STRATIGRAPHY AND GEOPHYSICAL LOGS FROM A COREHOLE DRILLED TO BEDROCK AT ROBINS POINT, J-FIELD, EDGEWOOD AREA, ABERDEEN PROVING GROUND, MARYLAND

By David S. Powars

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.304	meter (m)
mile (mi)	1.609	kilometer (km)
gallon (gal)	3.785	liter (L)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
pound, avoirdupois (lb)	0.4536	kilogram (k)
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m))	3.28	foot (ft)
kilometer (km)	0.6214	mile (mi)

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$°F = 1.8\ (°C) + 32$$

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level datum of 1929.

Abbreviated water-quality units in this report: Chemical concentrations and water temperature are given in metric units. Chemical concentration in water is expressed in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as well as weight (milligrams) of solute per unit of volume (liter) of water. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

Specific conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm). This unit is equivalent to micromhos per centimeter at 25 degrees Celsius, formerly used by the U.S. Geological Survey.

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ABSTRACT

A 961-foot-deep corehole was drilled at Robins Point on the southeastern tip of Gunpowder Neck Peninsula to obtain additional insight into the hydrogeological framework of J-Field in the Edgewood Area of Aberdeen Proving Ground, Maryland. The Robins Point corehole penetrated Quaternary and Cretaceous Coastal Plain sediments and the weathered zone of the underlying Paleozoic bedrock. The corehole is within the deep part of a Susquehanna River paleochannel that underlies most of J-Field and influences the shallow (less than 200 feet deep) ground-water-flow system.

Geophysical logs obtained from the corehole included natural gamma, multipoint normal resistivity (16-inch and 64-inch), 4-foot-guard focused resistivity, acoustic (sonic) velocity, and caliper. The stratigraphic units and aquifers and confining units that underlie J-Field were described and characterized on the basis of analysis of the core and borehole geophysical logs. The high percentage (approximately 90 percent) of total core recovered and the suite of geophysical logs provide a detailed key for interpreting regional stratigraphic, borehole geophysical, and marine seismic-reflection data.

Lithologies encountered in the corehole include, in ascending order: 72.4 feet (ft) of weathered metamorphic rock and saprolite (James Run Formation (?) of the lower Paleozoic), 711.4 ft of lower and upper Cretaceous fluvio-deltaic deposits, and 145.9 ft of Pleistocene and 31.3 ft of Holocene(?) fluvial and estuarine deposits.

On the basis of lithology, palynology, and regional correlations, the Coastal Plain section contains eight stratigraphic units that include, in ascending order: 241.3 ft of the Patuxent/Arundel Formations (undifferentiated), 209 ft of the Lower Patapsco, 261.1 ft of the Upper Patapsco, 15.7 ft of the Accomack Member of the Omar Formation, 199.7 ft of the Stumptown Member of the Nassawadax Formation, 10.5 ft of the Kent Island Formation, and 31.3 ft of unnamed Holocene deposits.

Aquifers and confining units identified include, in descending order: 41.8 ft of surficial aquifer, 90.9 ft of upper paleochannel confining unit, 28.8 ft of paleochannel confined aquifer, 15.7 ft of lower paleochannel confining unit, 123.7 ft of Upper Patapsco aquifer, 44.6 ft of Middle Patapsco confining unit, 92.8 ft of Middle Patapsco aquifer, 57.3 ft of Lower Patapsco confining unit, 151.7 ft of the Lower Patapsco aquifer, 115.4 ft of Potomac confining unit, 126.4 ft of Patuxent aquifer, an aquifer of 23.4 ft of saprolite, and a confining unit that consists of 48.7 ft of weathered-rock/ saprolite.

The Cretaceous aquifers vary from"dirty" channel sands to relatively "clean" channel sands. The Cretaceous confining units consist primarily of dense clay overbank paleosols that tend to restrict vertical ground-water movement. The lateral distribution of these clays, however, is unknown and is probably not very extensive based on the cut and fill nature of fluvio-deltaic deposits. Where the paleochannel lies beneath the Chesapeake Bay, ground water probably discharges into the bay. The upper paleochannel confining unit contains silt and very fine sand and therefore may be a leaky confining unit.

INTRODUCTION

A major objective of an ongoing investigation of the hydrogeologic framework of the Edgewood Area of Aberdeen Proving Ground (APG), Maryland, is to obtain information needed to assess the potential for contaminants to migrate off the post. To accomplish this task, a better understanding of the stratigraphy of the aquifers and confining units is needed, as well as detailed descriptions of the sedimentology. As part of this study, the U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers (COE), and Aberdeen Proving Ground, continuously cored a stratigraphic corehole to a depth of 961 ft at Robins Point, located at the southeastern tip of the Gunpowder Neck Peninsula, which is the farthest downdip position at APG (except for Pooles Island) (fig. 1). The drill site is within the deep part of a paleochannel of the Susquehanna River (Hughes, 1991, 1993). This paleochannel underlies most of J-Field (fig. 2) and influences the shallow (less than 200 ft deep) ground-water-flow system. The Robins Point corehole penetrated Quaternary and Cretaceous Coastal Plain sediments and the weathered zone of the underlying Paleozoic bedrock.

A 2-inch-diameter observation well was installed in the corehole to sample ground-water quality. The screen in the well was set at a depth of 392 to 402 ft. Water samples were collected to measure pH, alkalinity, specific conductance, and water temperature. Concentrations of total and dissolved iron and manganese, chloride, and total dissolved solids were determined and hardness was calculated on the basis of the concentrations of calcium and magnesium.

The Robins Point corehole provides important lithologic, paleontologic, and sedimentologic data needed for interpretation of depositional environments and recognition and correlation of hydrogeologic units. The Robins Point core provides a key to regional stratigraphic correlation, and therefore can greatly aid in the development and refinement of the regional hydrogeologic framework.

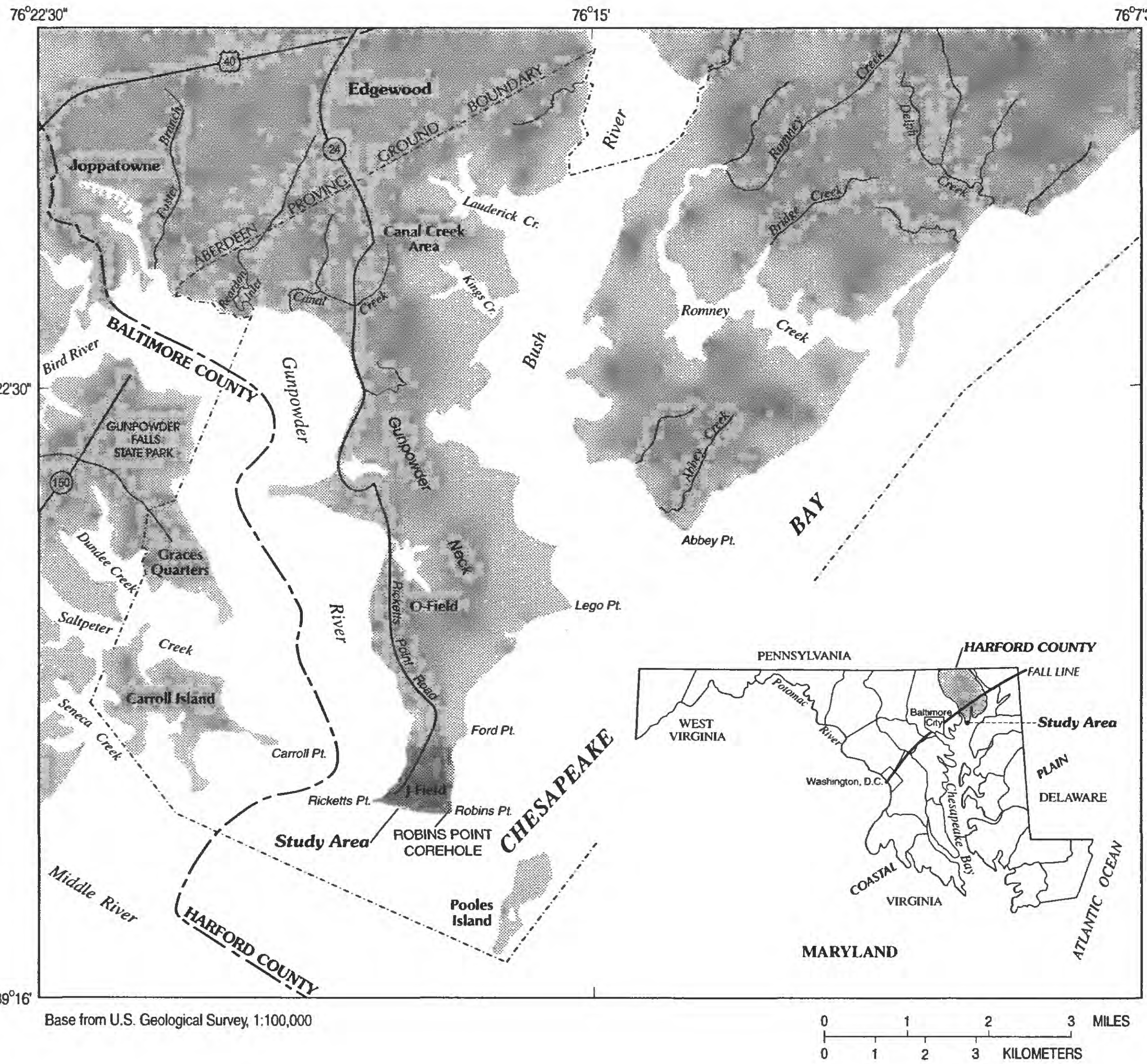

Figure 1. Location of the Robins Point corehole and the J-Field study area at Aberdeen Proving Ground, Maryland.

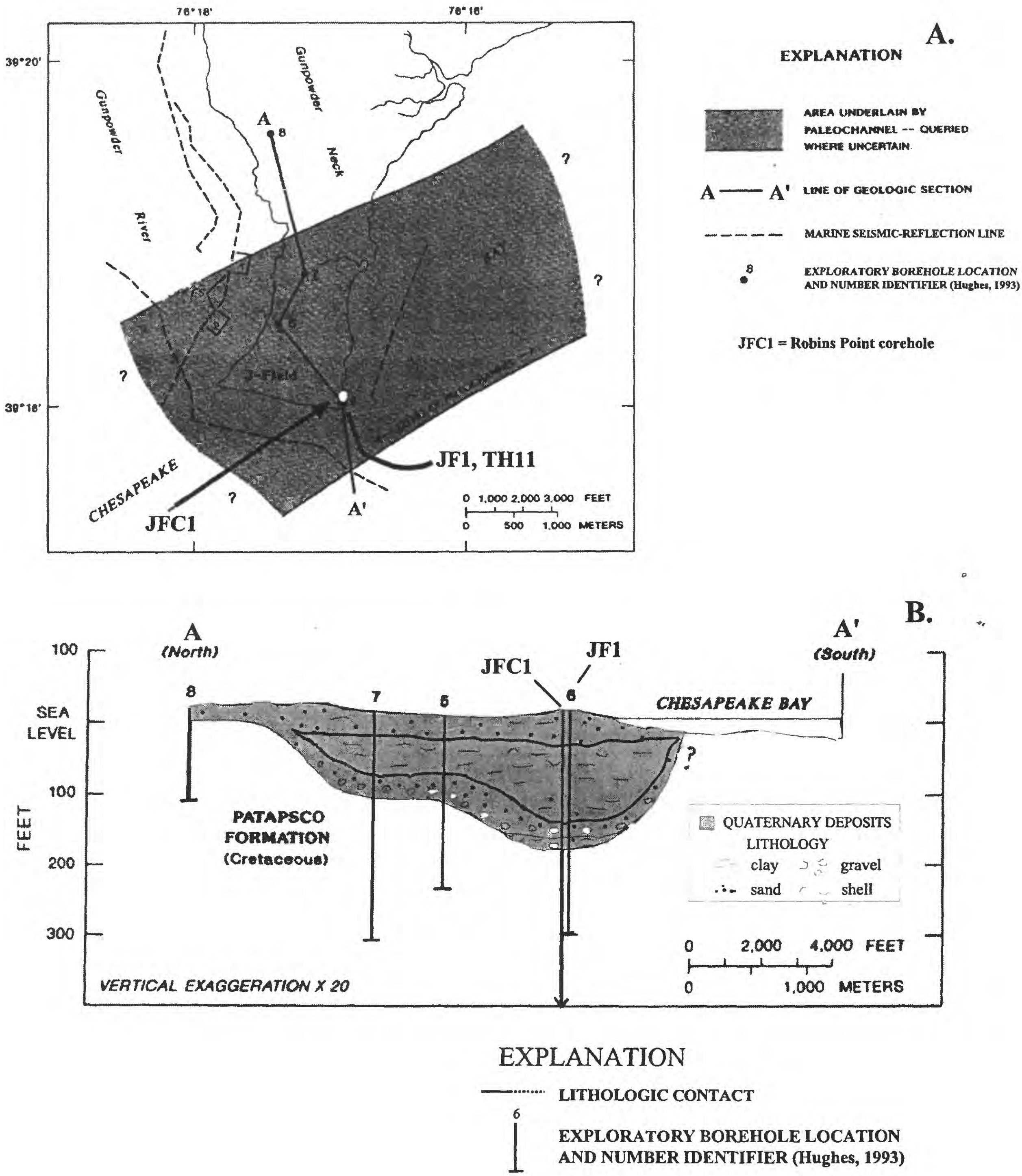

Figure 2. Location of: **(A)** JFC1 (Robins Point corehole), JF1, TH11, borehole data used in constructing geologic section A-A', and marine seismic-reflection lines used to delineate the paleochannel (modified from Hughes, 1993) [*Shaded area shows the location and trend of a Pleistocene Susquehanna River paleochannel.*]; and **(B)** Geologic cross section A-A' showing a profile of the paleochannel beneath J-Field.

Purpose and Scope

This report describes and characterizes the stratigraphic and geophysical properties of the aquifers and confining units that underlie Robins Point at J-Field. The lithology of the core was correlated with geophysical logs to characterize the physical properties of these units and their geophysical signatures. Pollen analysis of 34 samples provided relative stratigraphic ages.

The report also describes the methods that were used for drilling of the corehole, analysis and preservation of the core, and installation, development, and sampling of the observation well. Photographs of the Robins Point core at many depth intervals are included, as well as closeup photographs of contacts between selected formations.

Regional Geologic Setting

The Mid-Atlantic Coastal Plain is dominated by a basement downwarp known as the Salisbury Embayment (Richards, 1948). This embayment is filled with a thick, wedge-shaped section of fluvio-deltaic lower Cretaceous deposits, which thicken eastward toward the Atlantic Ocean and thin westward toward the Fall Line (fig. 3). The lower Cretaceous deposits are overlain by a similar, much thinner wedge of deltaic to marine upper Cretaceous, Paleogene, and Neogene deposits that are capped by fluvial and estuarine late Miocene to Holocene deposits.

The study area is located near the northwestern edge of this embayment, about 10 mi east of the Fall Line, on one of many low-relief peninsulas bordering the western margin of the upper Chesapeake Bay. This inner Coastal Plain lowland north of the Patapsco River and south of the Susquehanna River (figs. 3, 4) primarily owes its low topography to truncation by numerous Susquehanna River paleochannels and their tributaries and by subsequent aggradational filling of these paleochannels. The inner Coastal Plain lowland is surrounded to the north and south by an inner Coastal Plain with high relief more typically found along the Atlantic Coastal Plain (fig. 4). Only a few other areas along the Atlantic Coastal Plain have large river valleys running parallel to the Fall Line (that is, segments of the Delaware and Potomac Rivers) and those valleys have been related to structural control by fault systems (Mixon and Newell, 1982; Mixon and Powars, 1984; Newell and others, 1995).

Previous investigators of this inner Coastal Plain margin divided the lower Cretaceous deposits (known collectively as the Potomac Group) into three formations. In ascending order, these are the Patuxent, Arundel, and Patapsco Formations (Clark, 1910; Brenner, 1963; Hansen, 1968; Glaser, 1969; and Crowley and others, 1976). On the basis of outcrop studies, Owens (1969) mapped an undivided Potomac Group in Harford County; however, Edwards and Hansen (1979) subdivided the lower Cretaceous section into the Patapsco Formation and a Patuxent/Arundel undifferentiated unit. They pointed out that a broad lithostratigraphic zonation is possible, especially in the subsurface where hundreds of feet of section are available for study. These variations in nomenclature (fig. 5) result from the fact that fluvio-deltaic deposits are highly variable both laterally and vertically, which makes the correlation of individual beds between localities difficult. Palynological (pollen and spores) data are often used to correlate these sections, but factors such as ecological variability and reworking can cause complications.

The Potomac Group has been characterized in previous outcrop and subsurface investigations as consisting of fining-upward sequences typical of channel/point bar/flood-plain/backswamp deposition by meandering streams or braided streams (Hansen, 1968, 1969 a,b; Glaser, 1969; Reinhardt and Cleaves, 1978; Reinhardt and others, 1980; Minard, 1980; Mack, 1988; and Owens and Gohn, 1985). The

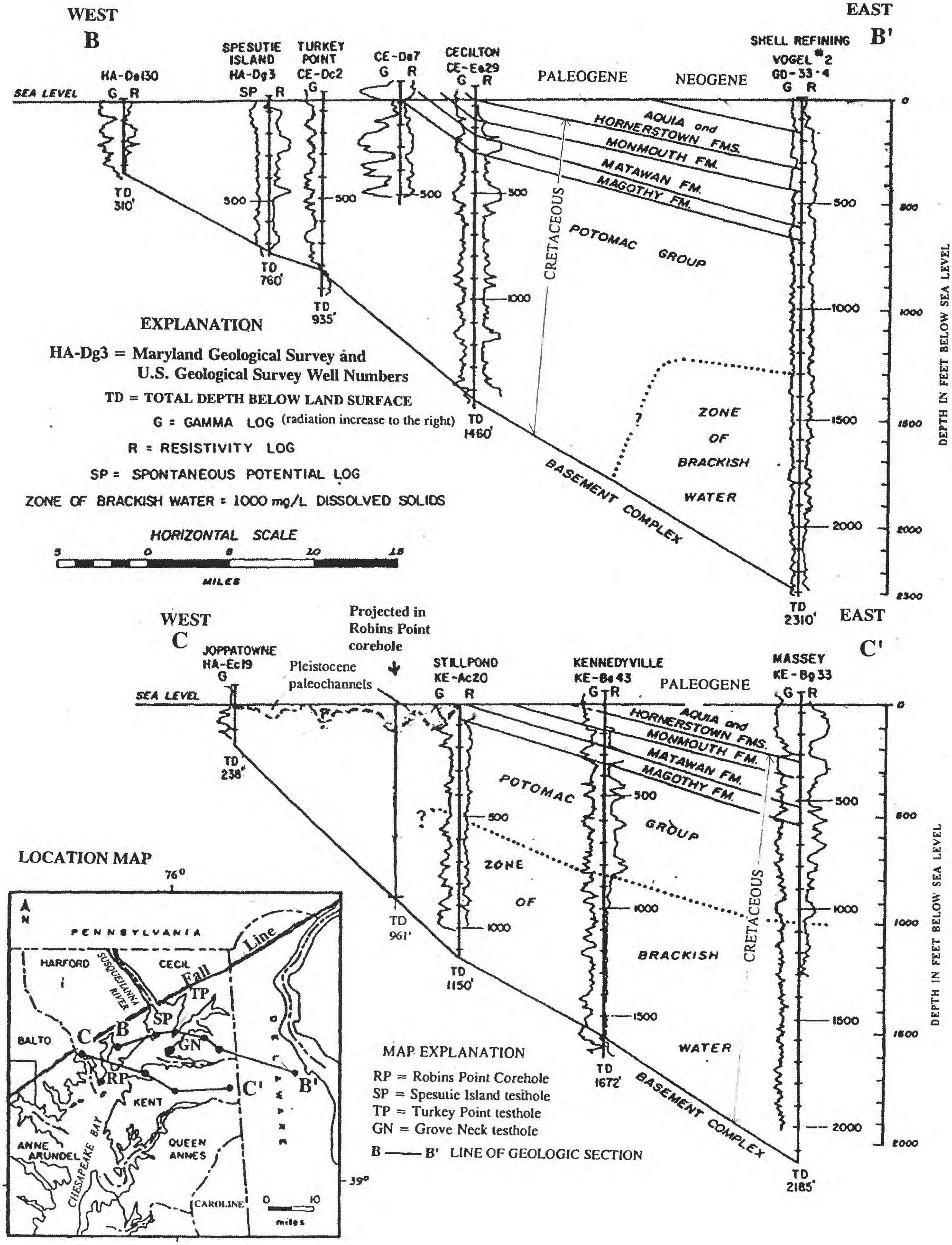

Figure 3. Location map and geologic sections B-B' and C-C' across the upper Chesapeake Bay region showing the relation of the stratigraphy at the Robins Point corehole (JFC1 on location map) to the regional geologic framework (modified from Otton and Mandle, 1984). [*Truncation of the inner Coastal Plain west of the Chesapeake Bay by Pleistocene paleochannels is shown on section B-B'.*]

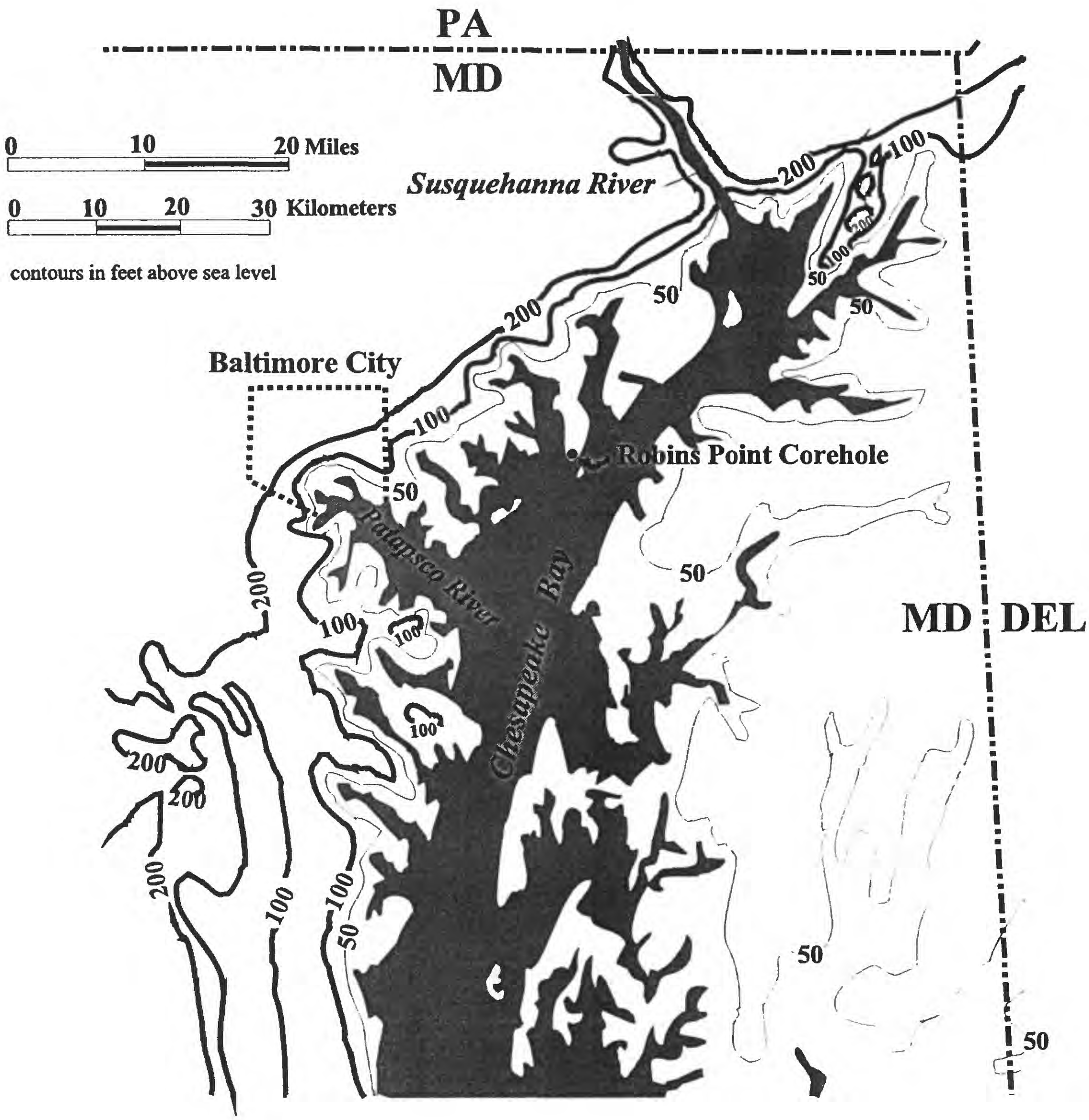

Figure 4. Generalized topography of the upper Chesapeake Bay showing truncated lowland on the west side of the bay between the mouths of the Patapsco and Susquehanna Rivers.

