattered pebbles
35.9–39.4	Not sampled
39.4–40.9	SAND, very coarse to granule; gray to yellow; feldspathic(?); poor recovery
40.9–44.4	Not sampled
44.4–45.9	same as 39.4–40.9 ft, sample partly wash
45.9–49.4	Not sampled
49.4–50.9	CLAY, silty, yellowish brown to gray; laminae of silt and very fine sand; 4 in-thick fine sand bed at 50 ft
50.9–54.4	Not sampled
54.4–55.0	Interbedded fine SAND and CLAY, silty, with silt and fine sand laminae, tan
55.0–55.9	SAND, very coarse to granule, yellowish brown; abundant pebbles

APPENDIX B

Sand Fraction Analyses, Oh25-02

Visual estimates of percentage of sand fraction. F, >5%; A, 2–5%; C, 1–2%; R, <1%; VR, <100 specimens; -, not detected.

Sample Number	Depth	Benthic Forams	Planktic Forams	Ostracodes	Radiolarians	Plant Remains	Barnacles	Mollusks & Others	Bones & Teeth	Diatoms	Glauconite	Phosphate	Pyrite
82598	0– 10	-	-	-	-	-	-	-	-	-	-	-	-
82599	10– 20	-	-	-	-	-	-	-	-	-	-	-	-
82600	20– 30	-	-	-	-	-	-	-	-	-	-	-	-
82601	30– 39	-	-	-	-	-	-	-	-	-	-	-	-
82602	39– 49	-	-	-	-	-	-	-	-	-	R	-	-
82603	49– 59	-	-	-	-	-	-	-	-	-	-	-	-
82604	59– 68	-	-	-	-	-	-	-	-	-	-	-	-
82605	68– 78	-	-	-	-	-	-	-	-	-	-	-	-
82606	78– 88	-	-	-	-	-	-	-	-	-	-	-	-
82607	88– 98	-	-	-	-	-	-	-	-	-	-	-	-
82608	98–108	-	-	-	-	-	-	-	-	-	-	-	-
82609	108–117	-	-	-	-	-	-	-	-	-	-	-	-
82610	117–127	-	-	-	-	-	-	-	-	-	-	-	-
82611	127–137	-	-	-	-	R	-	-	-	-	-	-	R
82612	137–147	-	-	-	-	R	-	-	-	-	-	-	R
82613	147–156	-	-	-	-	R	-	-	-	-	-	-	R
82614	156–166	-	-	-	-	R	-	-	-	-	-	-	R
82615	166–177	-	-	-	-	R	-	-	-	-	-	-	R
82616	177–187	-	-	-	-	R	-	-	-	-	-	-	R
82617	187–196	-	-	-	-	-	-	-	-	-	-	-	-
82618	196–206	-	-	-	-	A	-	-	R	-	-	-	R
82619	206–216	-	-	-	-	A	-	-	-	-	-	-	R
82620	216–226	-	-	-	-	A	-	-	-	-	-	-	R
82621	226–236	-	-	-	-	A	-	-	-	-	-	-	R
82622	236–246	-	-	-	-	A	-	-	-	-	-	-	R
82623	246–256	-	-	-	-	C	-	-	-	-	-	-	R
82624	256–266	-	-	-	-	C	-	-	-	-	-	-	R
82625	266–276	-	-	-	-	C	-	-	-	-	-	-	R
82626	276–285	-	-	-	-	R	-	-	-	-	-	-	R
82627A	285–295	-	-	-	-	-	-	-	-	-	-	-	-

Sample Number	Depth	Benthic Forams	Planktic Forams	Ostracodes	Radiolarians	Plant Remains	Barnacles	Mollusks & Others	Bones & Teeth	Diatoms	Glauconite	Phosphate	Pyrite
82628A	295–305	-	-	-	-	-	-	-	-	-	-	-	-
82629A	305–315	-	-	-	-	-	-	-	-	-	-	-	-
82630A	315–325	-	-	-	-	-	-	-	-	R	-	-	R
82631A	325–335	VR	-	VR	-	R	-	VR	VR	R	-	-	R
82632A	335–344	VR	-	VR	-	-	-	R	-	VR	-	-	VR
82633A	344–354	VR	-	VR	-	VR	-	VR	VR	VR	-	-	VR
82634A	354–364	VR	VR	VR	-	VR	-	VR	-	VR	-	-	VR
82635A	364–374	C	R	R	-	VR	-	VR	VR	R	-	-	R
82636A	374–384	VR	-	-	-	VR	-	VR	-	R/C	-	-	R/C
82637A	384–393	VR	VR	VR	-	-	C	C/A	VR	R/C	-	-	R/C
82638A	393–403	R	VR	VR	-	VR	R	VR/R	VR	VR	-	-	-
82639A	403–413	VR/R	VR	VR	-	VR	R	VR	VR	VR	-	VR	VR
82641	413–423	R	VR	VR	-	VR	R	R	VR	VR	-	VR	VR
82642	423–433	VR	-	VR	-	-	C	C	-	-	R	R	-
82643	433–443	VR	VR	VR	-	-	A	A	-	VR	R	VR	-
82644	443–452	VR	VR	VR	-	-	F	F	VR	-	VR	VR	-
82645	452–462	VR	VR	VR	-	VR	F	F	-	VR	VR	VR	-
82646	462–472	VR	VR	VR	-	VR	A/F	A/F	-	R	VR	VR	R
82647	472–482	VR	VR	VR	-	-	A/F	A/F	R	R	VR	VR	-
82648	482–492	VR	VR	VR	-	-	F	F	-	-	-	R	-
82649	492–503	VR	-	VR	-	-	A/F	C/A	-	-	-	R	-
82650	503–513	VR	VR	VR	-	VR	A/F	A/F	VR	-	VR	R	-
82651	513–523	VR	-	VR	-	VR	A/F	A/F	-	VR	VR	R	VR
82652	523–533	VR	-	VR	-	VR	A	F	-	VR	-	VR	VR
82653	533–543	VR	-	-	-	VR	C	R/C	-	VR	-	VR/R	VR
82654	543–553	VR	VR	VR	VR	VR	C	C	-	VR	-	VR	VR
82655	553–563	VR/R	VR	VR	VR	VR	A	R/C	VR	VR	-	R	-
82656	563–573	VR	VR	VR	VR	VR	A	R/C	VR	VR	-	R	-
82657	573–583	VR	VR	VR	VR	VR	A/F	R/C	-	VR	-	R	VR
82658	583–593	VR	VR	VR	VR	VR	F	R/C	VR	VR	-	R	-
82659	593–603	R	VR	VR	VR	VR	F	R/C	-	VR	VR	R	-
82660	603–613	VR	VR	VR	-	VR	F	R/C	-	VR	-	R	-
82661	613–623	R	VR	VR	VR	VR	A	C/A	VR	VR	-	R	-
82662	623–633	VR	VR	VR	VR	VR	A	C/A	-	VR	-	VR	-
82663	633–643	VR	VR	VR	R	VR/R	C	C/A	-	VR	-	VR	-