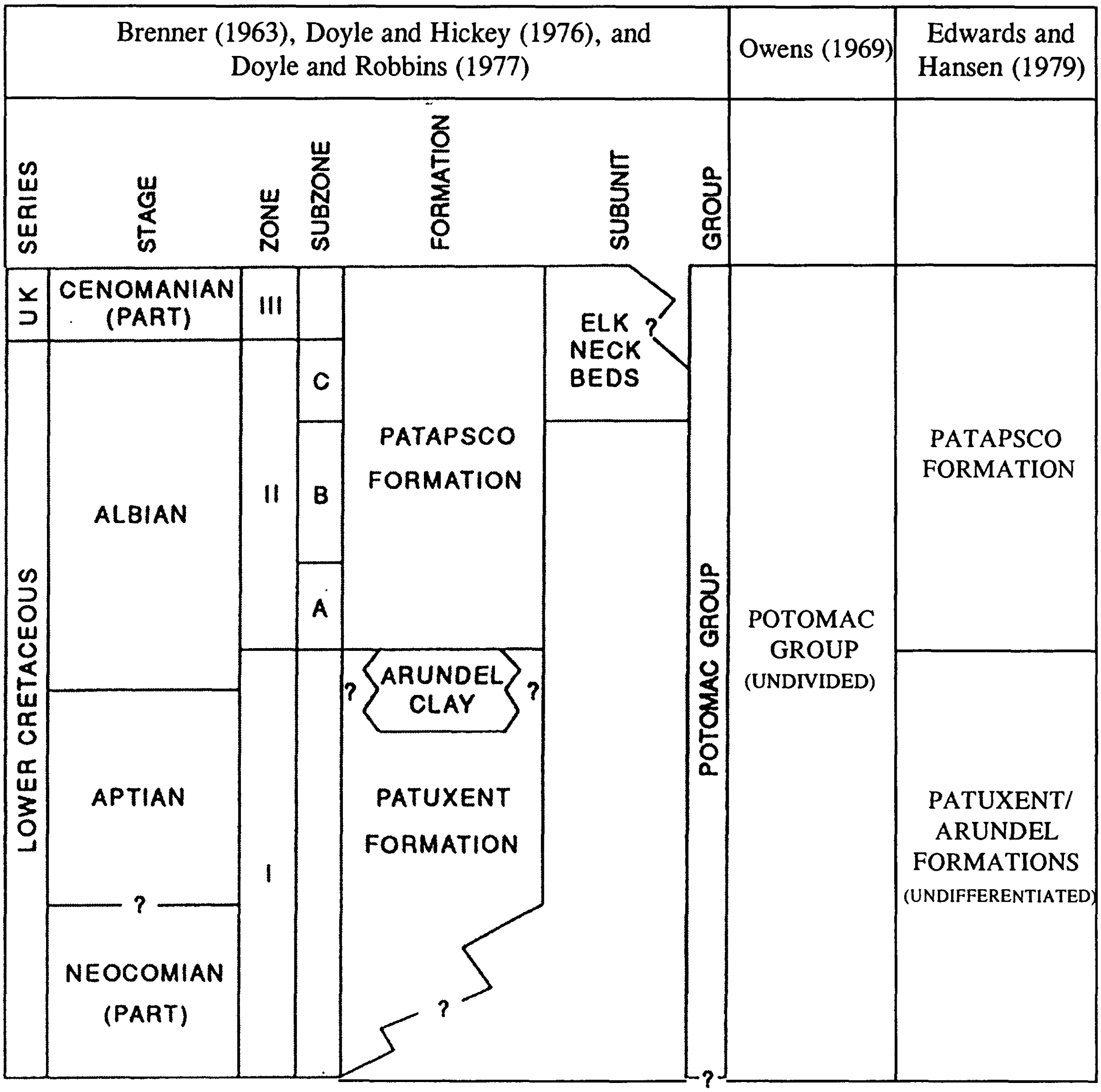

Figure 5. Stratigraphic units and pollen zones of the Potomac Group in the Mid-Atlantic States (modified from N. Frederiksen, U.S. Geological Survey, written commun., 1996).

generalized stratigraphic sequence of gravel at the base, clay in the middle, and interbedded sand and clay at the top that was proposed by Owens (1969) for the Potomac Group in outcrops in Harford County was not observed in the Robins Point core.

Owens (1969) reported that the lower Cretaceous deposits in Harford County are truncated by Pleistocene deposits (Talbot Formation) and upland gravels (late Tertiary). Hughes (1993) showed that a 40- to 160-ft-thick complex of Pleistocene fluvial and estuarine deposits fill a paleochannel of the Susquehanna River that truncates the Patapsco Formation (fig. 3). The extent of the paleochannel was mapped in adjacent offshore areas using marine seismic-reflection data (Hughes, 1991, 1993).

Acknowledgments

The author wishes to thank the following APG personnel for logistical support: John Wrobel and Gerald Garcia of the Directorate of Safety, Health, and Environment; and Maynard Geisler and Kenneth Deptol, safety technicians at range control, for controlling and coordinating site access. Thanks also is given to the following Army Corps of Engineers personnel from the Baltimore District for logistical support and equipment loans: Valerie Thurmond, William Krinner, and James Carpenter. Appreciation is extended to Lou Martino from Argonne National Laboratories for X-ray fluorescence analysis.

Efforts of the following USGS personnel contributed to the successful completion of the Robins Point corehole: Daniel Phelan, William Banks, Elizabeth Marchand, Joseph Beman, and Peggy Nemoff , who provided technical support; Eugene Cobbs, Jr., Eugene Cobbs, III, and Donald Queen, who performed the core drilling; Gerald Idler, who ran the geophysical logs, and Norman Frederiksen for pollen analysis.

The author also wishes to acknowledge Harry Hansen of the Maryland Geological Survey, and Gregory Gohn, Dorothy Tepper, and Daniel Phelan of the U.S. Geological Survey for their helpful reviews of the manuscript. Special thanks is extended to Jean Hyatt, Sheryl Protani, Donna Knight, and Timothy Auer of the Publications Section of the Maryland-Delaware-DC District of the U.S. Geological Survey.

STUDY METHODS

Preliminary Ground-Water-Quality Sampling

Ground water from the surficial and uppermost confined aquifer at the drill site was sampled and analyzed to determine the potential for natural or manmade contaminants to migrate downward during the process of drilling the corehole to bedrock. The USGS and COE installed a temporary well screened at the bottom of the surficial aquifer, from 32 to 35 ft below land surface (bls), prior to drilling the corehole so that a ground-water-quality sample could be taken. In addition, a water-quality sample was taken from well JF1 (fig. 2) in the first confined aquifer (screened from 185 to 190 ft bls), and data from previous sampling rounds at well JF1 and nearby surficial aquifer well TH11 (fig. 2) (screened from 8 to 18 ft bls) were reviewed. Both wells (JF1 and TH11) are within 80 ft of the corehole. Inorganic and organic water-quality data from the previous samples for wells JF1 and TH11 are presented in Phelan and others (1996). Well JF1 was sampled in 1990 and 1993. Well TH11 was sampled only in 1990 and could not be resampled because the well screen had collapsed.

The USGS and COE drillers auguered the temporary hole to 32 ft bls and drove a 2-in.-diameter stainless steel casing and a 3-ft-long drive point screen (0.010-in. slot). The screen was set on November 3, 1995, from 32 to 35 ft bls (3 ft beyond the auger bit). The temporary well and well JF1 were then sampled on November 6 and 8, respectively, for volatile and semivolatile organic compounds (VOC's and SVOC's), pesticides, explosive compounds, and dissolved and total metals. Fortyfive VOC, 92 SVOC, 14 explosive, 27 pesticides, and 24 total metals and 24 dissolved metals parameters were analyzed from each of the two water samples. A summary of these analyses is presented in appendix I-A.

After the water-quality sampling results were forwarded to the Army, the U.S. Environmental Protection Agency, and the Maryland Department of the Environment, permission was granted to begin work on the corehole. The 35-ft-deep temporary well was removed, and coring began adjacent to the augered hole so that core could be collected for the entire depth. The water-quality data and list of parameters that were analyzed are on file at the Baltimore Office of the Maryland-Delaware-DC District of the U.S. Geological Survey.

Drilling

The Robins Point corehole was drilled from November 29, 1995 to April 17, 1996. During the 44 days of actual drilling time, the average daily core recovery was 22 ft. The surface casing consisted of a 12-in. steel casing to 3.0-ft depth to divert drilling mud to the mud-recirculating pan, an 8-in. steel casing to 61.5 ft, and a 5-in. steel casing to 65.0 ft. The telescoping casing was necessary to ensure that there would be no downward migration of any contaminants that might be in the surficial aquifer during drilling, and to maintain adequate hole diameter during drilling.

The drilling was done by the USGS Geologic Division's Eastern Drilling Team. The corehole was continuously cored using a hydraulic rotary wire-line rig. The drill crew used 5-ft- and 10-ft-long HQ core barrels with a specially designed oversized bit. A variety of inner-barrel snouts (shoes) with various lengths were used, enabling the inner barrel to either be out in front of the drill bit in loose sand (to keep the drilling mud from washing away the sand), or just behind the drill bit for tough clay. A variety of core catchers were also used.

The caliper log shows that nearly the entire hole was 4.5- to 5.0-in. in diameter. Recovered core was generally 2.25-in. in diameter. A total of 207 coring runs were made with approximately 90 percent recovery. Only two intervals had long continuous core losses of 7.8 ft (combined over two runs) and 7.6 ft. Two more intervals had continuous losses of 4.9 and 4.7 ft and a few intervals had continuous losses of 3.0 to 4.0 ft. The two longest core-loss intervals were due to blockages by sand, grout, or sandstone fragments in the outer barrel, which prevented the inner barrel from locking in place. A record was kept of the core drilling time, down pressure, mud pressure, mud-pump gear, type of snout used, and drilling comments.

Core Analysis and Preservation

Although all drilling mud and cuttings were tested onsite with an organic vapor analyzer to screen for organic contaminants, none were detected. Ninety samples, typically taken at 10-ft intervals, were submitted for X-ray fluorescence analysis to screen the core for metal contamination. All drilling mud and cuttings were drummed and the drums were labeled with the depth and date of collection.

The core was thoroughly washed with clean water, using either a hose with a spray nozzle connected to a pump, or a gentle spray from a hand-pumped container. All of the drilling mud was removed from the surface to be photographed and described and care was taken not to dislodge loose sands. The length of core was measured and lost footages were assigned depths. Lithic core descriptions were made onsite and included semiquantitative, visual estimates using standard charts and visual aids, including a 10x hand lens and a low power microscope (less than 30x). The core was photographed in both color and black and white and was videotaped.

Fifty pollen samples were described in detail and were submitted for analysis to Norman Frederiksen of the USGS. To date, 34 of these pollen samples have been processed and analyzed, including 18 from the Quaternary section and 16 from the Cretaceous section.

Geophysical Logging

Borehole geophysical logging was performed on April 17, 1996, and was used to supplement the lithologic data so the screen on the observation well could be properly placed. These logs were also helpful in determining regional correlation of the units. The following geophysical logs were obtained from the corehole: natural gamma; multipoint normal resistivity (16-in. and 64-in.), 4-ft-guard focused resistivity; acoustic (sonic) velocity, and caliper. All the logs were run to a depth of about 957 ft except the 4-ft-guard focused resistivity log, which was run only to 440 ft because the 3.5-in.-diameter tool got lodged in the hole.

Installation, Development, and Sampling of the Observation Well

In June 1996, the COE (Baltimore District) and the USGS began the installation of 402-ft observation well JFC1 in the annulus of the Robins Point corehole. A diagram of the construction of the well is shown in figure 6. After geophysical logging operations were completed, the corehole was grouted with Portland cement from 400 ft below land surface to its base at 961 ft. The upper 400 ft of the corehole remained filled with cuttings and drilling mud to maintain annulus integrity.

The screened interval (392 to 402 ft bls) was selected on the basis of the need to acquire data on the piezometric surface at the bottom of the Middle Patapsco aquifer. This interval selection process involved a compromise between the need for a zone of relatively coarse material to allow a sufficient yield of ground water, and the need to be close to (but not below) the contact between the Middle Patapsco aquifer and the Lower Patapsco confining unit.

Drilling operations began on June 12, 1996, with the enlarging of the 4.5- to 5.0- in.-diameter corehole to 7.5 in. using a fish-tail bit. To ensure that the annulus followed the path of the original corehole, two collars collectively weighing about 900 lbs were placed behind the bit. The cement grout was removed during the enlargement of the annulus to a depth of 415 ft bls. This was followed by the installation of a 10-ft screen and a 10-ft sump below the screen. The sump and all casing other than the screen were constructed of flush-threaded, 2-in.-diameter, schedule 40, polyvinyl chloride (PVC) well casing that had been steam-cleaned prior to delivery onsite. The 2-in.-diameter 10-ft screen was constructed of stainless steel and had also been steam-cleaned prior to delivery. An optimal screen slot size of 0.10 in. was determined from the limited information on other wells screened in this unit and on sieve analyses performed when the corehole was drilled. To ensure that the casing string stayed centered in the annulus, centralizers were placed at the bottom of the sump, at the bottom and top of the screen, and every 50 ft thereafter. Approximately 4 ft of casing extended above land surface.

Development of well JFC1 began approximately 2 weeks after drilling and installation operations were completed, by using an Aardvark [1] pneumatic pump powered by an air compressor. The 2-in. diameter and depth of the well prevented the use of a suction or positive-displacement pump.

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1. Use of brand names in this report is for indentification purposes only and does not constitute endorsement by the U.S. Geological Survey.

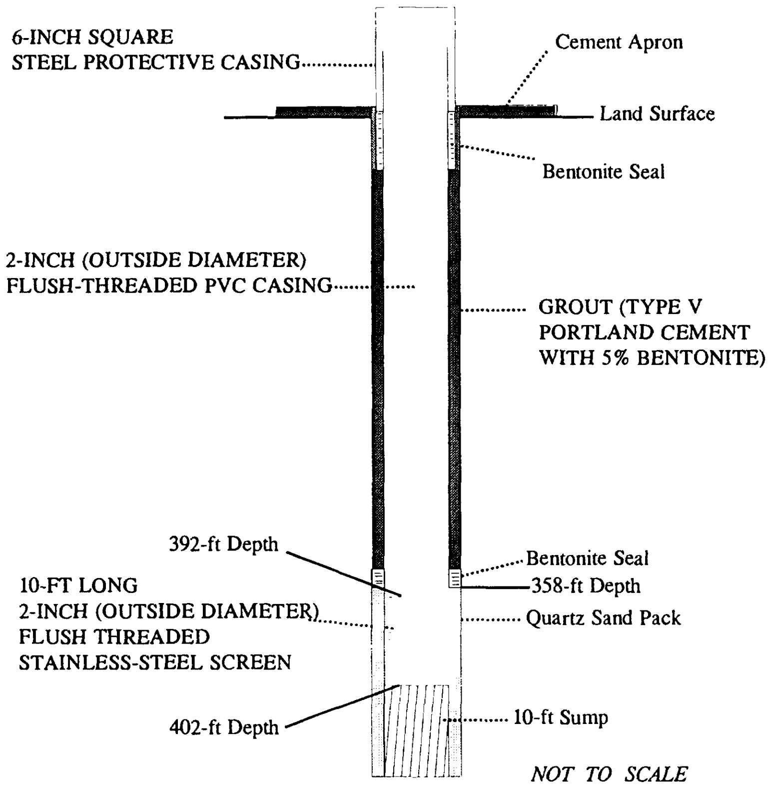

Figure 6. Construction of the observation well installed in the Robins Point corehole.

Development of the observation well took place between June 26th and 28th, 1996, and followed the criteria set forth in Standard Operating Procedure (SOP) 19 (U.S. Army Corps of Engineers, 1993). During purging operations, pH, specific conductance, and water temperature were recorded approximately every 20 minutes. Prior to development, the static water level was 36.3 ft below the top of the casing. By the time pumping ended on each of the 3 days, the water level had dropped from between 100 and 300 ft bls. Pumping during development varied between 1 to 3 gal/ min. As development of the well progressed, it was necessary to periodically lower the pump when recharge to the well did not equal or exceed the pump rate. During the 3-day development period, approximately 500 gal were removed from the well. This is equivalent to about 2.5 times the volume of the well, screen, and sump annulus plus the volume of the sand pack.

Values for pH, which were taken periodically during purging, ranged from 6.87 to 8.63. Values for specific conductance ranged from 256 to 643 µS/cm. Water temperatures ranged from a high of 26.6 degrees Celsius (°C) to a low of 16.9 °C. All constituents tended to stablize within the first hour of sampling and generally did not vary more than 10 percent during daily development activities.

To comply with Federal and State regulations regarding the quality of ground water, a water sample was collected from well JFC1 on September 25, 1996. Prior to sampling, the static water level was 6.77 ft below the top of the casing. A Keck pump was used to purge the well and collect water samples for analysis. Both purging and sampling were done using low-flow procedures as described in Standard Operating Procedure 13 (U.S. Army Corps of Engineers, 1993). The sample was analyzed for total and dissolved iron and manganese, chloride, and total dissolved solids. The hardness of the water was calculated on the basis of the concentrations of calcium and magnesium.

Stagnant water in the well annulus and sand pack was purged by incrementally lowering (so that the water level never went below the pump intake) the pump to a depth of 100 ft below the top of the casing and pumping at a rate of about 1 gal/min. After approximately 25 gal were removed and containerized, the pump was shut off and the well was allowed to recover to 15 ft below the top of the casing. The recovery rate was approximately 0.08 gal/min. The pump was again incrementally lowered until it was about 90 ft below the top of the casing. The well was purged for approximately 10 minutes at a rate of 1 gal/min.

Field measured properties showed less than a 10-percent variation during sampling. Specific conductance ranged from 433 to 448 µS/cm. Water temperature ranged between 16.8 °C and 20.9 °C. Values for pH ranged between 6.97 and 7.29. Water samples were shipped overnight with a chain-of-custody receipt to a contract lab. All constituents were analyzed in accordance with the U.S. Environmental Protection Agency's (USEPA) Contract Lab Procedures (CLP). Appendix I-B lists the values for the analyzed constituents.

STRATIGRAPHY OF ROBINS POINT COREHOLE (JFC1)

A generalized lithostratigraphic column for the corehole and gamma-ray and multipoint resistivity logs are shown in figure 7. A more detailed graphic illustration of the stratigraphy is shown superimposed on the left side of the gamma-ray log trace in appendix II.

Lithologies encountered in ascending order in the corehole [surface elevation about 4 ft above mean sea level (amsl)] include: 72.4 ft of weathered metamorphic rock and saprolite (888.6 to 961.0 ft, lower Paleozoic(?); 711.4 ft of lower and upper Cretaceous fluvio-deltaic deposits, mostly unconsolidated sand, clay, silt, and some gravel (177.2 to 888.6 ft); and 145.9 ft of Pleistocene and 31.3 ft of Holocene(?) fluvial and estuarine deposits, which consist mostly of unconsolidated clayey silt, sand, clay, and some gravel.

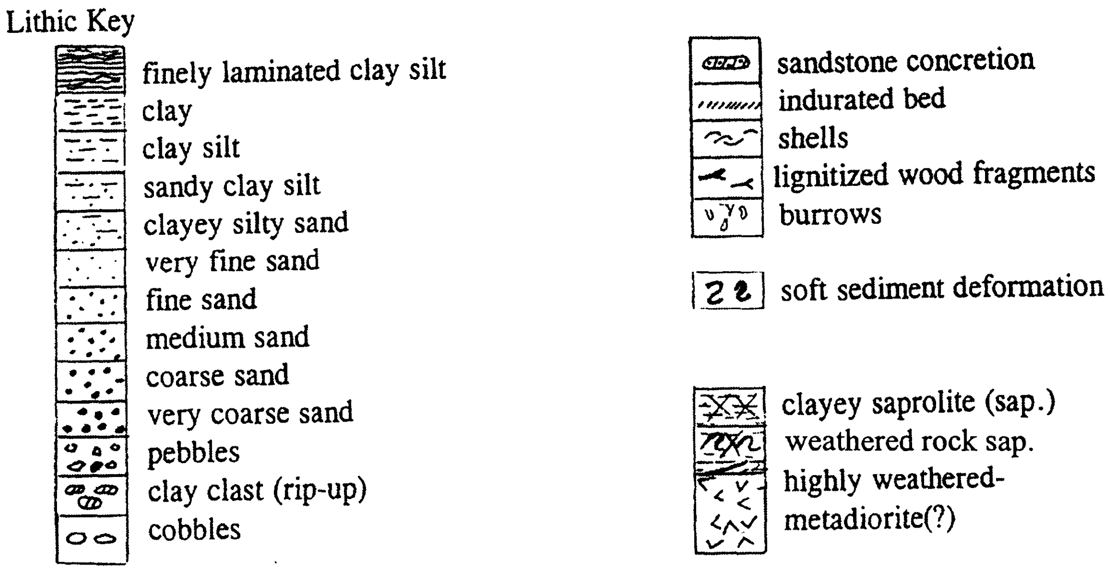

Figure 7. Generalized lithostratigraphic column and gamma and resistivity borehole logs for the Robins Point corehole. [*Arrows to right of lithology column depict fining-upward sequences, some indicated by horizontal dashed and solid lines shown between the geophysical logs. The letters A to E associated with angled arrows represent large-scale fining-upward cycles of possible tectonic or eustatic origin. "A" appears to be truncated, having lost the finer grained upper part. The small-scale fining-upward sequences may be the result of channel migration or avulsion. The Pleistocene glacial-interglacial stages are correlated with equivalent stratigraphic units mapped in the Chesapeake Bay region as follows: pre-Illinoian = Accomack Member of the Omar Formation (middle Pleistocene); Illinoian-Sangamon = Stumptown Member Nassawadax Formation; and Wisconsinan = part of the Kent Island Formation.*]

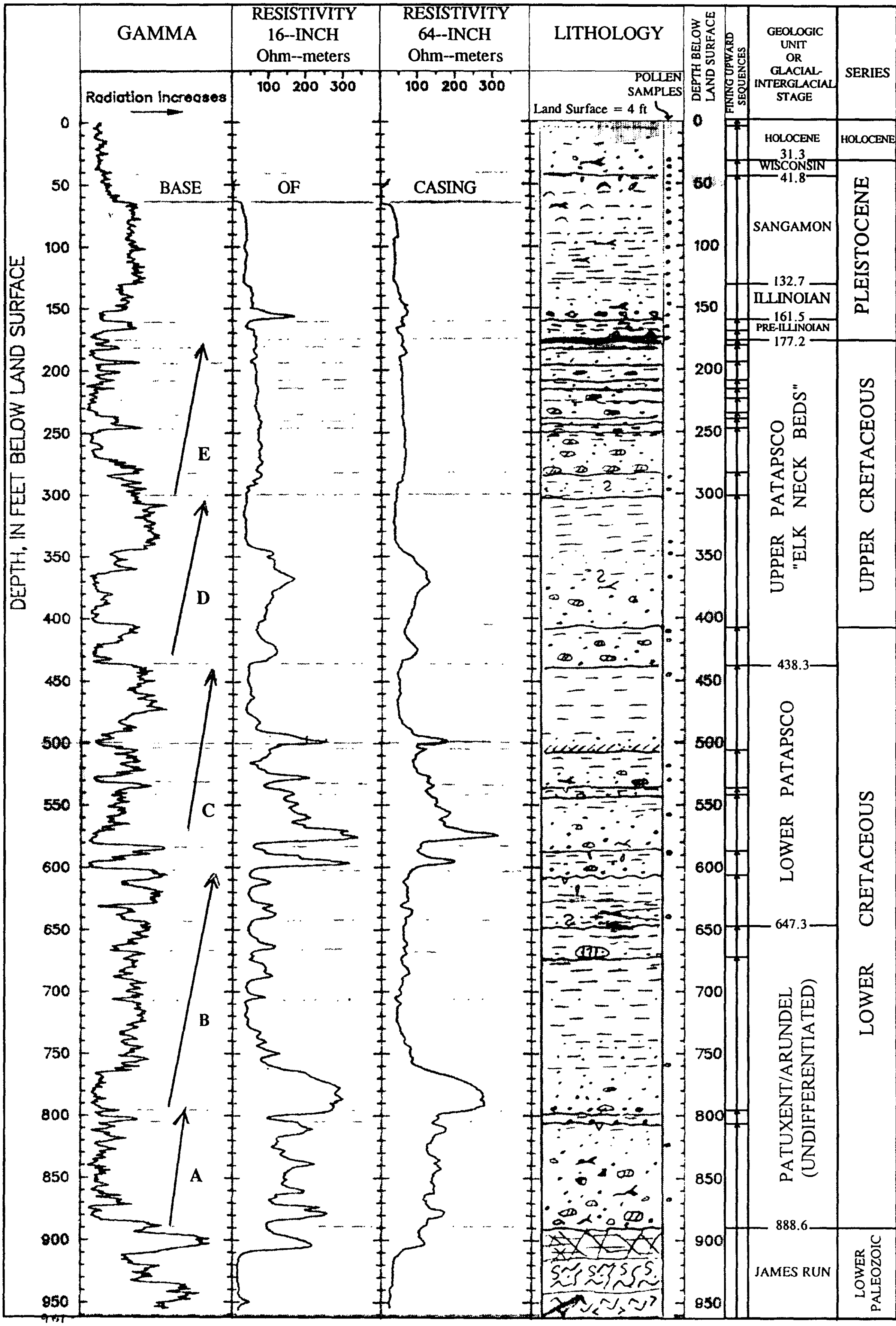

Figure 7. Continued

On the basis of lithology, palynology, and regional correlation, the lower Cretaceous deposits are subdivided into a lower 241.3-ft-thick unit correlated with the Patuxent/Arundel Formations (undifferentiated) and an upper 470.1-ft-thick unit correlated with the Patapsco Formation. A summary of the pollen analysis is shown in figures 8 and 9 (Norman Frederiksen, U.S. Geological Survey, written commun., 1996). On the basis of this analysis, the samples from 758 to 867 ft are assigned to pollen Zone I (see also fig. 5). No samples were examined between 639 to 759 ft because this interval mainly consists of intensely weathered paleosols associated with overbank deposits that lack spores and pollen grains. The base of the Patapsco Formation is placed at the sand-over-clayey paleosol contact at 647.3 ft. This contact separates a thick section of clayey overbank/paleosol strata (647.3 to 742.2 ft) that probably represents the Arundel Clay, from a slumped and/or faulted clay and sand interval (633.8 to 647.3 ft) that contains a pollen assemblage assigned to Zone IIa (see fig. 5). This contact correlates well with contacts in the Grove Neck, Turkey Point, and Spesutie Island testholes, for which some pollen data from split spoon cores and geophysical log data are available (Edwards and Hansen, 1979).

Analysis of the Robins Point core and the suite of geophysical logs shows that the Coastal Plain deposits primarily consist of numerous Cretaceous, Pleistocene, and Holocene(?) fining-upward sequences that overlie a metamorphic basement complex. In the Robins Point corehole, the Cretaceous deposits contain five large-scale fining-upward cycles, shown as A through E in figure 7 and appendix II. These large-scale cycles contain 22 fining-upward sequences that range in thickness from 4.6 ft to 123.3 ft. These sequences are designated by arrows in figure 7 and appendix II. The Pleistocene and Holocene deposits contain six fining-upward sequences that range in thickness from 7.3 ft to 119.7 ft.

These fining-upward sequences are bounded by sharp lithic breaks and are characterized by a coarse basal lag deposit (either a pebbly sand, a gravel, or a clay-clast conglomerate) that grades upward into interbedded, finer grained sands, silts, and clays. Conspicuous bedding is prevalent throughout most of the core, with only a few massive intervals encountered. Bedding ranges from planar laminations (0.25 to 1.0 mm thick); to thin beds (1.0 mm to 3.0 cm thick); to wavy to slightly inclined, and crossbedded (low and high angle) layers. Throughout the core, the sand fraction is nearly all quartz. There are only a few intervals within the Cretaceous deposits, however, where diffuse white grains might consist of weathered feldspars or tiny clay clasts (a possibility due to the large amounts of clay rip-up clasts in the core).

Paleozoic Bedrock (888.6 to 961.0 ft)

A zone of 72.4 ft of weathered rock and saprolite was encountered beneath the major unconformity at 888.6 ft that separates the lower Cretaceous deposits from bedrock. Within this zone, 60 ft of deformed, metamorphosed, predominantly mafic igneous rocks with cross-cutting dikes and faults were recovered. This zone can be divided into the following three units, in ascending order: 12.4 ft of highly weathered metadiorite(?), 36.6 ft of highly weathered rock/saprolite, and 23.4 ft of clayey saprolite. These basement rocks are tentatively correlated with the lower Paleozoic metavolcanic rocks of the James Run Formation (Southwick, 1969; Higgins and Conant, 1990).

The acoustic velocity log shows an increase in density from 946 ft downward, which corresponds to a dark-green to black, cross-cutting dike that separates a highly sheared and faulted (may contain clay gouge) mixture of mostly mafic igneous rocks from underlying denser, highly weathered metadiorite(?).

At a depth of 912 ft, dark-green to black, hard and soft, weathered rock/saprolite grades upward within a 0.5-ft-thick interval into a light-greenish-gray, highly clayey saprolite that shows no change in acoustic velocity (fig. 10). The resistivity logs, however, indicate a clay or highly mineralized fluid (brackish) signature within the weathered saprolite rock and highly weathered metadiorite(?) interval.

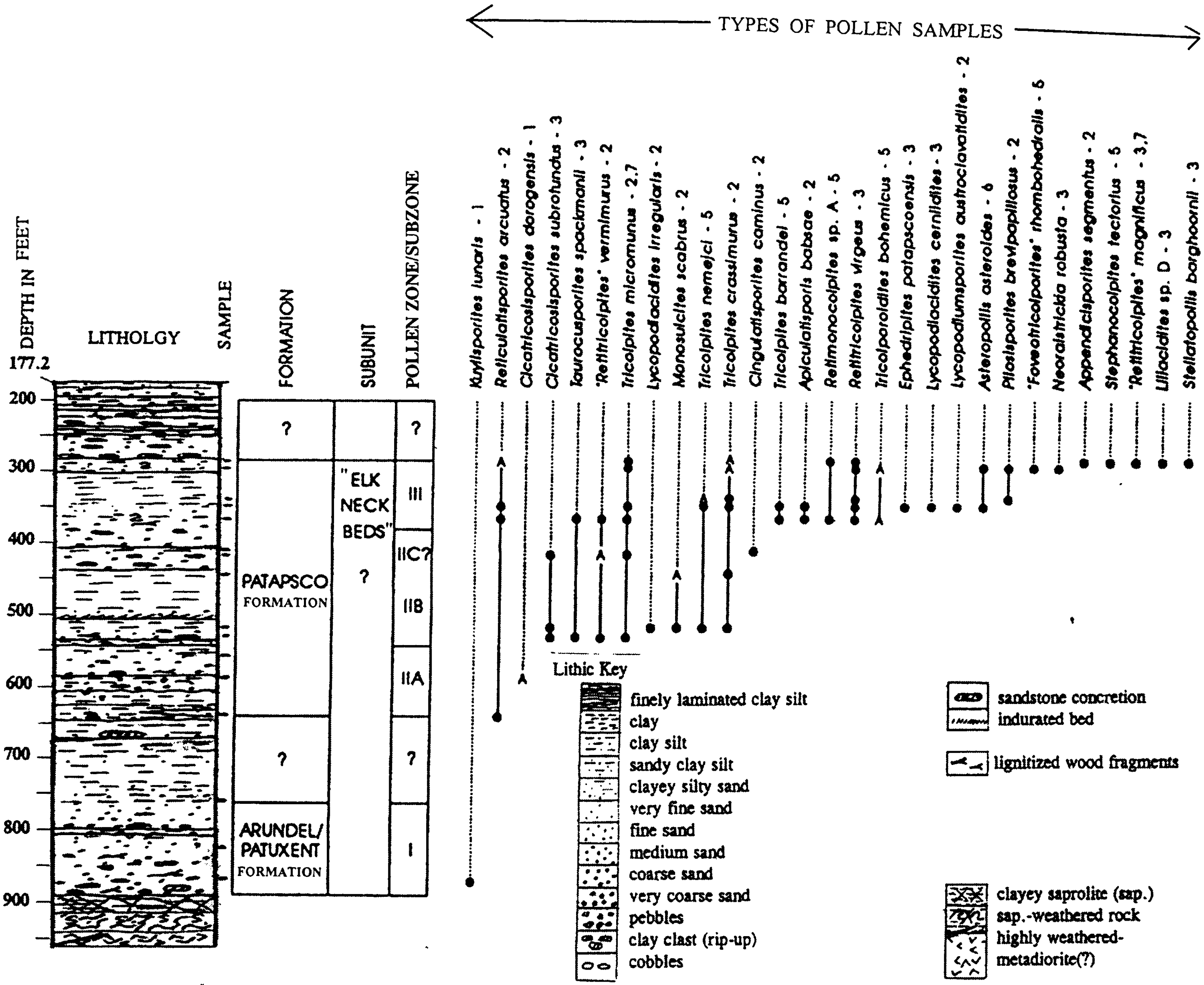

Figure 8. Distribution of biostratigraphically important Cretaceous spore/pollen taxa in samples from the Robins Point core (modified from Frederiksen, U.S. Geological Survey, written commun., 1996). [*Occurences represented by filled circles are of specimens that seem to be identical to or are very similar to the species listed, or the identification of the species was probable although not certain; A = aff. (affinity), meaning (in the terminology of Doyle and Robbins, 1977) that the specimen(s) observed was similar to but probably not the same species as the one listed. Biostratigraphic categories (numbers follow the species name) are: 1 - not known above Zone I; 2 - not known below Zone II; 3 - not known below subzone IIB; 4 - not known below subzone IIC; 5 - not known below Zone III; 6 - known only from subzone IIB; 7 - not known from higher than subzone IIC.*]

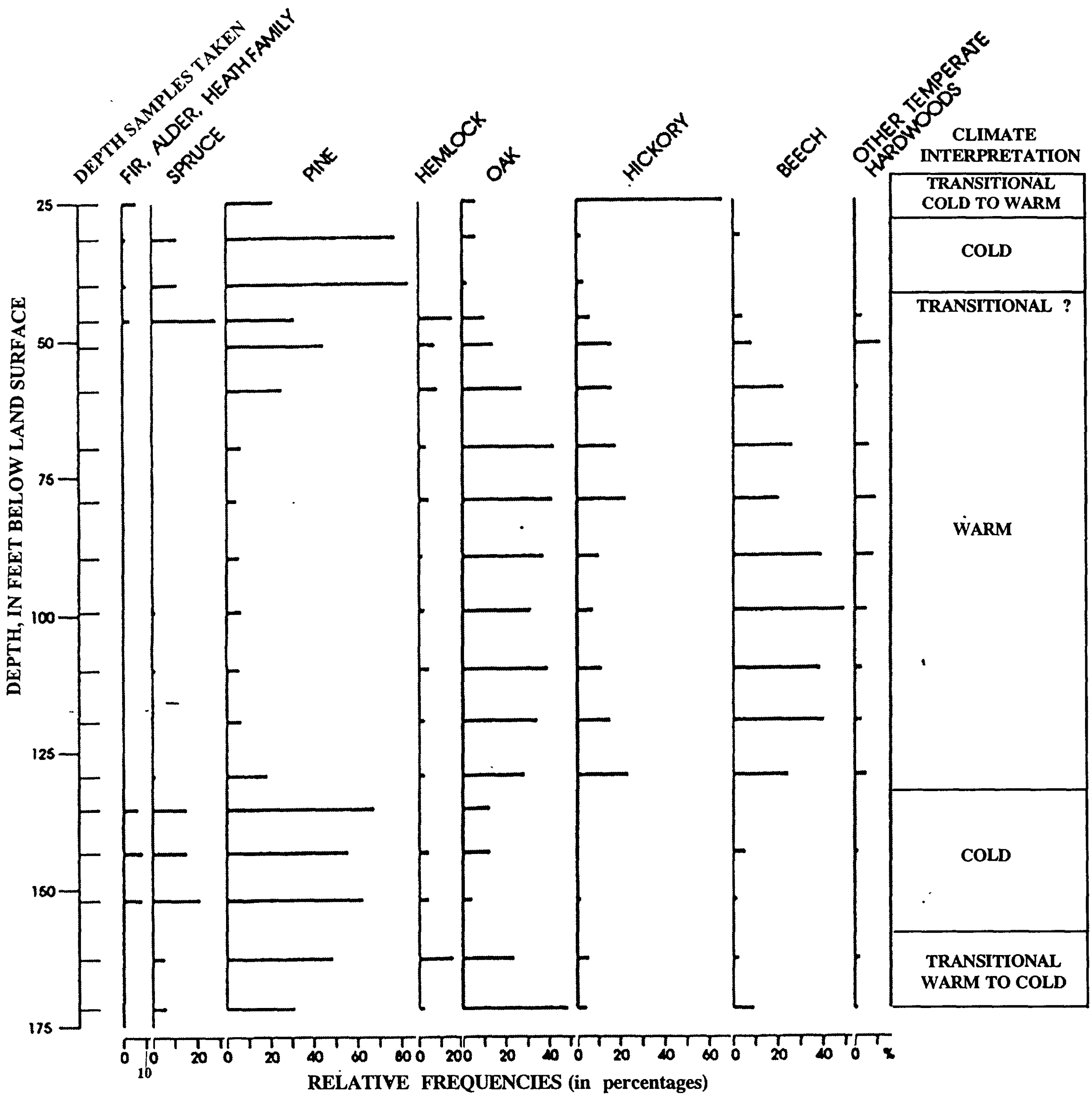

Figure 9. Summary of Quaternary pollen data from the Robins Point corehole. [*Relative frequencies are shown of climatically significant genera and genus groups of trees and shrubs, calculated from the count of only the taxa included in the diagram. Taxa are listed in order of their climatic affinities, from coolest on the left to warmest on the right.*]

Figure 10. Robins Point core, 902.5- to 926.3-foot depth interval, showing the transition from clayey saprolite to weathered rock/saprolite at the 910.5- to 913.8-foot interval. [*Note the banding and folding within the weathered-rock/saprolite interval. Scale is in centimeters.*]

The upper 23.4 ft of the clayey saprolitic interval consist of light-greenish-gray to greenish-gray, dense to soft, very clayey saprolite with abundant fractures and some concretions (?). The saprolite cannot be distinguished from the overlying Cretaceous sands on the resistivity logs. The saprolite has the highest gamma signature of any sediments shown on the gamma-ray log. There is no appreciable change in acoustic velocity between the saprolite and the overlying lower Cretaceous sand and clay. In fact, the clayey saprolite is less dense than the tight lower Cretaceous flood-plain/paleosol clays.

Correlation of stratigraphy with the geophysical logs allows development of signature characteristics that provide important keys for interpretation of regional borehole geophysical and marine seismic-reflection data.

Cretaceous Deposits (177.2 to 888.6 ft)

The 711.4 ft of Cretaceous deposits are divided into the lower Cretaceous Patuxent/Arundel Formations (undifferentiated) and the Lower and Upper Patapsco Formation of Cretaceous age. The contact between the undifferentiated Patuxent/Arundel and the Patapsco Formation is placed at 647.3 ft on the basis of lithic and pollen data (figs. 7, 8) and correlation with pollen and geophysical data from the Grove Neck, Turkey Point, and Spesutie Island testholes (Edwards and Hansen, 1979).

In the Robins Point corehole, the undifferentiated Patuxent/Arundel Formations are 241.3 ft thick and the Patapsco Formation is 470.1 ft thick. Cretaceous pollen subzone assignments by Fredericksen are shown in figures 5 and 8. In ascending order, the subzones includes zone I to the 758 to 867 ft sample interval (SI); subzone IIa to the 586 to 639 ft SI; subzone IIb to the 515 to 529 ft SI; subzone IIc(?) to the 409 to 415 ft SI; and zone III to the 284 to 365 ft SI (fig. 8). Pollen zone III represents the youngest strata of the upper Cretaceous deposits. On the basis of lithic and pollen data, the contact between the Lower and Upper Patapsco is placed at 438.3 ft, which makes the Lower Patapsco (pollen subzones IIa and IIb) 209 ft thick and the Upper Patapsco (pollen subzones IIc and zone III) 261.1 ft thick.

Patuxent/Arundel Formations (undifferentiated) (647.3 to 888.6 ft)

The Patuxent/Arundel Formations (undifferentiated) comprise the lower 283.8 ft of Cretaceous sediment. This unit contains four fining-upward sequences that range in thickness from 10.0 to 123.3 ft. The tops of these sequences are at 804.5 ft, 794.5 ft, 671.0 ft, and 647.3 ft. These sequences follow the generalized description given below. The entire interval also can be considered to be two large-scale fining-upward cycles, which are labeled A and B on the gamma log in figure 7. The entire interval can also be lithically divided into a lower sandy unit 121.2 ft thick with a few thin clay layers overlain at 767.4 ft by an upper clayey unit 120.1 ft thick with a few thin sand layers. The Patuxent/Arundel interval contains the thickest fining-upward sequences within the Cretaceous section. Detailed descriptions of these sequences are provided in appendixes II and III.