Sample Number	Depth	Benthic Forams	Planktic Forams	Ostracodes	Radiolarians	Plant Remains	Barnacles	Mollusks & Others	Bones & Teeth	Diatoms	Glauconite	Phosphate	Pyrite
82664	643–653	VR	VR	VR	VR	R	R/C	C/A	-	R	-	R	R
82665	653–663	VR	VR	VR	VR	VR	C/A	C/A	-	VR	VR	VR	VR
82666	663–673	VR	VR	VR	VR/R	R	R/C	A/F	-	VR	VR	VR	-
82667	673–683	VR	VR	VR	VR	VR	VR	R/C	-	VR	VR	VR	-
82668	683–693	VR	VR	VR	VR	VR	R	R/C	-	VR	VR	VR	-
82669	693–703	VR	VR	VR	VR/R	VR/R	R	R/C	-	VR	VR	VR	-
82670	703–713	VR	VR	VR	VR/R	R	VR	R/C	VR	VR	VR	VR	-
82671	713–723	VR	VR	VR	VR	R	R	F	VR	VR	VR	VR	-
82672	723–733	R	VR	VR	VR	VR	C/A	F	-	VR	VR	VR	-
82673	733–748	VR	VR	VR	VR	VR/R	C/A	F	VR	VR	VR	R	-
82674	748–763	VR	VR	VR	VR	R	C	C/A	-	VR	-	R	-
82675	763–778	VR	VR	VR	VR	VR	R/C	F	VR	VR	VR	R	
82676	778–793	VR	VR	VR	VR	VR	F	C/A	R/C	VR	VR	R/C	-
82677	793–808	VR	VR	VR	VR	VR	F	A	VR	VR	VR	R	-
82678	808–823	VR	VR	VR	VR	VR/R	A/F	R/C	VR	VR	VR	R	-
82679	823–838	R/C	VR	VR	VR	VR	F	A	VR	VR	VR	R	-
82680	838–853	R	VR	VR	VR	VR	F	A	VR	VR	VR	VR/R	-
82681	853–868	R	VR	VR	VR	-	A	C	VR	-	VR	VR	-
82682	868–878	R	VR	VR	VR	VR	A	C	VR	VR/R	VR	R	-
82683	878–888	C	R	VR	R/C	VR	C/A	C	VR	VR/R	VR	VR	-
82684	888–898	C	VR	VR	R/C	VR	A	C/A	VR	VR	VR		
82685	898–908	R	VR	VR	VR	-	F	A/F	VR	VR	R	R	-
82686	sample missing												
82687	918–928	VR	VR	VR	VR	VR	F	A/F	-	VR	R	R	-
82688	928–938	VR	VR	VR	VR	-	F	A/F	VR	VR	R	R	-
82690	938–948	VR	VR	VR	VR	R	A	A/F	-	VR	VR	R	-
82691	948–958	R	VR	VR	VR	VR	A	A	VR	VR	VR	VR	-
82691A	948–958	R	VR	VR	VR	VR	A	A	VR	VR	VR	VR	-
82692	958–968	VR	VR	VR	VR	VR	F	F	R	VR	VR	R	-
82693	sample missing												
82694	978–988	VR	VR	VR	VR	VR	R	R	-	VR	VR	VR	-
82695	988–998	VR	VR	VR	VR	VR	VR	VR	-	VR	VR	VR	-
82696	998–1008	VR	VR	VR	VR	VR	VR	VR	-	VR	VR	VR	VR
82697	1008–1018	VR	VR	VR	VR	VR	VR	VR	-	VR	VR	VR	-
82698	1018–1028	R	VR	VR	VR	VR	VR	VR	-	VR	R/C	VR	-

Sample Number	Depth	Benthic Forams	Planktic Forams	Ostracodes	Radiolarians	Plant Remains	Barnacles	Mollusks & Others	Bones & Teeth	Diatoms	Glauconite	Phosphate	Pyrite
82699	1028-1038	A	C	VR	VR	R	VR	VR	VR	VR	F	VR	-
82699A	1038-1048	A	C	VR	VR	VR	VR	R	VR	VR	F	VR	-
82701	1048-1058	C/A	R	VR	VR	VR	R	R	VR	VR	F	R	-
82702	1058-1068	R	VR	VR	VR	VR	R	C/A	-	VR	F	R	-
82703	1068-1078	R	VR	VR	VR	VR	R	C/A	VR	VR	F	R	-
82704	1078-1088	VR/R	VR	VR	VR	VR	VR	C/A	VR	VR	F	R/C	-
82705	1088-1098	VR	VR	-	VR	VR	VR	R	VR	VR	F	R/C	-
82706	1098-1108	VR	VR	-	VR	VR	VR	R	-	VR	F	VR	-
82707	1108-1118	VR	VR	VR	VR	VR	VR	R	VR	VR	F	R	-
82708	1118-1128	R	VR	VR	VR	R	R	R	VR	VR	F	R	-
82709	1128-1138	VR	VR	VR	VR	VR	VR	R	-	VR	F	VR	-
82710	1138-1148	VR	VR	-	VR	R	VR	R	-	VR	F	R	-
82711	1148-1158	VR	VR	-	VR	R	-	R	-	-	F	R	-
82712	1158-1168	VR	VR	-	VR	VR	VR/R	R	-	VR	F	VR	-
82713	1168-1178	VR	VR	-	VR	VR	VR	R	-	-	F	VR	-
82714	1178-1188	VR/R	VR	VR	VR	VR	VR	VR	-	VR	F	VR	-
82715	1188-1198	VR	VR	VR	VR	VR	VR	VR	-	VR	F	VR	-
82716	1198-1208	R/C	R	VR	VR	VR	VR	VR	-	VR	F	VR	-
82717	1208-1218	C/A	C	R	VR	VR	VR	R	-	VR	F	R	-
82718	1218-1228	F	C	R	VR	VR	VR	R	VR	-	F	R	VR
82719	1228-1238	C	R	VR	VR	VR	VR	R	VR	-	F	R	-
82720	1238-1248	C	R	VR	VR	VR	R	C	VR	-	F	R	-
82721	1248-1258	C	R	-	VR	VR	VR	R	VR	-	F	R	-
82722	1258-1268	A	VR	VR	-	VR	VR	R	VR	-	F	R	VR
82723	1278-1288	C/A	VR	VR	VR	VR	VR	R	VR	-	F	R	-
82724	1288-1298	C/A	VR	-	-	VR	VR	R	VR	-	F	R	VR
82725	1298-1308	C	VR	-	-	VR	VR	R	VR	-	F	R	VR
82726	1308-1318	C	VR/R	VR	-	VR	VR	R/C	VR	-	F	R	-
82727	1318-1328	R/C	VR	VR	-	VR	-	R	VR	-	F	VR	-
82728	1328-1337	C	R	-	VR	VR	VR	R	VR	-	F	VR	VR