A summary of the Cretaceous pollen analysis (Frederiksen, U.S. Geological Survey, written commun., 1996) is shown in figure 8. The samples from 758 to 867 ft are assigned to pollen zone I. The samples taken between 639 to 759 ft were not examined because the intensely weathered overbank paleosol Cretaceous deposits typically lack spores and pollen grains. From a lithic point of view, the thick section of clayey overbank paleosol strata between 647.3 to 742.2 ft probably represents the Arundel Clay.

The basal contact of the Patuxent/Arundel Formations (undifferentiated) with the saprolitic bedrock at 888.6 ft is sharp (1.0-cm relief, fig. 11). The basal sand consists of very pebbly (up to 1.5 cm), very micaceous (flakes up to 3.0 mm), coarse to very coarse sand and granules with some fine to medium sand.

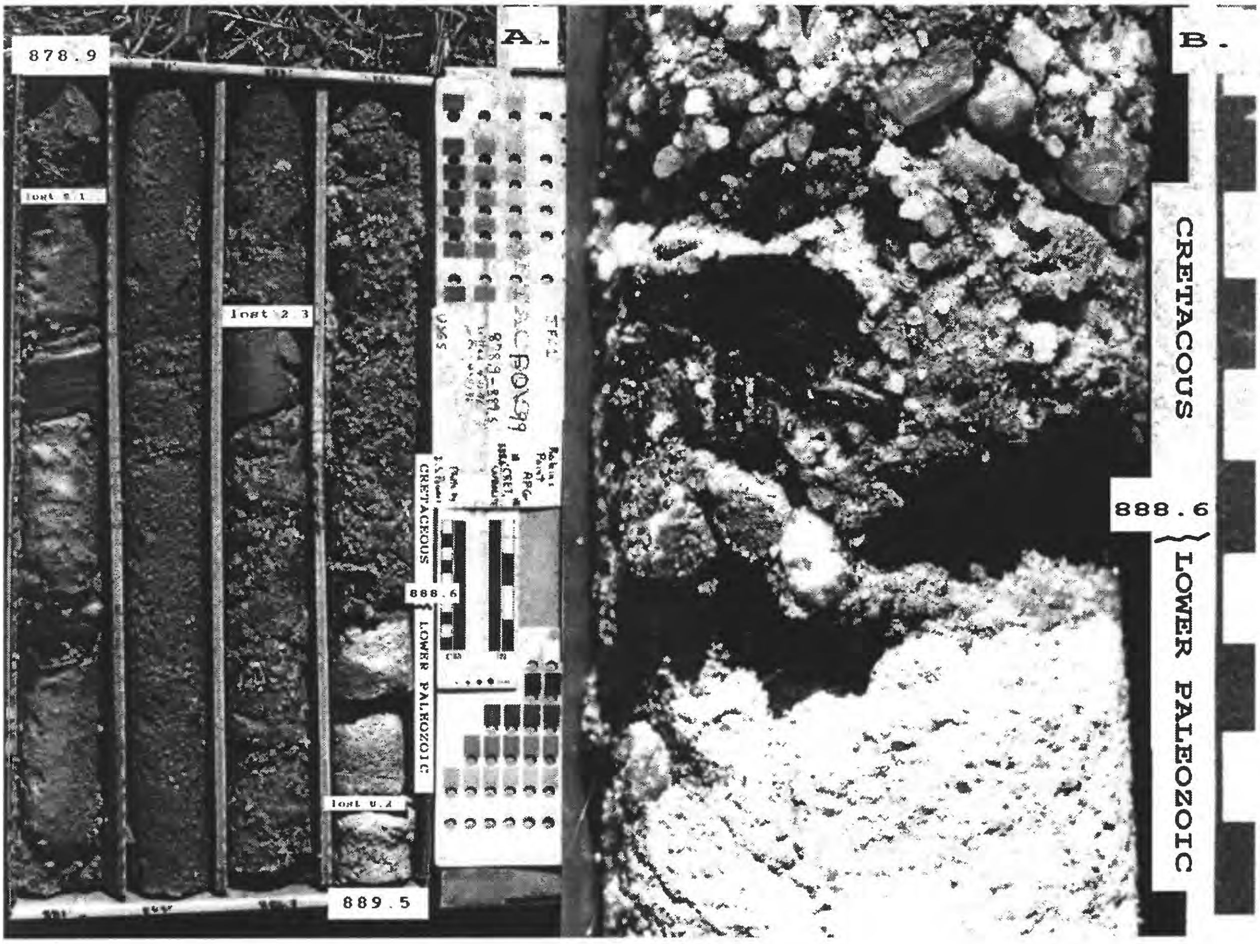

Figure 11. Robins Point core, 878.9- to 889.5-foot depth interval, with closeup showing the major erosional unconformity at 888.6 feet that separates the sandy lower Cretaceous deposits (Potomac aquifer) from the underlying lower Paleozoic (?) clayey saprolite (saprolite aquifer). [*Scale is in centimeters.*]

Dark-gray (mostly laminated and lignitic/woody) and light-gray (possible saprolite) clay rip-up clasts (up to cobble size), and black lignitic wood fragments (up to 1.0-ft thickness) are abundant. The sand and pebbles consist of very angular (primarily very angular in the lowest 13.0 ft) to subrounded grains of clear to smoky quartz. Rose quartz and dark-green rock fragments are less common. The rock fragments resemble the crystalline rocks recovered in the core. A few scattered bright-green sand grains are probably chlorite, and there are scattered grains (up to 3 cm) of pyrite. These sands probably are light-gray to white, as are associated finer grained matrix layers. Drilling mud infiltration, which occurred in all highly permeable sands below 345.5 ft, caused these sands to appear light-brown, as recorded in photographs taken at the drill site.

The interval from 767.4 to 888.6 ft consists primarily of medium to coarse, crossbedded sand, with some very angular coarse grains (up to 3.0 cm) that are typically concentrated into discrete layers. Some coarse sands contain abundant granule- to boulder-sized, dark- to light-gray, clay rip-up clasts and silt- to boulder-sized, black, lignitic wood fragments. The clay clasts typically are internally laminated to thinly bedded and are lignitic. The abundance of these large clay clast and wood fragments results in sharp kicks to the right on the gamma log and corresponding shifts to the left on the 16-in. resistivity log (fig. 7). The 64-in. resistivity log indicates the overall sandy composition of this interval, and that these sands are at least somewhat laterally extensive. These characteristics indicate that this interval may represent a series of stacked high-energy lag deposits within a meandering(?) river system, with nearby swamp and overbank deposits as a source for the abundant clay-clast and lignitic material. These lag deposits probably include lateral accretionary and channel-macroform deposits.

A finer grained interval from 742.2 to 767.4 ft contains interbedded (laminated, to thin-bedded or crossbedded) dark- to light-gray, clayey, silty, very fine to fine sand and clay. Scattered black lignitic wood fragments and pyrite chunks are present, and there is a dramatic increase in mica in the lower 8.0 ft. This interval represents a lower energy environment than the interval below 767.4 ft. This interval may have been deposited in cutoff-meander swamps or fringe swamps. This interval is transitional from the coarse channel deposits below to very tight, dry clay channel-overbank paleosol deposits above.

The clay channel-overbank paleosol interval from 647.3 to 742.2 ft contains a number of possible fining-upward cycles that are tens of feet thick, as indicated on the gamma and 16-in. resistivity logs in figure 7. This 94.9-ft-thick clayey interval is multicolored (bright reds, yellows, purples, and browns) and contains intensely weathered paleosols as indicated by abundant iron-rich glaebules (nodules and concretions, fig. 12) and pedotubules (cracks and fractures) that are often truncated by laminated to thinly-bedded silty clay or thin sandy beds. The harder concretions in this interval probably consist of siderite, hematite, goethite, and limonite and the softer concretions, which can be broken with a knife or fingernail, may consist of gypsum. The concretions are sometimes concentrated into discrete layers that comprise up to 60 percent of the core in this interval. Similar updip, thick, variegated, dense clay sections may have been deposited in shallow, discontinuous backswamp basins maintained by ponded drainage and slow sediment influx (Glaser, 1969).

Within the upper clayey Arundel Clay (?) equivalent interval, a thin sand layer at 665.7 to 671.2 ft contained some indurated to semi-indurated, cobble- to boulder-sized sandstone concretions. These concretions and thin sand layers are recognized in the 16-in. resistivity log by sharp shifts to the right, indicating their higher conductance than the surrounding clayey layers. These same concretions and sand layers, however, are barely reflected in the 64-in. resistivity log, indicating that they are too thin to resolve with this tool or that they have a limited lateral extent.

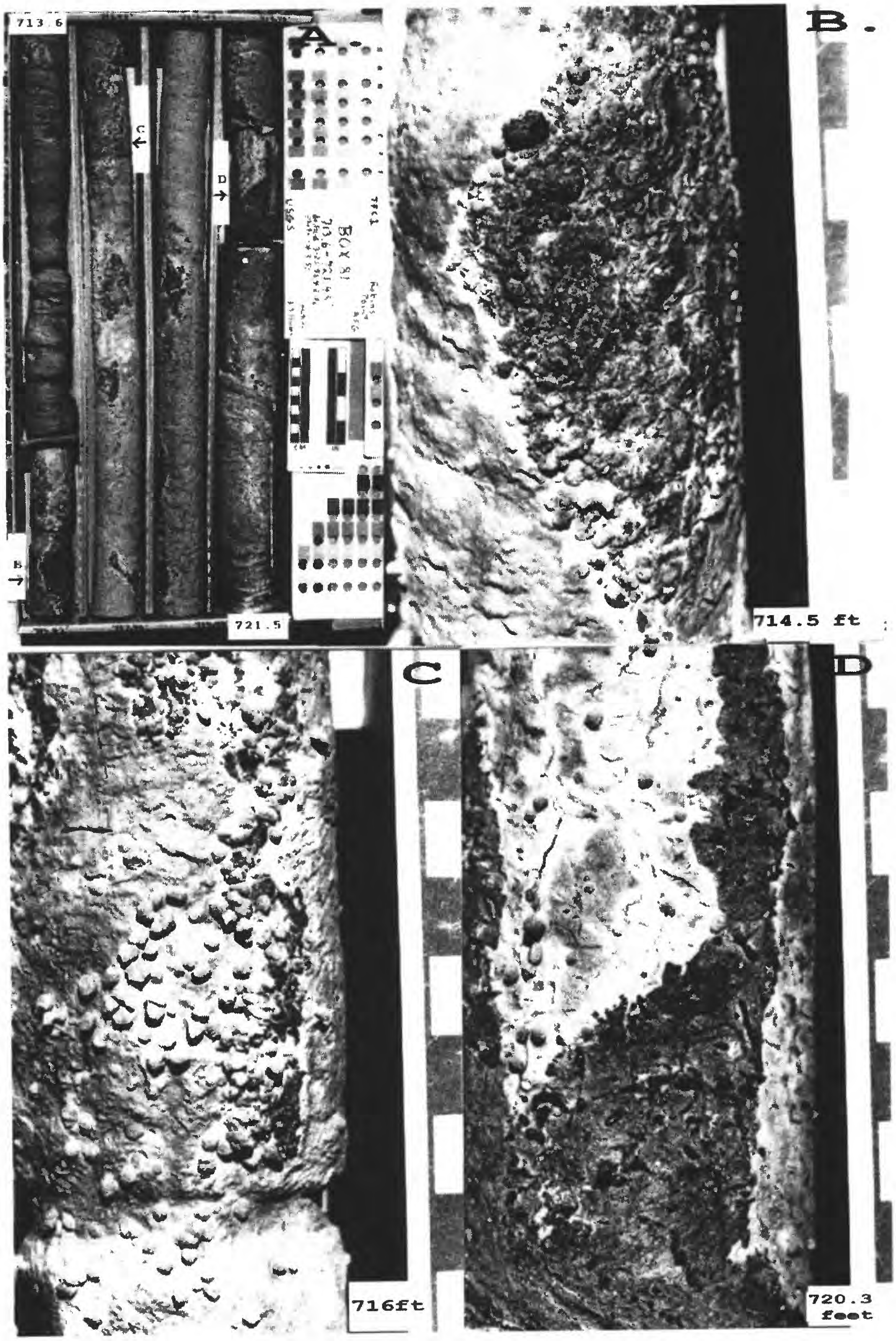

Figure 12. Robins Point core, 713.6- to 721.5-foot depth interval, showing iron-rich glaebules (nodules and concretions) in tight, highly cracked multicolored (variegated) clay typical of intensely weathered paleosols (Sigleo and Reinhardt, 1988). [*Closeup photographs B, C, and D are of sections located within A. Scale is in centimeters.*]

Patapsco Formation (177.2 to 647.3 ft)

On the basis of lithic and pollen data the Patapsco Formation is represented in this corehole by the upper 470.1 ft of unconsolidated lower and upper Cretaceous sand, clay, and gravel. It contains 18 fining-upward sequences that range in thickness from 5.9 to 105.7 ft. The Patapsco Formation is divided into lower and upper parts, as was done by Wolfe and Pakiser (1971) for the Patapsco in Cecil County, Maryland. The Lower Patapsco is assigned to pollen subzones IIa and IIb and the Upper Patapsco is correlated with Wolfe and Pakiser's (1971) "Elk Neck Beds" (pollen subzones IIc and zone III, fig. 8). Pollen zone III represents the lowest part of the upper Cretaceous. On the basis of lithic and pollen data, the contact between the Upper and Lower Patapsco is placed at 438.3 ft and correlates well with the Grove Neck and Spesutie Island testhole data (Edwards and Hansen, 1979; fig. 3). On the basis of lithic and pollen data, the base of the upper Cretaceous deposits is tentatively placed at 406.6 ft, which is the base of a fining-upwards sequence that contains a pollen assemblage assigned to zone III.

The base of the Patapsco Formation is placed at the sand- over-clayey paleosol contact at 647.3 ft (fig. 13). This contact separates a thick section of clayey overbank/paleosol strata (647.3 to 742.2 ft, which may be the Arundel Clay) from a slumped and/or faulted, clay and sand interval showing soft-sediment deformation (633.8 to 647.3 ft) that contains a pollen assemblage assigned to zone IIa.

Lower Patapsco (438.3 to 647.3 ft)

On the basis of lithic and pollen data, the Lower Patapsco interval is 209 ft thick and extends from 438.3 to 647.3 ft (figs. 7, 8). This interval contains six fining-upward sequences, which range in thickness from 5.9 to 66.4 ft (fig. 7, appendix II and III). These fining-upward sequences typically are separated by sharp contacts where a coarse-grained sand overlies a silty clay or clay (fig. 7, appendix II). The sands typically contain granules and/or pebbles; dark-gray clay rip-up clasts; and black, lignitic wood fragments; or, in one place, a thin clay-clast conglomerate. Some of the sands are crossbedded.

The lowest sequence contains a basal slumped and/or faulted, clay and sand interval that shows soft-sediment deformation (633.8 to 647.3 ft) that is overlain by a 9.3-ft thick clayey paleosol interval. This interval grades upwards into an interval from 604.8 to 624.5 ft that contains burrowed, light-gray, silty clay to clayey silty sand in the lower 9 ft. Burrowed, dark- to light-gray, lignitic clay to clayey silt that includes more soft-sediment deformation features characterizes the upper 6.5 ft.

These slumping and soft-sediment deformation features probably were deposited in crevasse-splays, or at channel edges, with slumping related to deposition of suites of channel deposits. The dark, burrowed, lignitic-rich clays were probably deposited in a swamp with a reducing environment as the environment of deposition. The change from the oxidized, multicolor paleosol to gray colors with lignite may indicate a change from a well-drained to a partially flooded environment.

The four sequences between 504.7 to 604.8 ft contain relatively thin (0.4 to 10.1 ft), light-gray to white sand intervals, and relatively thick (5.5 to 34.3 ft), dark to light, laminated to thin-bedded clay to clayey silt beds, with some thin, very fine sand interbeds. These deposits probably represent moderate energy channels within a fringing swamp. The lithic contact at 534.5 ft is interpreted as the contact between pollen subzone IIa and IIb.

The thickest fining-upward sequence (66.4 ft thick) in the Lower Patapsco contains a 9-ft-thick basal sand. This sandy sequence is overlain by a 57.3-ft-thick interval from 438.3 to 495.6 ft that marks a return to a multicolored clayey overbank-paleosol section similar to those in the Patuxent/Arundel Formations

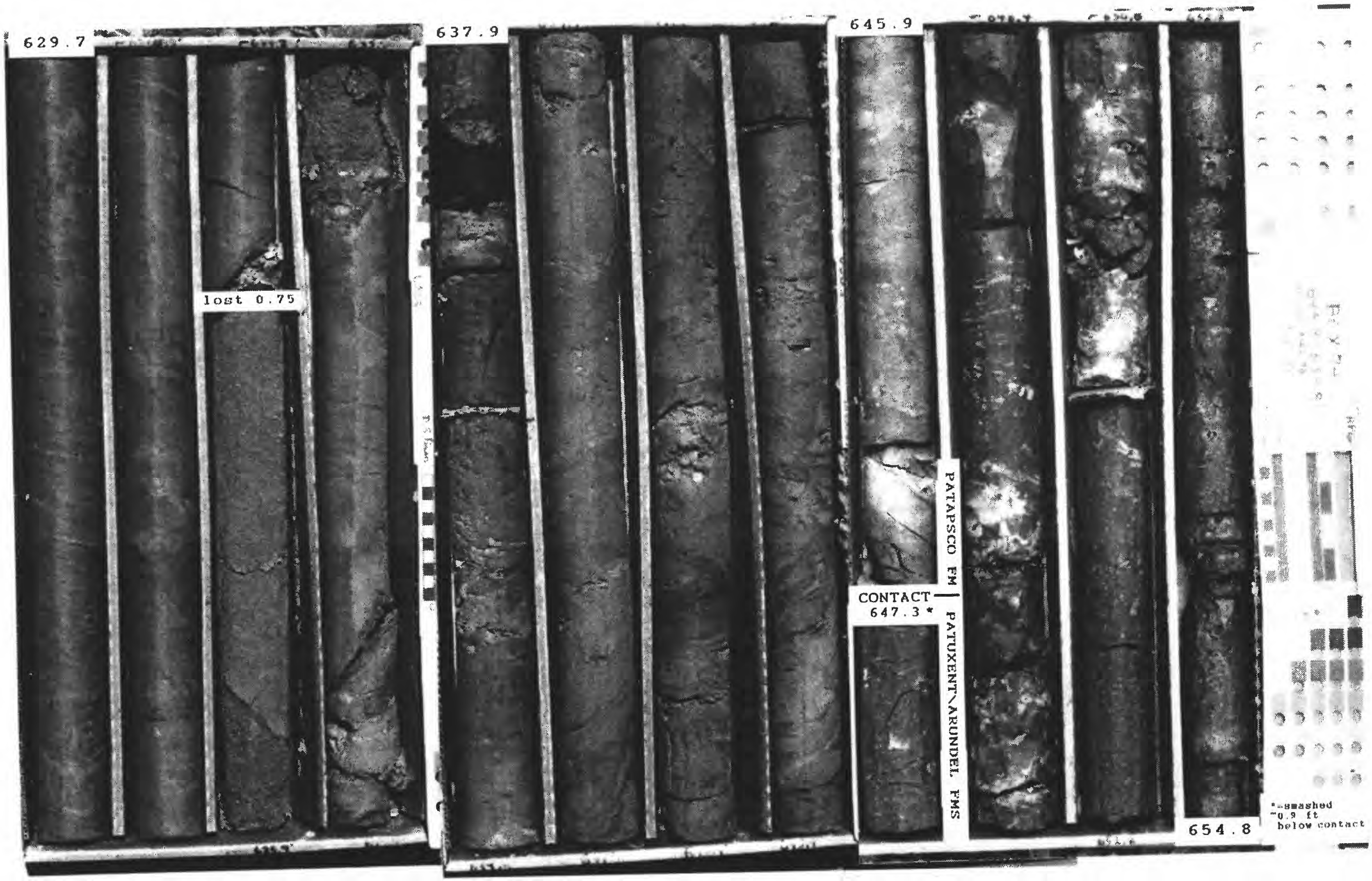

Figure 13. Robins Point core, 629.7- to 654.8-foot depth interval, showing the Patuxent/Arundel Formations (undifferentiated) contact with the Patapsco Formation at 647.3 feet, which separates the clay and slumped soft-sediment interval (base of lower Patapsco aquifer system) from the clayey paleosol-overbank deposits (Potomac confining unit = Arundel Clay Formation?). [*Scale is in centimeters.*]

(undifferentiated). In the Lower Patapsco, however, paleosols are more frequently truncated by laminated to thin interbeds. This sequence probably represents relatively shallow, sandy channel deposits overlain by clayey overbank-flood-plain deposits or ponded backswamp basin deposits (Glaser, 1969).

Upper Patapsco (177.2 to 438.3 ft)

On the basis of lithic and pollen data, the 261.1-ft-thick interval from 177.2 to 438.3 ft is assigned to the Upper Patapsco ("Elk Neck Beds" equivalent). This interval contains 11 relatively thin fining-upward sequences that range from 4.6 to 35.1 ft thick, and a 105.7-ft-thick fining-upward sequence from 300.9 to 406.6 ft. The top 8 sequences are all less than 15 ft thick. The basal fining-upward sequence from 406.6 to 438.3 ft is interpreted to represent the pollen subzone IIc interval and the rest of the section from 177.2 to 406.6 ft is interpreted to represent the pollen zone III interval (figs. 7, 8). The contact between the 482 ft of lower Cretaceous sediments and 229.4 ft of upper Cretaceous sediments is at 406.6 ft.

These fining-upward sequences typically grade from poorly sorted medium to coarse sands, with disseminated white clay rip-up clasts or clay-clast conglomerates, to better sorted finer sands, to silty clay and clayey silt at the top. The sands are light gray to white and are primarily of medium grain size, although the grain size ranges from very fine to very coarse. The following were the only two intervals within the Upper Patapsco section that contained granules and pebbles: a clay-clast conglomerate from 279.5 to 281.5 ft included a few scattered fine pebbles (up to 1.0 cm); and the basal sands from 422.2 to 438.3 ft included pebbles (up to 1.5 cm).

The sands in the interval from 345.5 to 438.3 ft grade upward from medium to very coarse sand (the lower sand includes pebbles); to very fine to fine sand; to dark-gray, laminated, silty clay to clay. The sands are crossbedded to interbedded to massive. They contain dark-gray to white clay rip-up clasts (fine pebble to cobble size), and scattered to abundant, black, lignitic wood fragments (up to 5 cm). These relatively thick sand intervals probably represent a return to high-energy main trunk channels in close proximity to swamp deposits (source of the rip-up clasts).

The interval from 345.5 to 438.3 ft contains the thickest sand layers (16.1 and 41.4 ft) in the Patapsco Formation. These sands are separated by 15.6 ft of burrowed, interbedded sand and dark- to light-gray clay that is laminated to thinly bedded. Within the 41-ft-thick sand from 365.2 to 406.6 ft, the drillers noted a gain of about 100 gallons of water within 30 minutes while drilling the interval from 392.2 to 399.2 ft. This was the only interval where there was a large inflow of water. The observation well that was later set in the corehole was screened over this interval from 392 to 402 ft (fig. 14). An inflow of about 10 to 15 gal was observed while drilling the interval between 495.0 and 503.5 ft.

This 41-ft-thick sand is in the lower part of the thickest fining-upward sequence, which is 105.7 ft thick. This sand is overlain by 19.7 ft of interbedded fine-grained sand and silty clay that grades into 44.6 ft of multicolored clay overbank-paleosol deposits (300.9 to 345.5 ft, fig. 15). This multicolored clay overbank-paleosol section is similar to those in the Patuxent/Arundel Formations (undifferentiated) and the Lower Patapsco. In the Upper Patapsco, however, the paleosol sections contain thicker intervals of laminated to thin-interbeds that truncate the cracked and more intensely weathered paleosol, as indicated by the presence of iron-rich glaebules (nodules and concretions) and pedotubules. These were probably deposited in a low/energy, overbank-flood-plain or ponded backswamp environment.

The fining-upward sequence from 281.5 to 300.9 ft contains numerous slump and soft-sediment deformation features that indicate either channel bank slumping or crevasse-splay deposition. This interval contains the highest zone within the Cretaceous section of dark- to medium-gray, laminated to

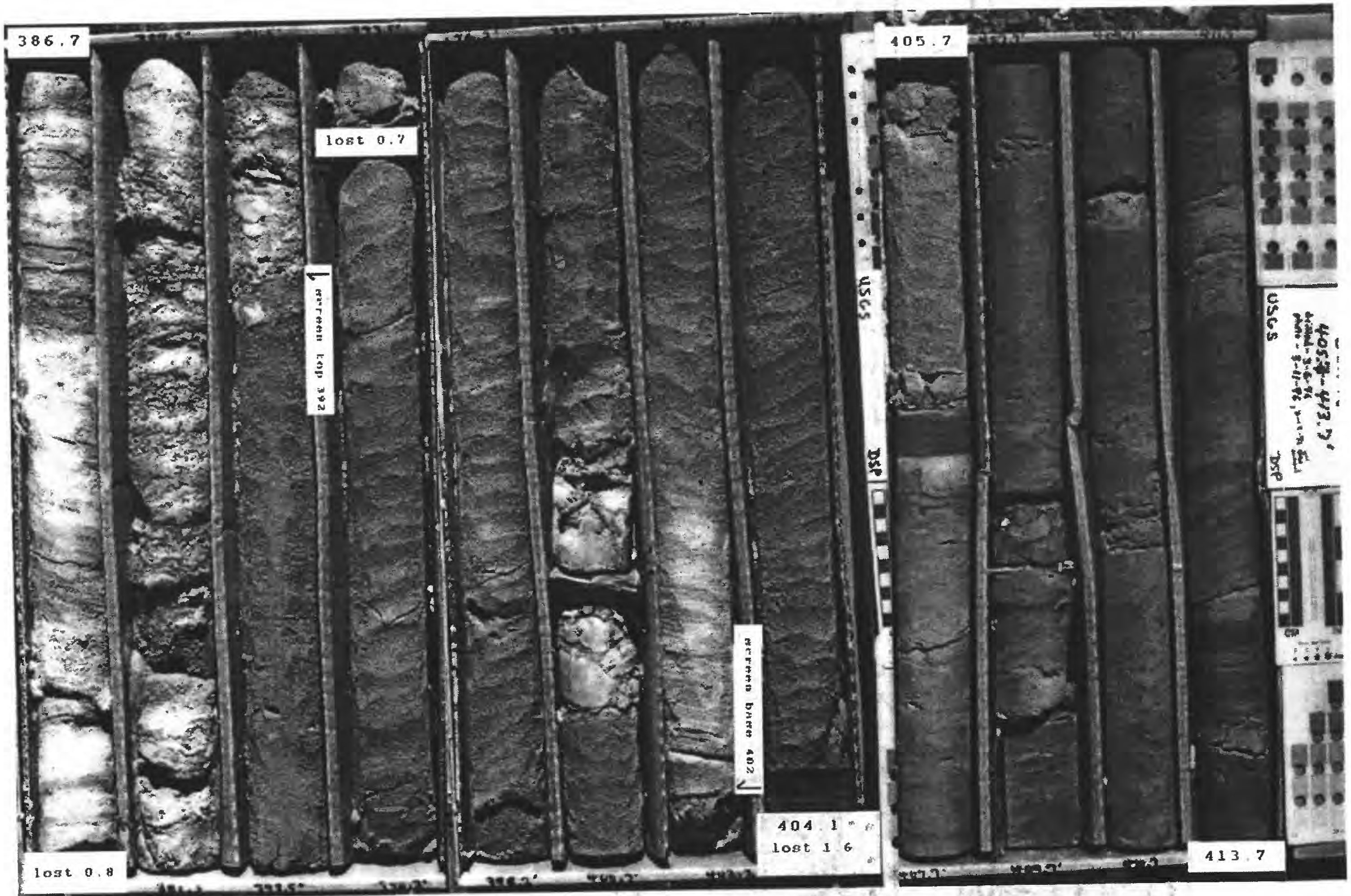

Figure 14. Robins Point core, 386.7- to 413.7-foot depth interval, showing the sandy lithology of the screened interval from 392.0 to 402.0 feet for the observation well. [*Note the sand-over-clay contact at 406.5 feet; it is interpreted as the contact between upper and lower Cretaceous deposits. Scale is in centimeters.*]

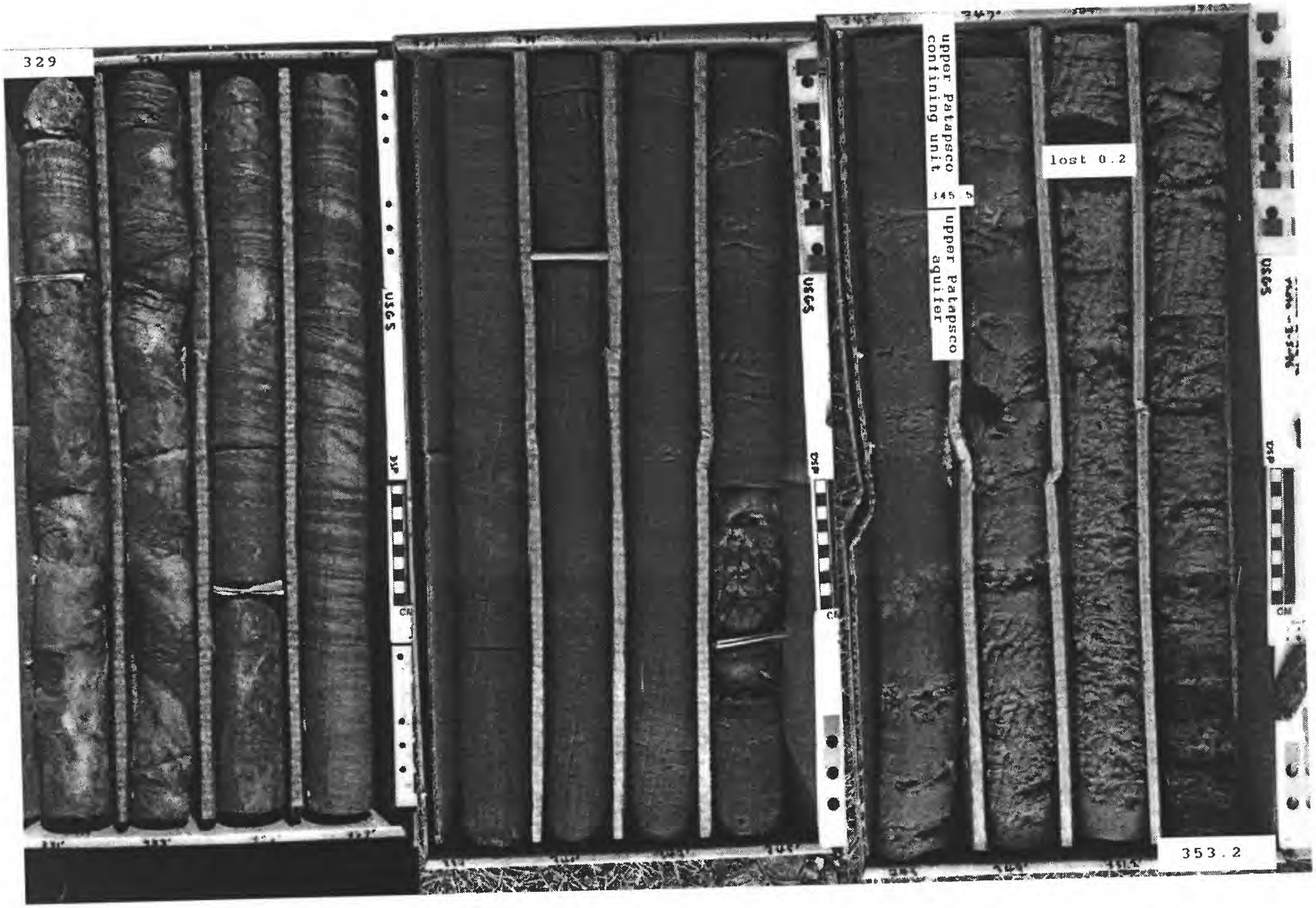

Figure 15. Robins Point core, 329.0- to 353.2-foot depth interval, showing the base of the uppermost confining unit (44.6 feet thick; upper Patapsco confining unit) in the Cretaceous deposits at 345.5 feet, which represents a clay to sand transition. [*Scale is in centimeters.*]

thinly interbedded clay; to clayey silt; to very fine sand; to fine sand. The best pollen assemblages typically come from dark-gray to black clayey silts such as those found in this interval. White clays typically are dominated by kaolinite (Owens, 1969) and are often barren or contain a sparse, poorly preserved pollen assemblage. Because the Cretaceous section above this interval does not contain dark clayey silts, no samples from it were submitted for pollen analysis.

From 177.2 to 281.5 ft, nine relatively thin fining-upward sequences are present. Sands in this interval range in thickness from 5.0 to 12.1 ft, except for the next-to-lowest sequence which is 33.6 ft thick. The clays in these sequences range in thickness from 1.1 to 3.2 ft and are typically truncated along their upper contacts. The uppermost sequence, from 177.2 to 181.8 ft, is truncated by Pleistocene deposits. These nine fining-upwards sequences with their relatively thicker sand and thinner clay packages indicate a dramatic change in depositional style. These deposits may reflect a change from a meandering river system to high energy, shallow channels with sporadic discharge more typical of a braided-stream system. The signature of these fining-upward sequences in the Upper Patapsco ("Elk Neck Beds") can be seen on the geophysical logs in figure 7.

Quaternary Deposits (land surface to 177.2 ft)

On the basis of lithic and pollen data, the Quaternary deposits are divided into 146.1 ft of Pleistocene deposits, from 31.1 to 177.2 ft, and 31.1 ft of Holocene deposits. The Quaternary section contains three Susquehanna River transgressive paleochannel-fill sequences. The paleochannels were cut during sea-level lowstands (glacial intervals) and filled as sea level rose (interglacial intervals). The Pleistocene deposits contain four fining-upward sequences that range in thickness from 7.3 to 119.7 ft.

To subdivide the Pleistocene deposits, the lithic and pollen data (fig. 9) (Norman Frederiksen, U.S. Geological Survey, oral and written commun., 1996) have been correlated with amino-acid-racemization data from mollusk shells sampled in exploratory borehole 6 (located about 60.0 ft southeast from the Robins Point corehole; fig. 2) (J. Wehmiller, University of Delaware, oral and written commun., 1995). The following three sequences are recognized: pre-Illinoian glacial-interglacial deposits from 161.5 to 177.2 ft; Illinoian glacial-Sangamon interglacial deposits from 41.8 to 161.5 ft; and Wisconsinan glacial deposits from 31.3 to 41.8 ft (figs. 7, and appendix II). These sequences correlate respectively with the Exmore, Eastville, and Cape Charles paleochannels and represent the three main Susquehanna River paleochannels mapped throughout the Bay by borehole and marine seismic-reflection data (Mixon, 1985; Colman and Mixon, 1988, and Powars and others, 1989). These three sequences are, respectively, interpreted as equivalent to the Accomack Member of the Omar Formation, the Stumptown Member of the Nassawadax Formation, and the Kent Island Formation to unnamed Holocene deposits (Mixon and others, 1989). On the basis of the stratigraphy and depth and width of the paleochannel beneath J-Field (figs. 2, 3), it represents the main trunk channel of the Eastville paleochannel (Illinoian-Sangamon sequence) and possibly the main trunk channel of the Exmore paleochannel (pre-Illinoian). The Pleistocene section is capped by Holocene deposits containing two fining-upward sequences. The lower one contains a interglacial temperate flora.

Middle Pleistocene (161.5 to 177.2 ft)

On the basis of the amino-acid data, which provides a Sangamon age for the interval from 41.4 to 132.7 ft, and the lithic and pollen data from the Pleistocene deposits, the two lowermost fining-upward sequences (169.9 to 177.2 ft, and 161.5 to 169.9 ft) are interpreted as glacial to late-interglacial pre-Illinoian deposits (middle Pleistocene). The lowest sequence unconformably overlies the Cretaceous deposits and grades upward from 4 ft of brownish-gray, pebbly (angular to subrounded, up to 3.0 cm), very coarse sand lag deposit to a light-gray to tan, well-sorted, organic-rich fine sand (figs. 16, 17). This 4-ft-thick lag deposit is considered to be pre-Illinoian glacial deposit because most paleochannel downcutting mainly occurs during the glacial phase and this lag deposit is a remnant of the downcutting phase. The overlying deposits contain a transitional pine-oak-hemlock forest pollen assemblage that indicates a late interglacial phase. The upper sequence from 161.5 to 169.9 ft consists of tight, dark-greenish-gray clay, with angular pebbles in a clay matrix at the base.

On the basis of the pollen data found in the interval from 161.5 to 177.2 ft, the Pleistocene paleochannel beneath J-Field was cut before the Illinoian very coarse basal lag (cobbles up to and larger than 8 cm) was deposited (figs. 18, 20A). This basal lag deposit had been considered the base of the Pleistocene by Hughes (1993). The interval correlates with the Exmore paleochannel, which indicates that it was cut about 250,000 years ago on the basis of uranium-series data or 450,000 years ago on the basis of amino-acid-racemization data.

This demonstrates the reuse and stacking of Susquehanna River paleochannels that is also indicated in some of the marine seismic-reflection data (Hughes, 1993; Williams Banks, U.S. Geological Survey, written commun., 1996).

Upper Pleistocene (31.3 to 161.5 ft)

Lithic and pollen data from the interval of 132.7 to 161.5 ft indicate deposition during a glacial phase. This interval is assigned to the Illinoian because an amino-acid-racemization mean value of 0.24 for shells from the overlying unit suggests a Sangamon age (roughly 130,000 to 80,000 years ago; J. Wehmiller, University of Delaware, oral and written commun., 1995). Lithic and pollen data from the interval of 47.3 to 132.7 ft indicate deposition during a warm-temperate, interglacial phase. This interval is assigned to the Sangamon on the basis of the amino-acid data obtained from mollusk shells from this interval. The lithic contact at 132.7 ft that separates the Sangamon and Illinoian deposits is shown in figures 19 and 20B.

A pollen sample from the interval of 41.8 to 47.3 ft contains a mixture of temperate and cold floras, which indicates that these deposits are from a climatically transitional period between the early glacial phase of the Wisconsinan and the late-interglacial phase of the Sangamon (Norman Frederiksen, written commun., 1996, fig. 9). This sample comes from within a 4-ft-thick, relatively soft, plastic, dark- gray to olive-gray silty clay interval, which contains some organic matter and a few scattered sand patches that may represent burrows, indicating that the cold flora may have come from the overlying sandy Wisconsinan glacial deposits (fig. 21). This 4-ft-thick silty clay interval is also lithically different from the underlying shelly, more compact clayey silts with warm-temperate pollen assemblages that were probably deposited at the end of the Sangamon sea-level highstand. These lithic changes favor a late-interglacial/early glacial transitional phase interpretation for this interval.

The interval from 41.8 to 161.5 ft represents a typical Mid-Atlantic glacial-interglacial paleochannel-fill sequence (Mixon, 1985; Colman and Mixon, 1988; Powars and others, 1989; Newell and others, 1995). This interval grades upwards as follows: (1) a 5.3-ft-thick gravel lag (cobbles larger than 8 cm); (2) 3.5 ft of pebbly (up to 2.5 cm), medium to very coarse sand; (3) 20.3 ft of interbedded (laminated to thinly interbedded), organic-rich (finely disseminated to wood fragments) clayey silt to silty clay with a few sparse coarse quartz grains (up to granules) that are typically scattered but concentrated at the base; (4) 36.2 ft of massive to thinly interbedded to laminated, shelly, clayey silt to very fine sandy, clayey silt (thinner bedding and organic content increase downward, and there are a few coarse granules at the base; figs. 19, 20B); and (5) 5.5 ft of burrowed (some sand filled) clayey silt to silty clay to very fine sandy silt. The interval from 115.0 to 132.7 ft contains the highest percentage of clay found in this Sangamon

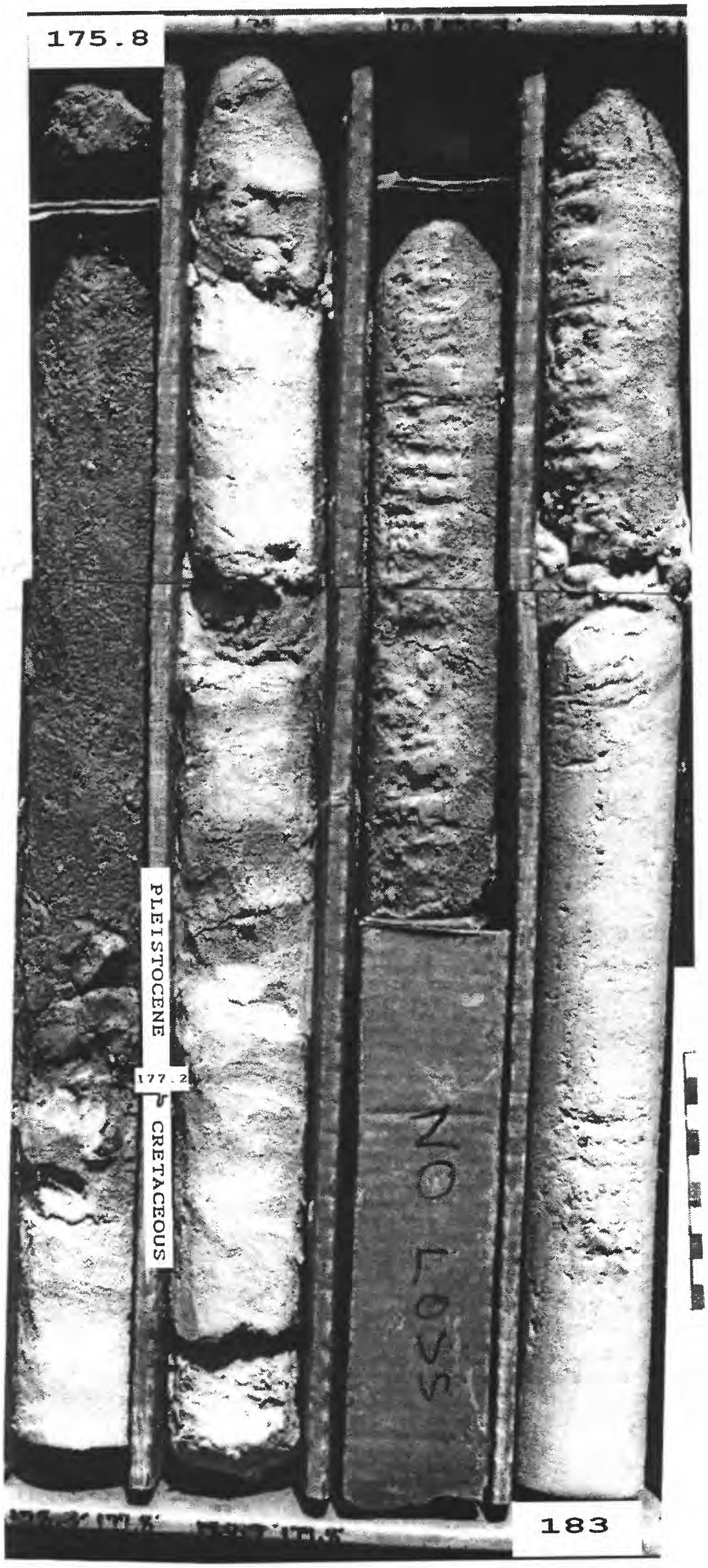

Figure 16. Robins Point core, 175.8- to 183.0-foot depth interval, showing the major erosional unconformity at 177.2 feet that separates the Pleistocene from the Cretaceous, marked by a pebbly lag deposit overlying much denser sandy clay. [*Note subangular to subrounded, wide variety of pebbles in basal lag deposit. Scale is in centimeters.*]