APPENDIX C

Descriptive Logs of Sand Fractions, Oh25-04 and -05

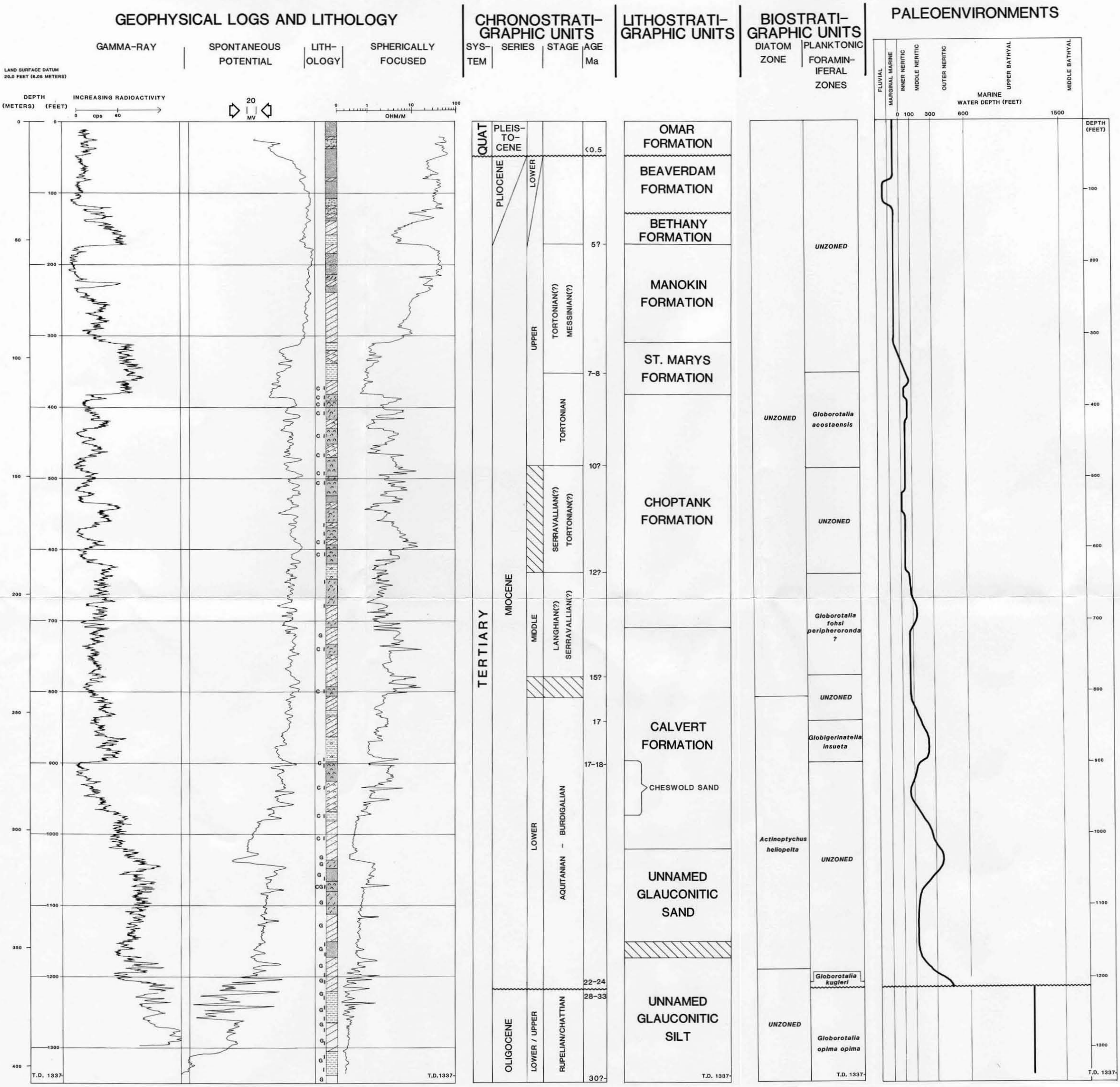
Oh25-04

Depth interval (feet below ground surface)	DGS Sample No.	Description
0 – 1.5	82953	SAND, fine to medium, subangular to subrounded, abundant coarse granules, very pale orange (10YR 8/2); quartz, clear to milky; feldspar common; fine chert granules; few opaque heavy minerals; poorly sorted (bimodal?)
1.5 – 3.0	82954	SAND, medium to coarse, subrounded; abundant granules to very small pebbles; very pale orange (10YR 8/2); quartz, clear to milky; feldspar common; fine chert granules and pebbles, few opaque heavy minerals; poorly sorted (bimodal?)
3 – 4.5	82955	same as above; no pebbles
4.5 – 6.0	82956	missing
6 – 7.5	82957	missing
7.5 – 9.0	82958	same as 82954
9.0 – 10.5	82959	same; very abundant pebbles, red chert, quartz
10.5 – 12	82960	SAND as above mixed with pebbles SAND, very fine to fine, subangular to subrounded; very pale orange (10YR 8/2); quartz, clear; feldspar few to common; opaque heavy minerals common; well sorted
12 – 12.5	82961	SAND, very fine to fine; subangular; white (N9); quartz, clear; opaque heavy minerals abundant, to 1%; muscovite common; feldspar common to abundant; well-sorted
12.5 – 13.5	82962	same as above
13.5 – 15	82963	SAND, fine to very fine, mixed with medium to coarse; subangular to subrounded; white (N9), few granules; quartz, clear to milky; feldspar abundant; slight greenish and reddish stains on granules common; muscovite common to abundant; moderately sorted
15 – 16.5	82964	same as above, no granules
19.5 – 21	82965	as above, few very small pebbles
24.5 – 26	82966	SAND, medium, subrounded, white (N9); quartz, clear to milky; 5% feldspar; well sorted; rare opaque heavy minerals
29.5 – 31	82967	SAND, very fine to fine, subangular, white (N9) to very pale orange (10YR 8/2); quartz, clear to milky; abundant opaque heavy minerals; feldspar abundant to common; muscovite abundant (to 1%)
34.5 – 36	82968	as above, fine to very fine
39.5 – 40	82969	as above mixed with SAND, medium to coarse, subrounded, very pale orange (10YR 8/2); granules, commonly stained orange to red; 1–5% feldspar; quartz clear to milky; opaque heavy minerals common; organics(?) rare; rare iron oxide-cemented grains; few pebbles
40 – 41	82970	SAND, medium to coarse; subrounded, very pale orange (10Y8/2) to white (N9); granules common, stained orange; quartz clear to milky; 5–10% feldspar; few to common opaque heavy minerals
44.5 – 46	82971	same as above, glauconite common
49.5 – 51	82972	same as above, glauconite common
54.5 – 56	82973	same as above, glauconite common
59.5 – 61	82974	same, abundant granules; small pebbles common, chert, quartz