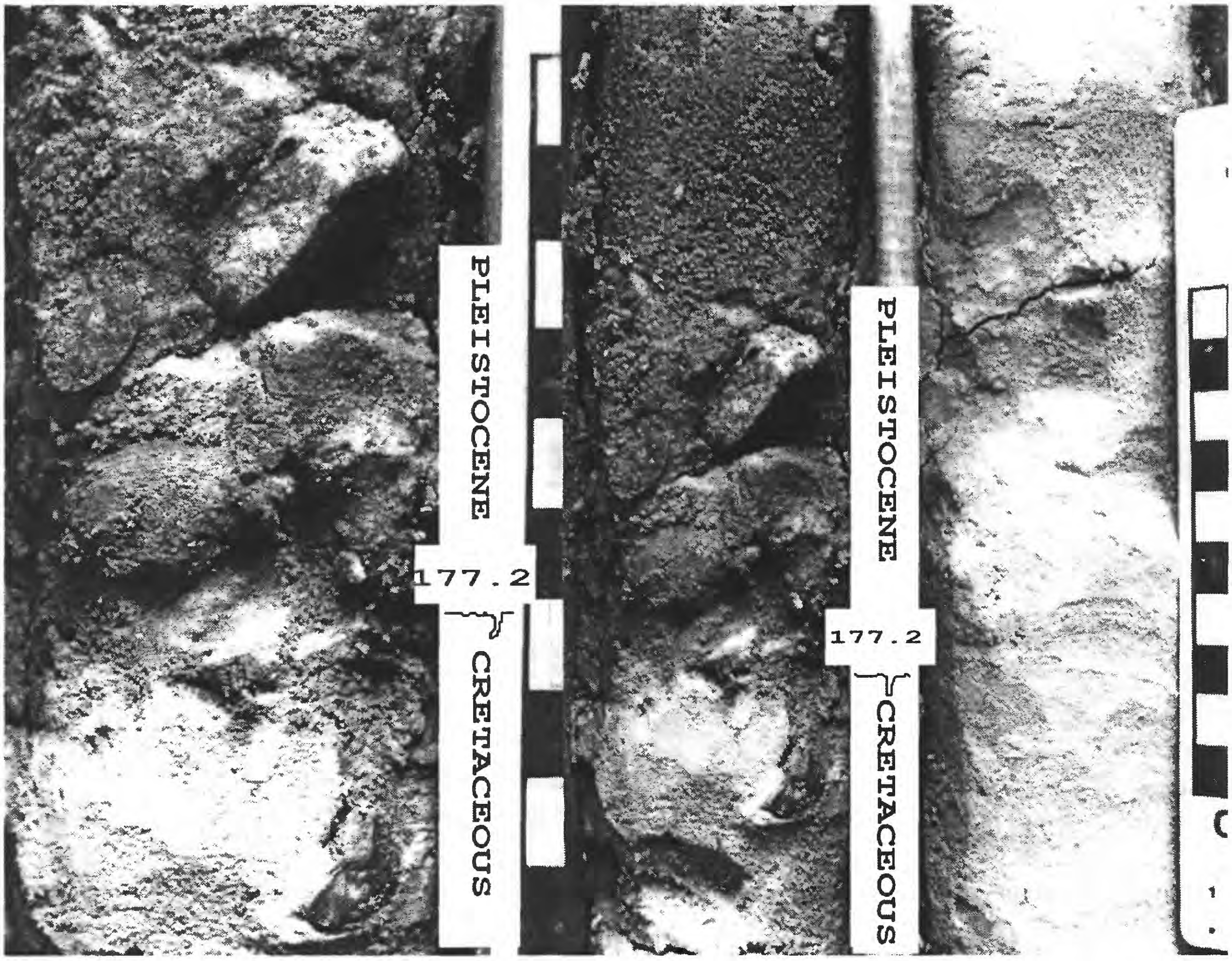

Figure 17. Closeup of the Robins Point core showing the Cretaceous-Pleistocene contact at depth of 177.2 feet.

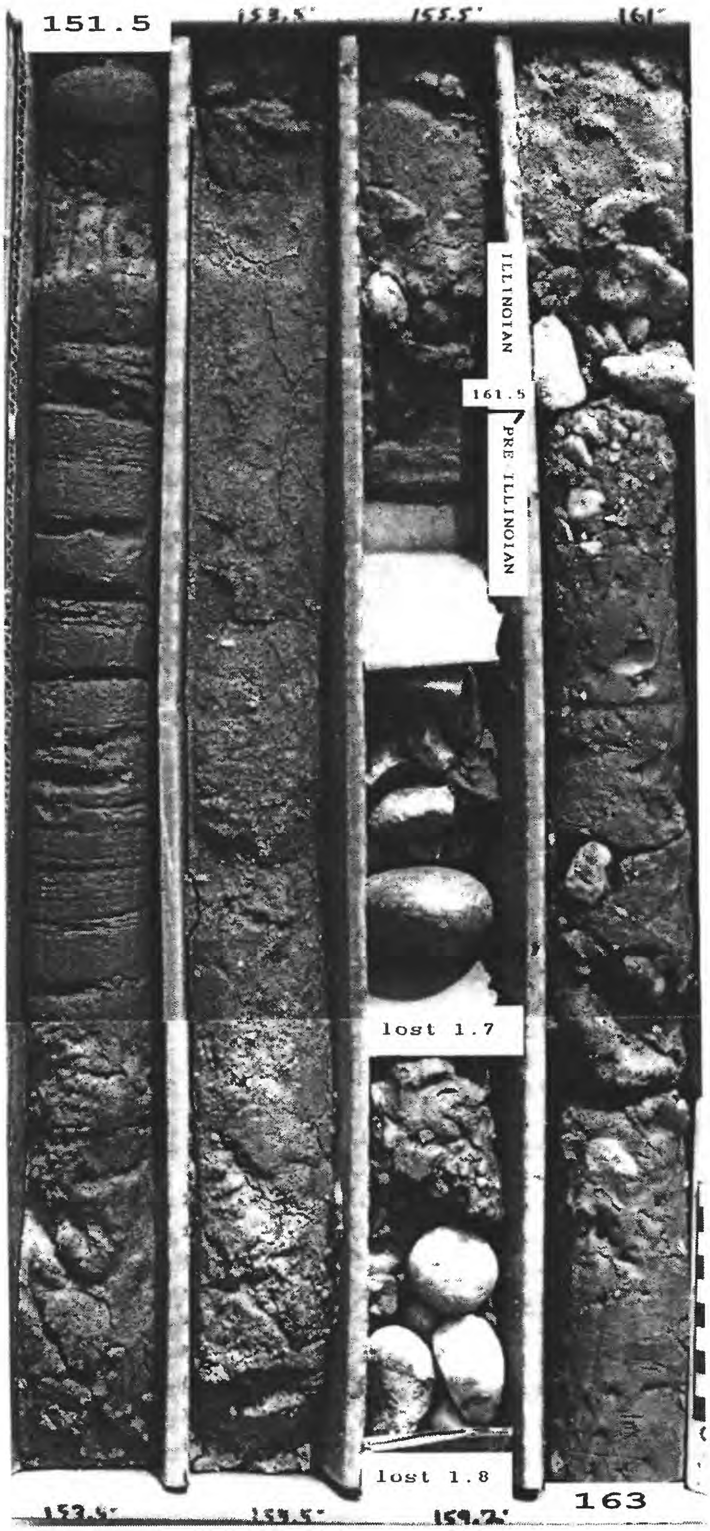

Figure 18. Robins Point core, 151.5- to 163-foot depth interval, showing the contact at 161.5 feet between the Illinoian cobbly lag deposits (paleochannel confined aquifer) and the finer grained pre-Illinoian deposits (lower paleochannel confining unit). [*Scale is in centimeters.*]

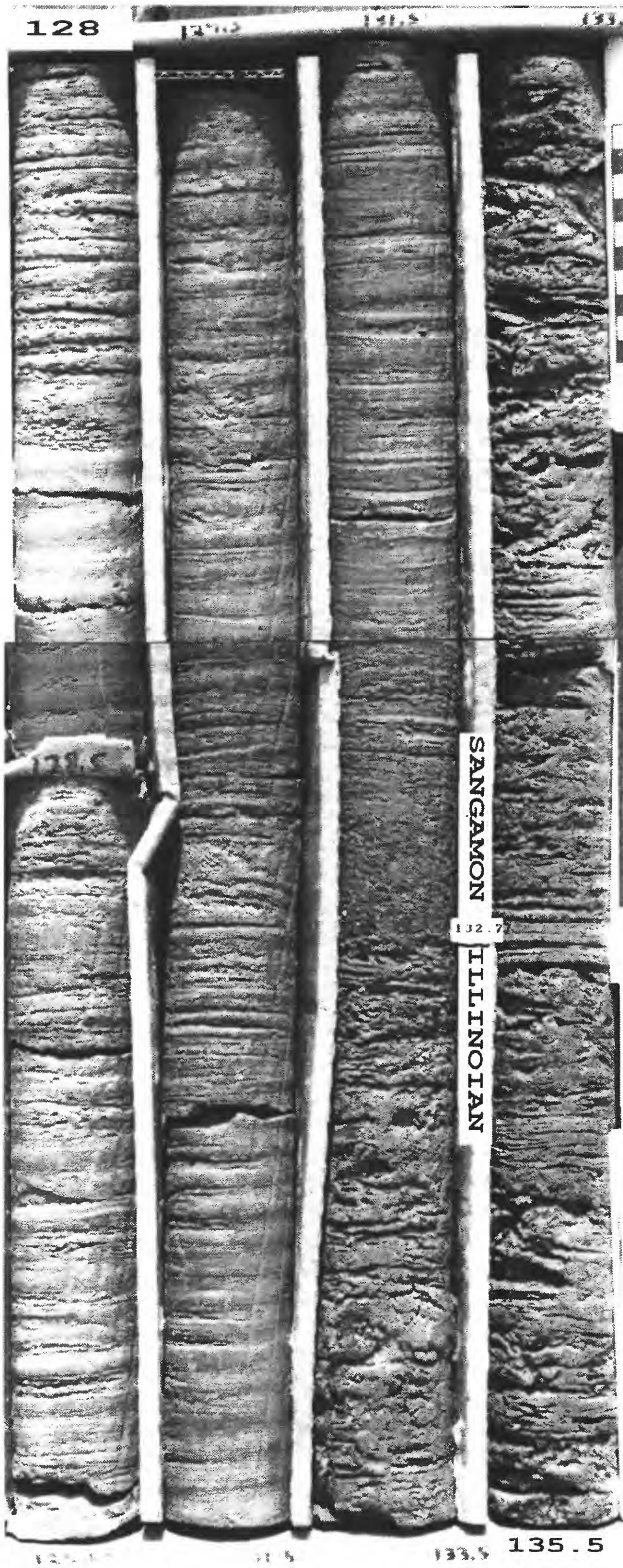

Figure 19. Robins Point core, 128- to 135.5-foot depth interval, showing the contact at 132.7 feet between the sandy Illinoian glacial deposits (paleochannel confined aquifer) and the overlying clayey Sangamon interglacial deposits (upper paleochannel unit). [*Scale is in centimeters.*]

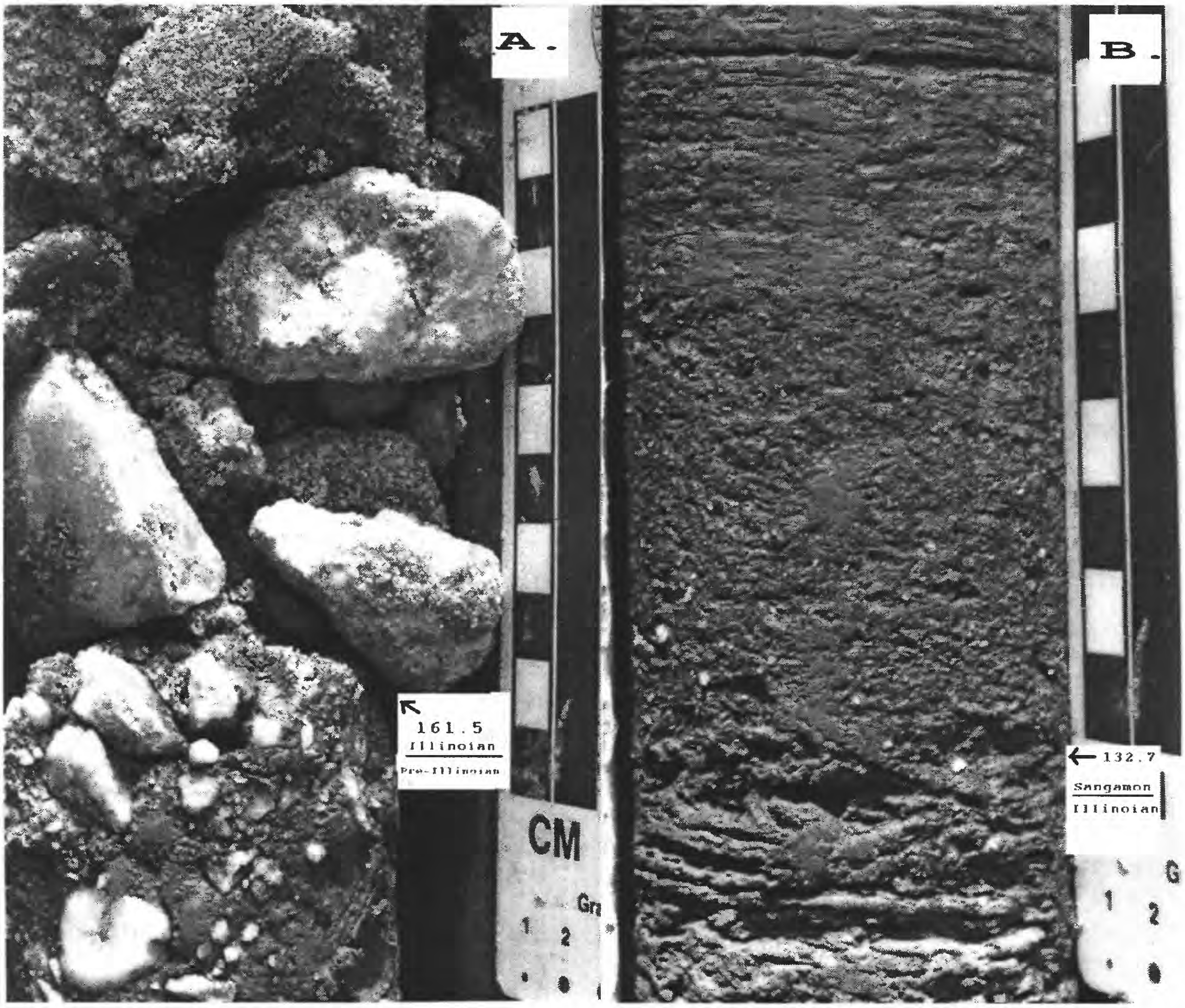

Figure 20. **(A)** Closeup of the Robins Point core showing the contact between the Illinoian (paleochannel confined aquifer) and the pre-Illinoian (lower paleochannel confining unit) deposits at 161.5 feet;
(B) Closeup showing the contact between the Illinoian glacial (paleochannel confined aquifer) and Sangamon interglacial deposits (upper paleochannel confining unit) at 132.7 feet.

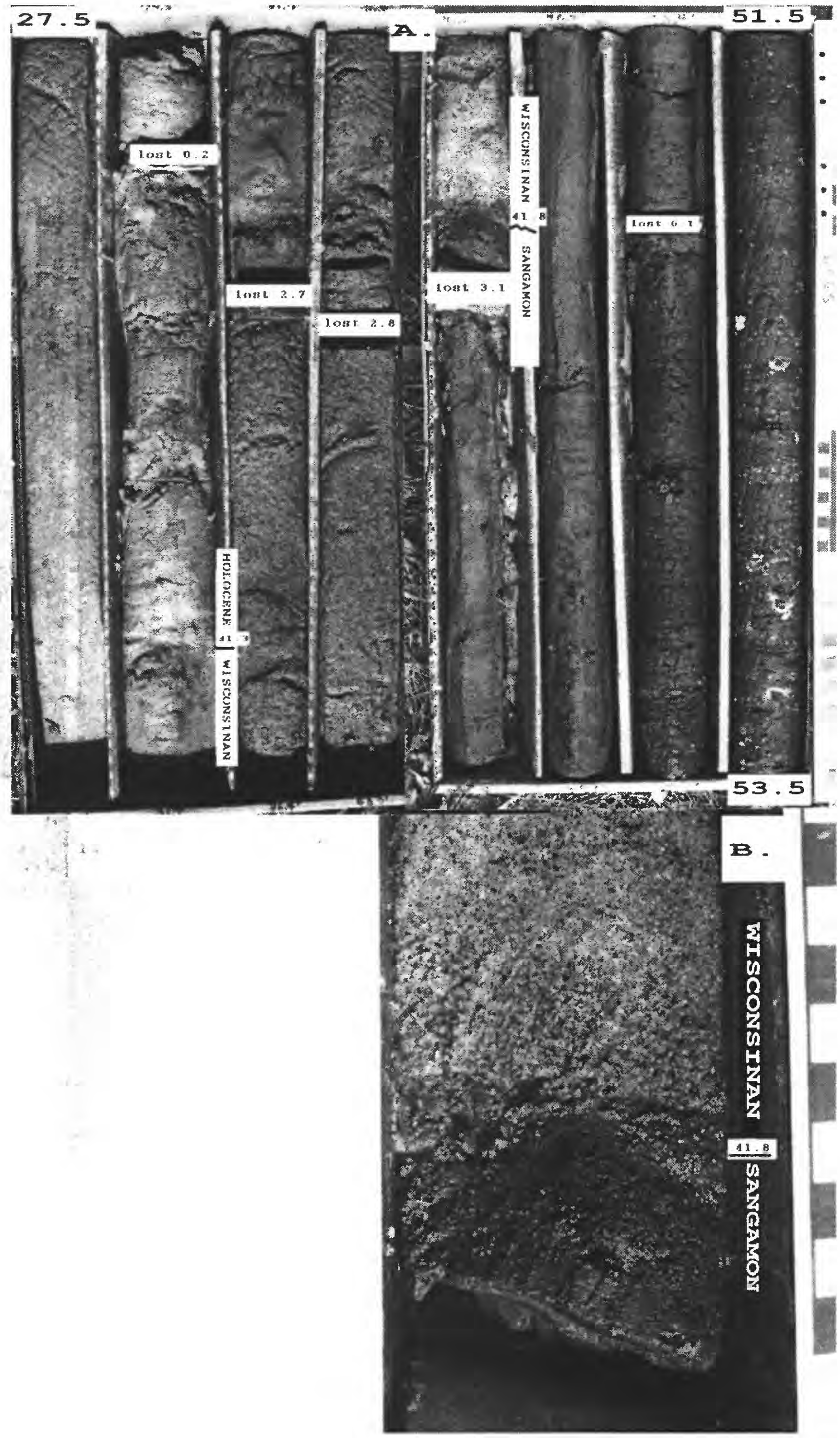

Figure 21. **(A)** Robins Point core, 27.5- to 53.5-foot depth interval, showing the contact at 41.8 feet between the sandy Wisconsinan and the underlying clayey Sangamon deposits, and the contact at 31.3 feet between the oxidized (yellowish) finer grained Holocene and the grayish, coarser grained Wisconsinan deposits. [*White spots in the 51.5- to 53.5-foot interval are shell material.*]
(B) Closeup showing the contact between the base of the Wisconsinan glacial deposits (surficial aquifer) and the top of the Sangamon interglacial deposits (upper paleochannel confining unit) at 41.8 feet.

section and in the uppermost 161.1 ft of the section. The interval from 120.0 to 153.0 ft contains scattered grayish-blue blebs of vivianite, a ferrous phosphate mineral typically found in lake sediments, estuarine sediments, and peat bogs.

This sequence represents fluvial channel deposits overlain by estuarine deposits that are very similar to those deposited in the Chesapeake Bay during the Wisconsinan-Holocene glacial-interglacial cycle. The fossiliferous late-Sangamon section at the top of the sequence probably reflects the end of restricted valley-fill deposition and a change to a more open, broader estuary with deposition occurring during the interglacial highstand. This interval correlates with the Eastville paleochannel and was probably cut about 150,000 years ago.

The interval from 31.3 to 41.8 ft is a fining-upward sequence that grades from primarily organic-rich (wood concentrated at 32.2 ft), poorly sorted, medium to coarse angular sand, to a well-sorted, fine to medium sand with thin interbeds of clayey silt (fig. 21). These well-sorted sands grade upward into interbedded clayey silt and very fine to fine sand in a clayey matrix. Pollen from this interval indicates deposition during a glacial phase, and this unit is assigned to the Wisconsinan. This interval correlates with the Cape Charles paleochannel and was cut about 20,000 years ago.

The pre-Sangamon glacial pollen assemblage, which has been assigned to the Illinoian, may be a unique record for the Mid-Atlantic Coastal Plain.

Holocene(?) (Ground surface to 31.3 ft)

The uppermost 31.3 ft contains two fining-upward sequences, which include a lower 23.95-ft-thick section and an upper 7.35-ft-thick section. The lower sequence grades upward from primarily grayish-brown (oxidized), interbedded, silty, medium-to-coarse sand and clayey silt to a thin (1.25 ft), light-gray to brownish-gray, laminated, clayey silt. The pollen sample from 25.2 to 25.3 ft contained about half the number of pollen specimens found in the other Quaternary pollen samples (not including the barren sample taken from 9.7 to 10 ft). The pollen data indicate a temperate forest environment, which indicates that these deposits are Holocene.

The upper 7.35-ft-thick fining-upward sequence grades from very oxidized, yellow-brown to brown, massive to thinly interbedded, fine to medium sand and clayey silt, to a section of clayey, silty, very fine to fine sand interbedded with thin, clayey silt layers and capped with a dark-gray to black, organic-rich soil that is 0.6 ft thick. This interval also contains weakly cemented iron-oxide layers, including a layer at the base at 7.35 ft and a 0.3-ft-thick iron-cemented concretionary layer that interfingers with rootlets at 2.7 ft.

GEOPHYSICAL LOGS

Because the signatures on the gamma and resistivity logs (fig. 22) correlate well with specific lithologic units in the Robins Point core (fig. 7), these logs provide a key for stratigraphic interpretation of other geophyscial logs in this region. For example, many of the Cretaceous sandy basal lag deposits show high gamma values, typically of clays, but the resistivity logs indicate a sand. The core shows that these intervals contain an abundance of clay rip-up clasts or are clay-clast conglomerates, thereby explaining the apparent discrepancy between the two logs.

Gamma Log

In deposits that are dominantly fluvial, the gamma log gives a good indication of lithology. This method measures the natural radiation that is emitted from rocks and sediments. Clay typically emits more radiation than silt, and silt emits more than sand and gravel. On the gamma log, deflections to the left

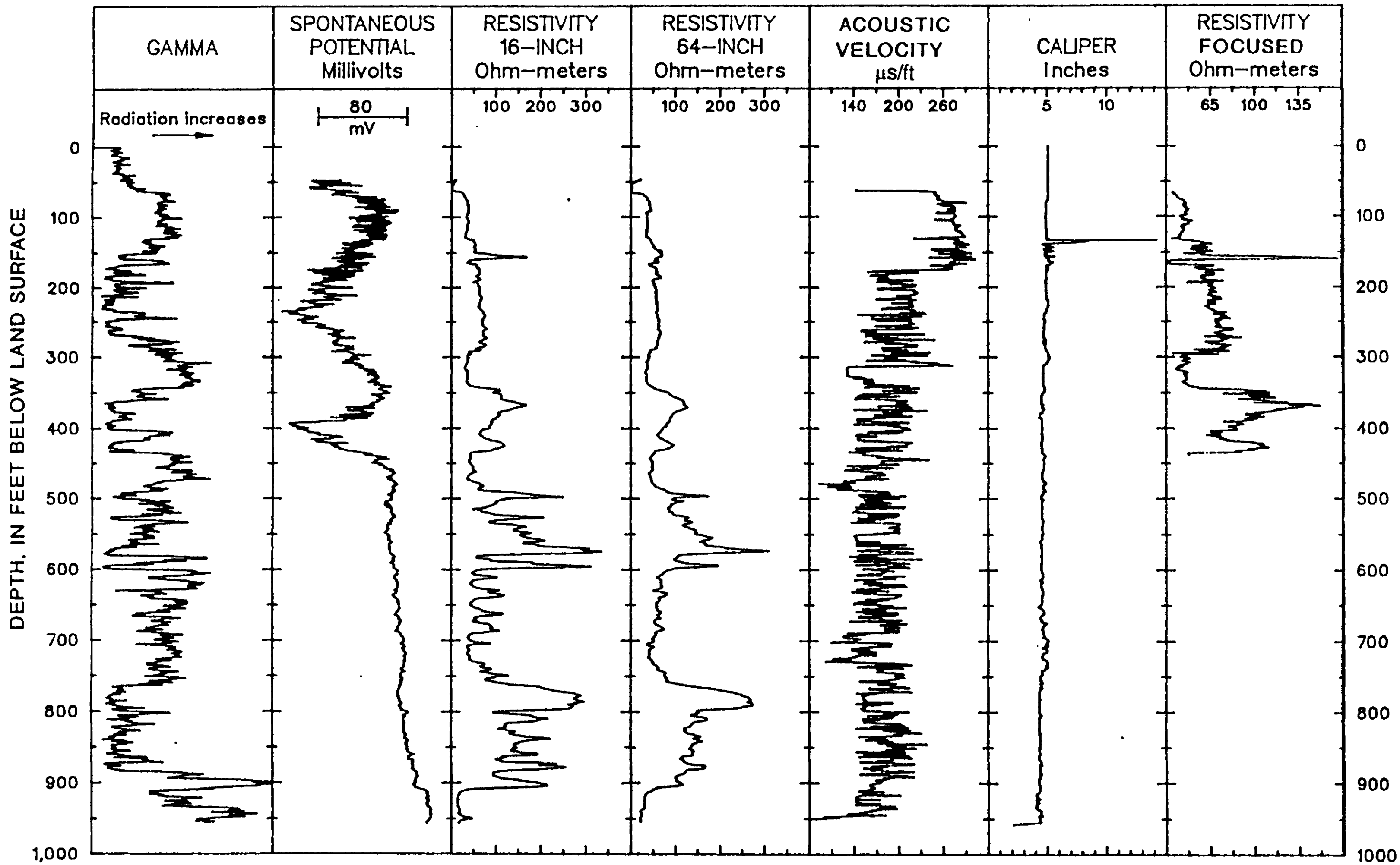

Figure 22. Geophysical logs from the Robins Point corehole.
[*µs/ft = microseconds per foot.*]

represent sands that contain primarily non-radioactive quartz. Deflections to the right indicate silts and clays that contain radioactive elements. Upward gradual shifts to the right indicate fining-upward trends and upward gradual shifts to the left indicate coarsening upward trends. Abrupt shifts to the left generally indicate sharp erosional sand-over-clay contacts and abrupt shifts to the right indicate sharp clay over sand contacts. These contacts reflect dramatic shifts in the depositional environment. The casing causes the signal to be sharply deflected to the left, with a substantial decrease in amplitude (fig. 22, appendix II).

Resistivity Logs

Resistivity logs measure the variation in resistivity that is caused by the different subsurface materials and by differences in total dissolved solids in the water in the formation. In general, sand with freshwater in the pore spaces is much more resistive than clay and will cause a deflection to the right on the log. Clays or sand with brackish water in the pore spaces will cause a deflection to the left.

The 16-in., 64-in., and 4-ft focused resistivity (guard) logs run in the corehole have different volumes of investigation. The 16-in. resistivity measures the resistivity of thin beds, but is most affected by borehole conditions and fluid invasion into the formation. The 64-in. log measures the resistivity of thick beds away from the borehole by averaging a greater volume of material than the 16-in., is not sensitive to borehole conditions, but cannot give accurate resistivity values for thin beds. The 4-ft focused resistivity log measures resistivity in a relatively thin sheet about 12 ft into the formation, and is not affected by borehole conditions or thin beds.

Because most of the corehole appears to have penetrated freshwater-bearing fluvial deposits, the resistivity logs primarily reflect lithologic contrasts such as gross sand-to-clay ratios, or clean sand verses a dirty sand. The resistivity logs show a deflection to the left at 912 ft, at the contact between the clayey saprolite and the weathered rock/saprolite. This deflection indicates a more conductive (brackish ?) fluid in the otherwise resistant rock.

Comparison of the resistivity logs with the spontaneous-potential (SP) log, which is run simultaneously with the 16- and 64-in. resistivity log, can help determine changes in water quality in the corehole and in the formations. The SP log for the corehole, however, did not appear to be operating properly and is therefore questionable. The noise on the SP log above the 180-ft depth was caused by a nearby generator that was turned on at this point during the logging, and the log was not responding to lithologic changes below 500 ft.

The freshwater that was used to drill the corehole had a specific conductance of 45 μS/cm at 25 degrees Celsius. The specific conductance of the drilling mud just prior to logging was 800 μS/cm.

Acoustic Velocity Log

The acoustic velocity (sonic) log measures the interval transit time of a compressional sound wave traveling through 1 ft of formation. The log is recorded in microseconds per foot which is the reciprocal of velocity (Asquith and Gibson, 1982). The transit time is dependent on lithology and porosity. The Robins Point acoustic velocity log shows the unconsolidated nature of the Pleistocene deposits, the hard and compacted Cretaceous overbank-paleosol clay intervals and the much higher velocity of the nearly fresh rock encountered at the bottom of the hole.

Caliper Log

The caliper log measures the diameter of the corehole and shows that only one thin interval (134 to 138 ft) that has been washed out to about 8 to 11 in. This interval corresponds to the interbedded sand and clayey silt at the top of the Illinoian glacial deposits.

FACTORS AFFECTING GROUND-WATER FLOW BENEATH J-FIELD

On the basis of lithology and palynology, the stratigraphic units in the Robins Point corehole have been correlated with hydrogeologic units as shown in figure 23. Seven aquifers and six confining units have been identified. These include, in descending order: 41.8 ft of surficial aquifer, 90.9 ft of upper paleochannel confining unit, 28.8 ft of paleochannel confined aquifer, 15.7 ft of lower paleochannel confining unit, 123.7 ft of Upper Patapsco aquifer, 44.6 ft of Middle Patapsco confining unit, 92.8 ft of Middle Patapsco aquifer, 57.3 ft of Lower Patapsco confining unit, 151.7 ft of Lower Patapsco aquifer, 115.4 ft of Potomac confining unit, 126.4 ft of Patuxent aquifer, an aquifer of 23.4 ft of saprolite, and 48.7 ft of weathered rock/saprolite confining unit.

The Cretaceous aquifers vary from "dirty" channel sands (including fine-grained material and/or clay clasts and abundant lignite) to relatively "clean" channel sands. The Cretaceous confining units consist primarily of dense clay overbank paleosols that appear relatively dry and tend to act as a barrier that restricts vertical ground-water flow. The lateral distribution of these clay paleosols is unknown and is probably not very extensive based on the cut and fill nature of fluvio-deltaic deposits. Beneath J-Field, the clay paleosols may act as a barrier to vertical flow of ground water. The Middle Patapsco confining unit from 300.9 to 345.5 ft is the uppermost of these barriers.

The significantly higher density of the Cretaceous deposits, which have been compacted compared to the Pleistocene deposits, indicates that ground-water flow in the paleochannel confined aquifer (equivalent to the basal sands of Illinoian glacial deposits) may follow the paleochannel trend shown in figure 2. The slope of the base of these Susquehanna River paleochannels beneath Chesapeake Bay is very low, and deep thalawags have been documented (Hack, 1957; Coleman and Mixon, 1988). On the basis of available data, the direction of ground-water flow within the upper confined aquifer could be either northeast or southwest along the paleochannel trend. Where the paleochannel lies beneath the Chesapeake Bay, ground water probably discharges into the bay, as suggested by previous studies (Hughes, 1993; Vroblesky and Fleck, 1991).

The upper paleochannel confining unit contains more silt and very fine sand than was reported by Hughes (1993), which indicates that it may be a leaky confining unit. Paleochannels typically have remnants of the erosive channel sands, which are residual from downcutting of the paleochannel. These sands line the sides of the channels and create a leaky edge effect. Hughes (1995) indicated that ground water flows upward along the sandy paleochannel edges.

Data from other boreholes within J-Field indicate the paleochannel cut into fluvio-deltaic clay, silt, and sand of the Patapsco Formation, with clay to clay-silt dominating the section (Hughes, 1993; and Valerie Thurmound, U.S. Army Corps of Engineers, written commun., 1996).

A diagram showing hydrogeologic units and generalized ground-water-flow directions near J-Field is shown in figure 24. Summaries of the hydrogeologic framework of the upper Chesapeake Bay area is provided by Vroblesky and Fleck (1991) and Otton and Mandle (1984). Regional aquifer-system analysis,

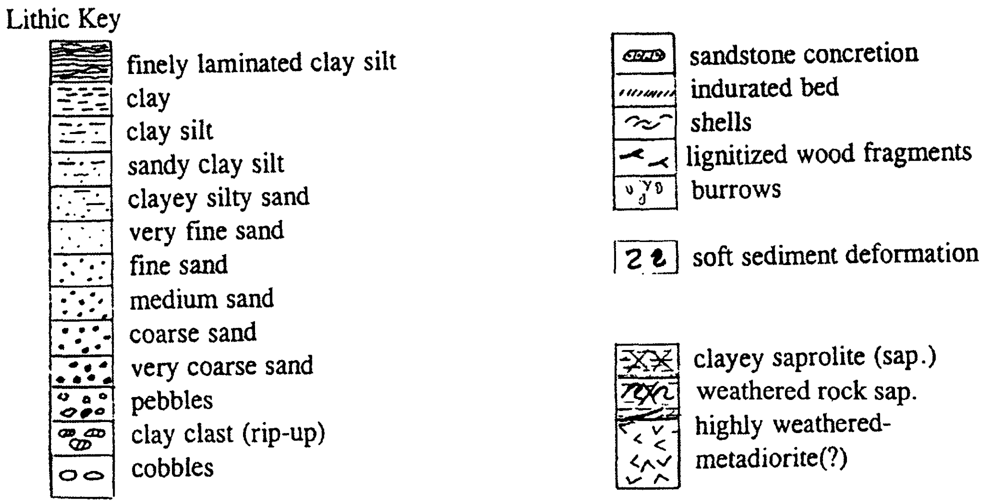

Figure 23. Correlation of stratigraphic units and hydrologic units in the Robins Point corehole with layers in the regional ground-water-flow model of Vroblesky and Fleck (1991).

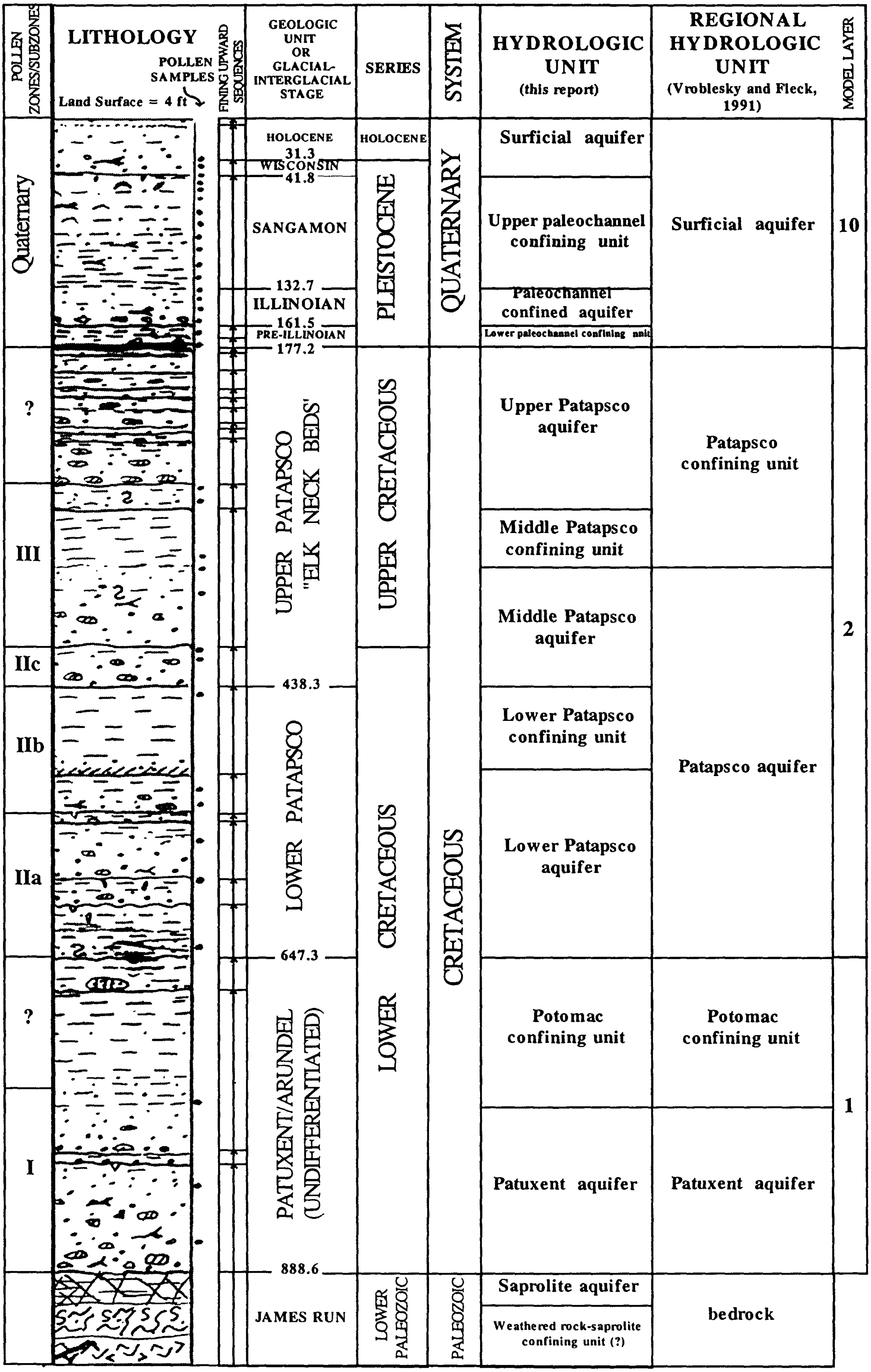

Figure 23. Continued

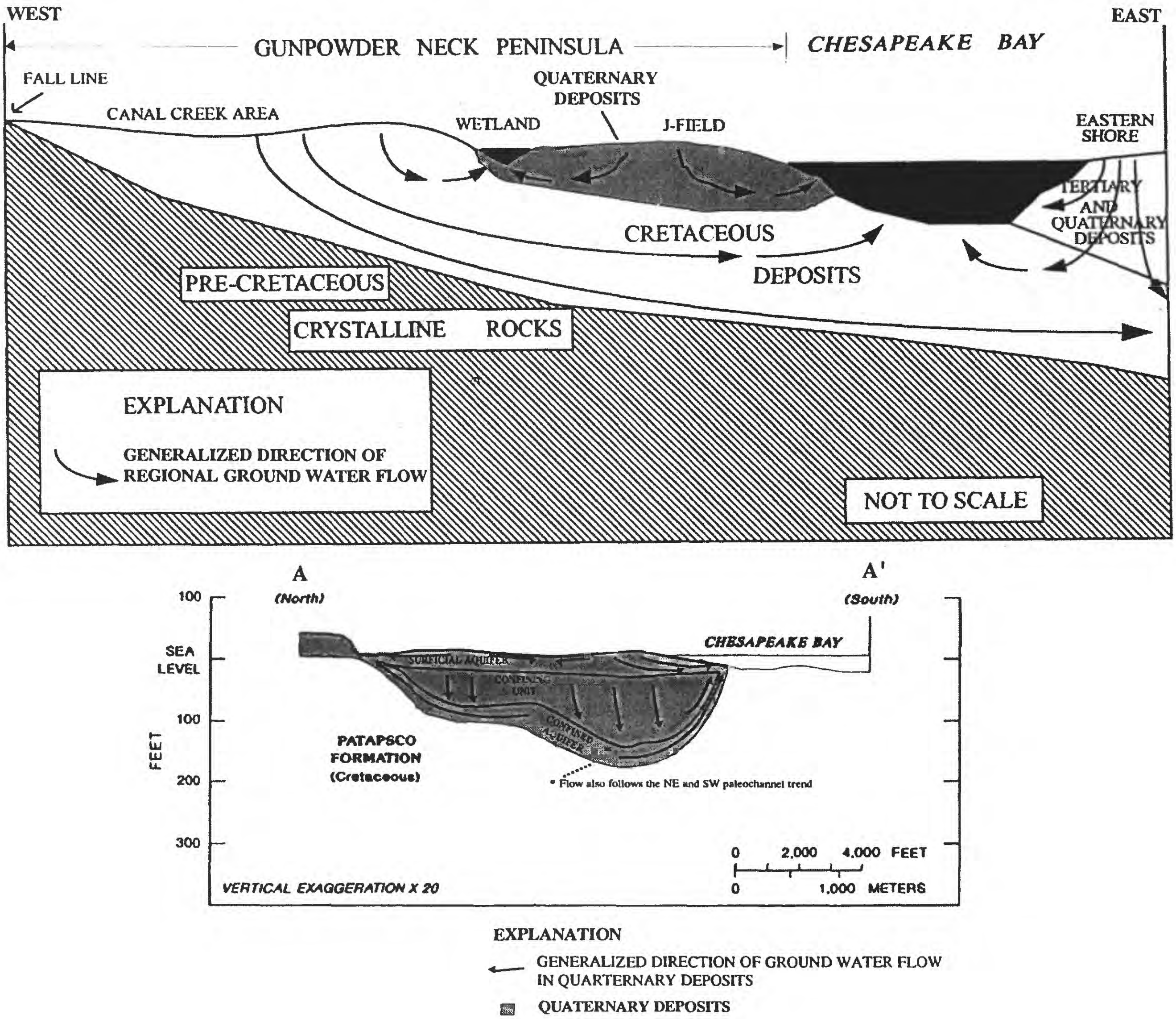

Figure 24. Schematic diagrams showing hydrogeologic units and generalized ground-water-flow directions along Section A-A'. [*Location shown in figure 2.*]

including ground-water-flow modeling, is provided by Leahy and Martin (1994) and Fleck and Vroblesky (1996). Drummond and Blomquist (1993) provide a summary of the hydrogeology and water quality (including a ground-water-flow model) of the Coastal Plain aquifers in Harford County.

SUMMARY AND CONCLUSIONS

A 961-ft-deep continuously cored corehole was drilled at J-Field, in the Edgewood Area of Aberdeen Proving Ground (APG) to characterize the stratigraphic and geophysical properties of the aquifers and confining units. The corehole was drilled at Robins point, which is at the southeastern tip of Gunpowder Neck Peninsula. The high percentage (approximately 90 percent) of total core recovery and the suite of geophysical logs provide a detailed key for interpreting regional borehole geophysical and seismic data. The Robins Point core provides a key to regional stratigraphic correlation and can therefore support the development and refinement of the regional hydrogeologic framework.

The study area is located within the inner Coastal Plain lowland north of the Patapsco River and south of the Susquehanna River. This area was truncated by numerous Susquehanna River paleochannels and their tributaries and by subsequent aggradational filling of these paleochannels.

Lithologies encountered in the Robins Point corehole (surface elevation about 4 ft above mean sea level) in ascending order, include: 72.4 ft of weathered metamorphic rock and saprolite (888.6 to 961.0 ft, James Run Formation(?) lower Paleozoic); 711.4 ft of lower and upper Cretaceous fluvio-deltaic deposits, mostly unconsolidated sand, clay, silt, and some gravel (177.2 to 888.6 ft); and 145.9 ft of Pleistocene and 31.3 ft of Holocene(?) fluvial and estuarine deposits, mostly unconsolidated clayey silt, sand, clay, and some gravel.

On the basis of lithology, palynology, and regional correlation, the Coastal Plain deposits contain eight stratigraphic units, which in ascending order, include: 241.3 ft of the Patuxent/Arundel Formations (undifferentiated, lower Cretaceous), 209 ft of the Lower Patapsco (lower Cretaceous), 261.1 ft of the Upper Patapsco (lower and upper Cretaceous), 15.7 ft of the Accomack Member of the Omar Formation (pre-Illinoian, middle Pleistocene), 119.7 ft of the Stumptown Member of the Nassawadax Formation (Illinoian-Sangamon, upper Pleistocene), 10.5 ft of the Kent Island Formation (Wisconsinan, upper Pleistocene), and 31.3 ft of unnamed Holocene deposits. Assignment of the Pleistocene deposits to these formations is based on regional correlation, which indicates the filling of equivalent Susquehanna River paleochannels. These sequences correlate respectively with the Exmore, Eastville, and Cape Charles paleochannels and represent the three main Susquehanna River paleochannels mapped throughout the Chesapeake Bay using borehole and seismic data.