Oh25-05

Depth interval (feet below ground surface)	DGS Sample No.	Description
0 – 1.5	82975	SAND, medium to coarse, subangular to subrounded; very pale orange (10YR 8/2); quartz, clear, some milky; feldspar <1%; few chert; few granules; few opaque heavy minerals; moderately well sorted
1.5 – 3.0	82976	SAND, as above, medium, few large granules; overall finer than above
3.0 – 4.5	82977	SAND, fine, subangular to subrounded; very pale orange (10YR 8/2) to white (N9); quartz, clear; muscovite common; feldspar few to common; few iron oxide-cemented grains; opaque heavy minerals common; well sorted
4.5 – 6.0	82978	SAND, as above; few to common large granules; muscovite common; rare glauconite
6.0 – 7.5	82979	SAND as above mixed with coarse to very coarse; abundant granules, quartz, clear, subrounded; few to common chert
7.5 – 9.0	82980	SAND as above; fewer granules, coarse to very coarse
9.0 – 10.5	82981	SAND, fine, subangular to subrounded, very pale orange (10YR 8/2); quartz, clear to milky; few feldspar; abundant opaque heavy minerals; rare to few muscovite; few granules
10.5 – 12	82982	SAND, fine to medium, subangular to subrounded, very pale orange (10YR 8/2); quartz, clear to milky; few feldspar; common opaque heavy minerals; rare muscovite; few to common granules; red iron oxide cement; few very small pebbles
12 – 13.5	82983	SAND, fine to medium, subangular to subrounded, moderate orange pink (5YR 8/4); quartz, clear to milky, abundant iron oxide stains; few opaque heavy minerals; few to common pebbles
13.5 – 15	82984	SAND, fine, subangular to subrounded; very pale orange (10YR 8/2); quartz, clear to milky; few opaque heavy minerals; few feldspar; few granules
15 – 16.5	82985	SAND, as above, iron oxide cement common; abundant opaque heavy minerals; few muscovite; rare pebbles
16.5 – 18	82986	SAND, fine, subangular to subrounded, white (N9), quartz, clear, some milky; abundant dark orange iron oxide stains; few opaque heavy minerals
24.4 – 25.9	82987	SAND, medium to coarse, subrounded, white (N9); quartz, clear, few milky; few feldspar; few to common opaque heavy minerals; granules and very small pebbles few to common, quartz, chert
29.4 – 30.9	82988	SAND, coarse to very coarse, subrounded, very pale orange (10YR 8/8); quartz, clear to milky; iron oxide stain common; common feldspar; common chert; abundant granules, quartz, chert
34.5 – 35.9	82989	SAND, medium to fine; subangular to subrounded, white (N9); quartz, clear to milky; common feldspar; few to common opaque heavy minerals; rare pebbles
39.4 – 40.9	82990	SAND, coarse, subrounded, white (N9) to very pale orange (10YR 8/8); quartz, clear to milky; common feldspar; granules common
44.4 – 45.9	82991	SAND as above; feldspar abundant to common; iron oxide stains common; abundant granules
49.4 – 50.9	82992	SAND, fine to very fine, subangular, very pale orange (10YR 8/2); quartz, clear to milky; abundant muscovite; common glauconite, very rounded and weathered; opaque heavy minerals common to few; few feldspar; well sorted
54.4 – 55	82993	SAND, as above; iron oxide cement and stains common
55 – 55.9	82994	SAND, medium to coarse, subrounded to subangular, moderate orange pink (5YR 8/4); quartz clear to milky; abundant iron oxide stains; glauconite few to common; few muscovite; granules common

Delaware Geological Survey
University of Delaware
Newark, Delaware 19716



Silty Clay to Clayey Silt
Silt
Sandy Silt
Silty Sand
Sand, fine to coarse
Sand, gravelly to Gravel
Shell
Shelly Sand to Sandy Shell
Silty Shell to Shelly Silt
G Glauconite (>5%)
I Indurated
C Calcareous Cement

STRATIGRAPHIC CONTACT WITHIN THIS INTERVAL

PLATE 1. INTERPRETIVE SUMMARY, WELL NO. Oh25-02, LEWES, DELAWARE