This is the first time upper Cretaceous (pollen zone III) deposits have been documented in Harford County. The pre-Sangamon glacial pollen assemblage, which has been assigned to the Illinoian, may be a unique record for the Mid-Atlantic Coastal Plain.

The Coastal Plain deposits consist of numerous Cretaceous, Pleistocene, and Holocene(?) fining-upward sequences. The Cretaceous deposits contain five large-scale fining-upward cycles. These large-scale cycles contain 22 fining-upward sequences that range in thickness from 4.6 to 123.3 ft . The Pleistocene and Holocene deposits contain six fining-upward sequences that range in thickness from 7.3 to 119.7 ft. These fining-upward sequences are bounded by sharp lithic breaks and are characterized by a coarse basal lag deposit (either a pebbly sand, a gravel, or a clay-clast conglomerate) that grades upward into interbedded, finer grained sand, silt, and clay.

Conspicuous bedding is prevalent throughout most of the core, with only a few massive intervals encountered. Bedding ranges from planar laminations (0.25 to 1.0 mm thick); to thin beds (1.0 mm to 3.0 cm thick); to wavy to slightly inclined, and crossbedded (low and high angle) layers. Throughout the core, the sand fraction is nearly all quartz.

Thirteen hydrological units were identified, including seven aquifers and six confining units. In descending order, these units include: 41.8 ft of surficial aquifer, 90.9 ft of upper paleochannel confining unit, 28.8 ft of paleochannel confined aquifer, 15.7 ft of lower paleochannel confining unit, 123.7 ft of Upper Patapsco aquifer, 44.6 ft of Middle Patapsco confining unit, 92.8 ft of Middle Patapsco aquifer, 57.3 ft of Lower Patapsco confining unit, 151.7 ft of Lower Patapsco aquifer, 115.4 ft of Potomac confining unit, 126.4 ft of Patuxent aquifer; an aquifer of 23.4 ft of saprolite, and 48.7 ft of weathered-rock/saprolite confining unit.

The Cretaceous aquifers vary from dirty channel sands, which include fine-grained material and/or clay clasts and abundant lignite, to relatively clean channel sands. The Cretaceous confining units primarily consist of dense clay overbank paleosols that may tend to restrict vertical ground-water flow. The lateral distribution of these clays is unknown, however, and is probably not too extensive based on the cut-and-fill nature of fluvio-deltaic deposits. The significantly higher density of the compacted Cretaceous deposits compared to the Pleistocene deposits suggests that ground-water flow in the upper confined aquifer may follow the paleochannel trend. Where the paleochannel lies beneath the Chesapeake Bay, ground water probably discharges into the bay. The upper paleochannel confining unit contains more silt and very fine sand than was reported earlier and indicates that this may be a leaky confining unit.

Most of the corehole appears to have penetrated freshwater-bearing fluvial deposits. The resistivity log deflection to the left, however, at the weathered-rock/saprolite contact (at 912 ft) indicates a more conductive (brackish ?) fluid in the otherwise resistant rock.

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APPENDIXES

APPENDIX I. *Ground-water quality in Robins Point corehole (JFC1)*

APPENDIX I. *Ground-water quality in Robins Point corehole (JFC1)*

Appendix I-A. *Summary of ground-water-quality results in temporary well screened from 32 to 35 feet below land surface in the surficial aquifer*

[The complete list of parameters sampled and all analytical results are on file at the Baltimore office of the Maryland-Delaware-D.C. District of the U.S. Geological Survey]

All inorganic constituents were below the U.S. Environmental Protection Agency's (EPA) maximum contaminant levels (MCL's) (U.S. Environmental Protection Agency, 1990) with the exception of dissolved thallium. The initial analytical results based on inductively coupled plasma-mass spectrometer (ICP-MS) techniques for dissolved thallium in both wells [270 micrograms per liter (µg/L) in well JF1, and 210 µg/L in the temporary 35-ft-deep well] indicated concentrations above the MCL of 2 µg/L. In order to provide maximum resolution, samples were re-analyzed using graphite-furnace atomic-adsorption techniques. All analytical results showed non-detects for thallium (less than 50 µg/L) on the re-analysis, but the reporting limit for the re-analysis (50 µg/L) was above the MCL.

All organic constituents, except for heptachlor epoxide, were non-detects or were below the MCL's. The detection of 1.2 µg/L of heptachlor epoxide exceeded the MCL of 0.4 µg/L. The detect, however, was in only the second column of the gas-chromatography, and was not detected in the first column. The USEPA's contract laboratory program (CLP) protocol states that when an analyte is not detected on both columns, the lower value (or in this case, the non-detect value) should be reported as the quantifiable value.

APPENDIX I. *Ground-water quality in Robins Point corehole (JFC1)--Continued*

Appendix I-B. *Summary of ground-water-quality results in observation well screened from 392 to 402 feet below land surface in the Middle Patapsco aquifer. (Samples taken on September 25, 1996)*

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter]

Specific conductance [1] (µS/cm)	pH [2]	Temperature [1] (°C)	Hardness, [2] as $CaCO_3$ (mg/L)	Alkalinity, [1] as $CaCO_3$ (mg/L)	Carbon dioxide [2] (mg/L)	Chloride [2] (mg/L)	Total dissolved solids [2] (mg/L)	Iron [2] Total (µg/L)	Iron [2] Dissolved (µg/L)	Manganese [2] Total (µg/L)	Manganese [2] Dissolved (µg/L)
433 to 448	6.97 to 7.29	16.8 to 20.9	49.2	7.5	1.8	53.4	252	7.4	7.0	0.54	0.55

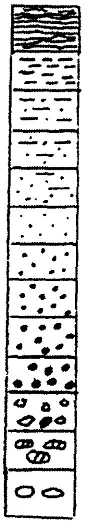
[1] Analyzed in the field.

[2] Analyzed in the laboratory.

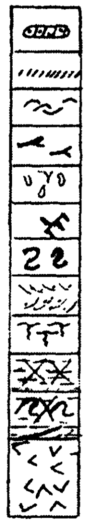
APPENDIX II. *Lithostratigraphic column and gamma logs for Robins Point corehole (JFC1)*

[Lithostratigraphy shown to left of gamma log trace. See section on gamma logging in the text and see figure 22. Core recovery and loss are shown on the right side of the column. Fining-upward sequences are shown on the left side of the column.]

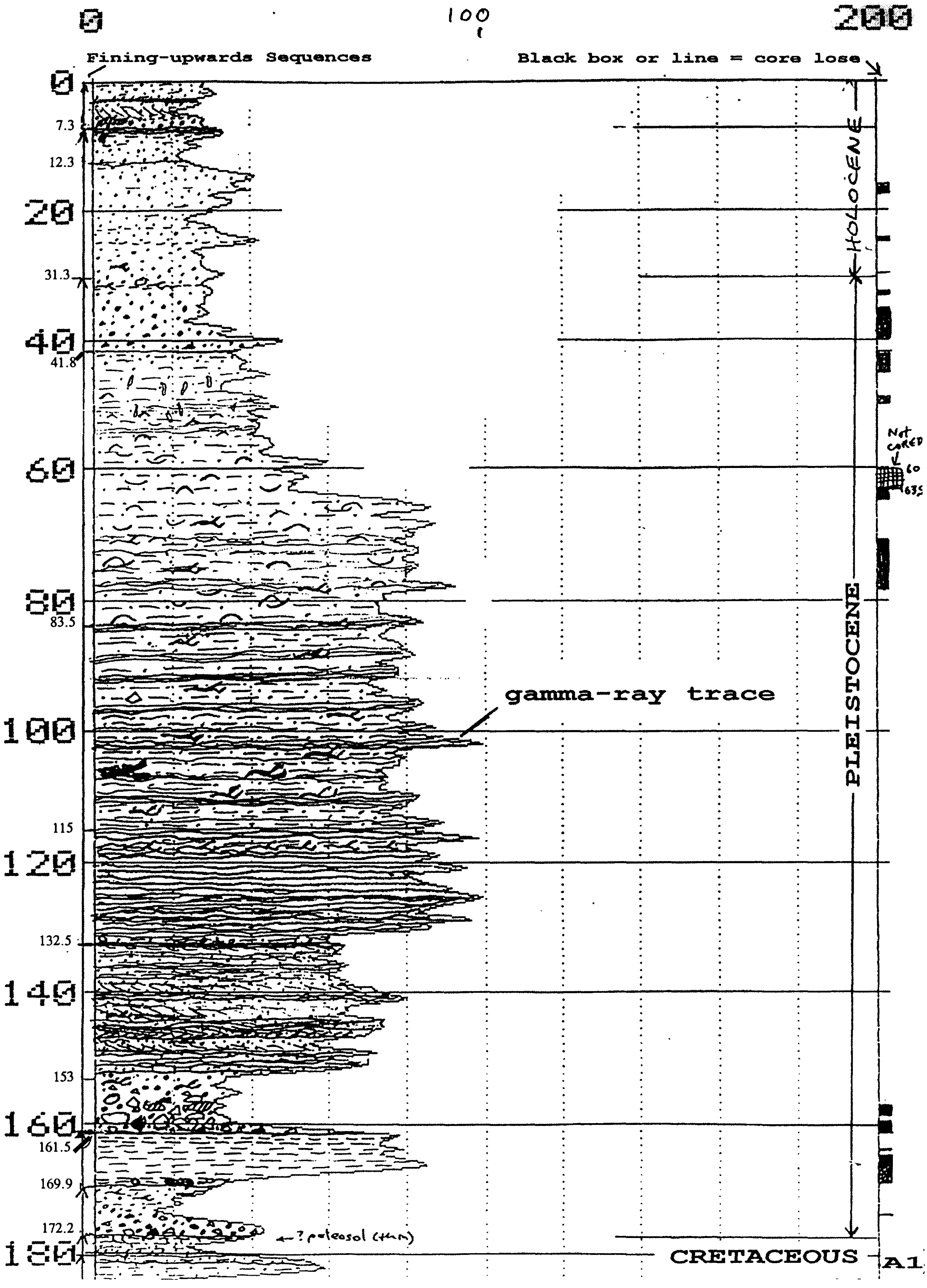
Lithic Key



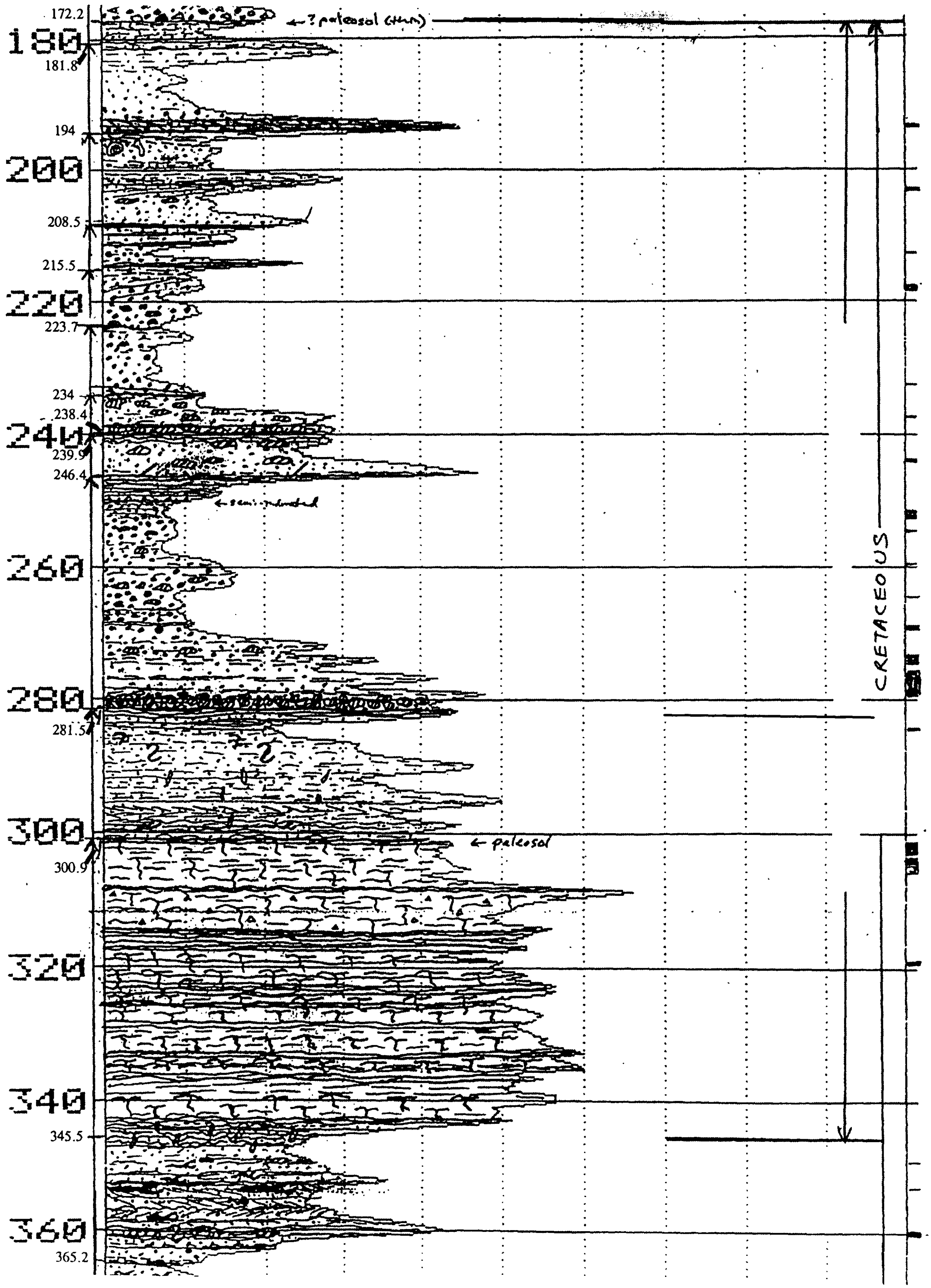
- finely laminated clay silt
- clay
- clay silt
- sandy clay silt
- clayey silty sand
- very fine sand
- fine sand
- medium sand
- coarse sand
- very coarse sand
- pebbles
- clay clast (rip-up)
- cobbles

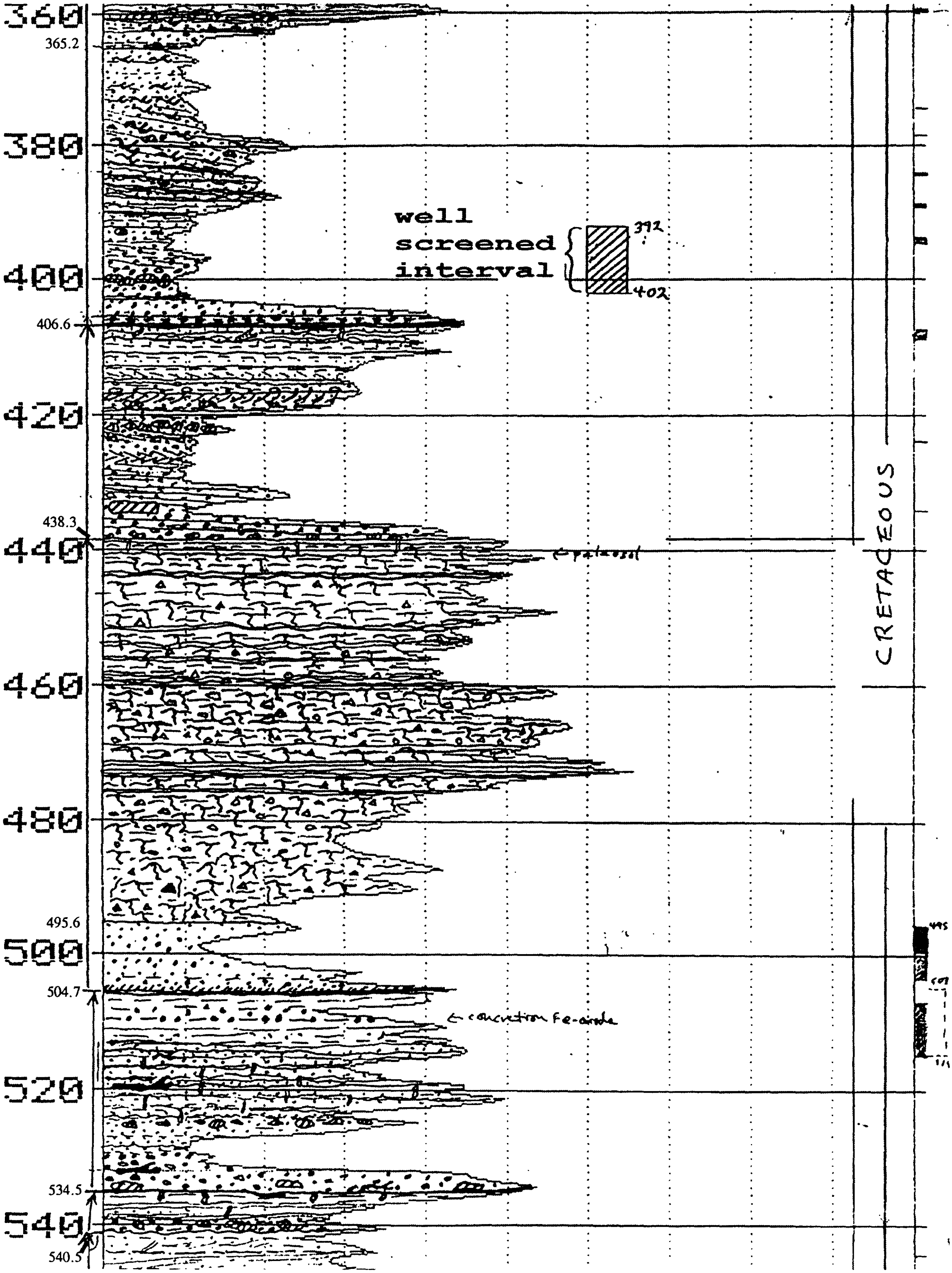


- sandstone concretion
- indurated bed
- shells
- lignitized wood fragments
- burrows
- slumping
- soft sediment deformation
- cross bedding
- paleosol
- clayey saprolite (sap.)
- weathered rock sap.
- highly weathered-metadiorite(?)

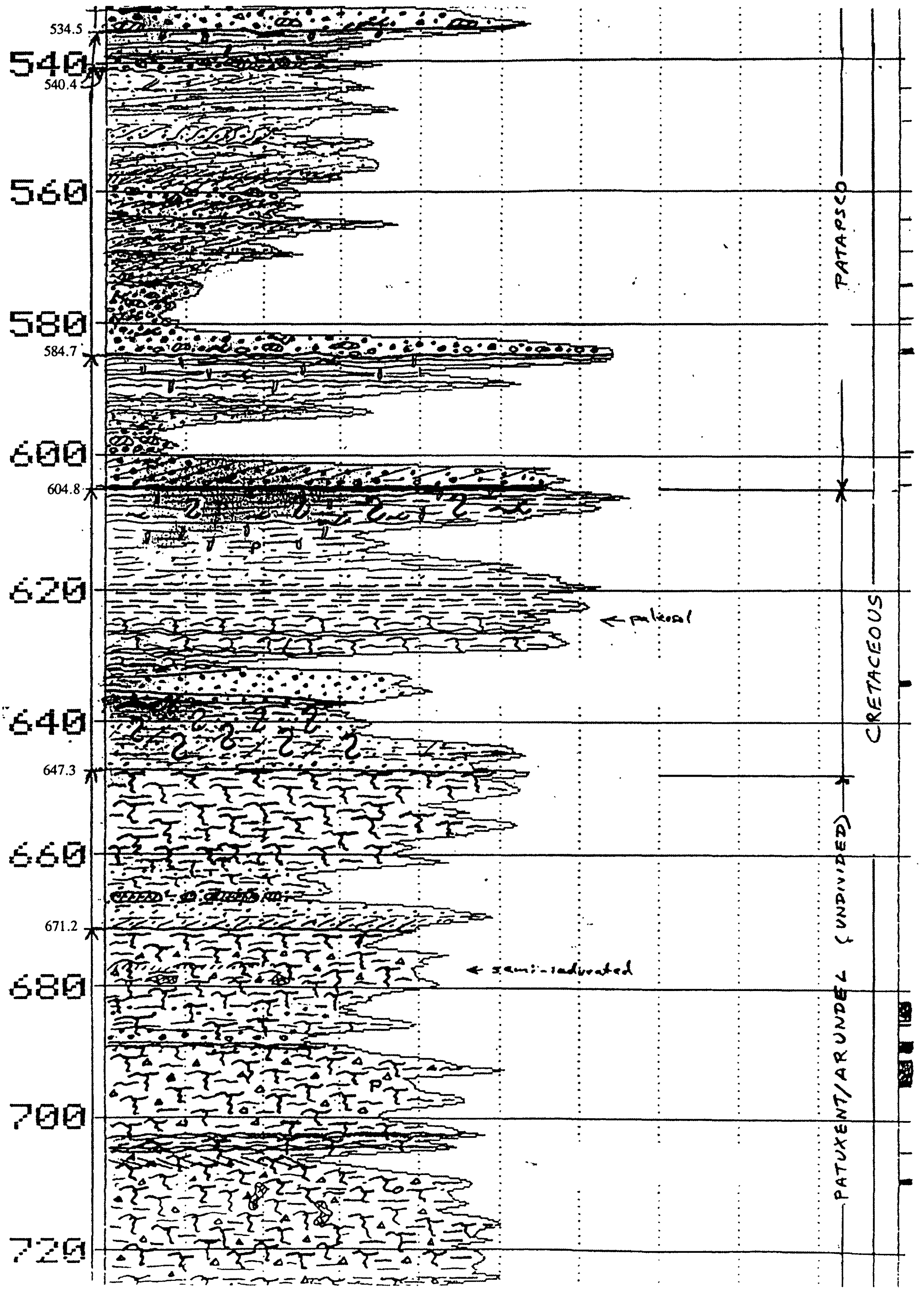


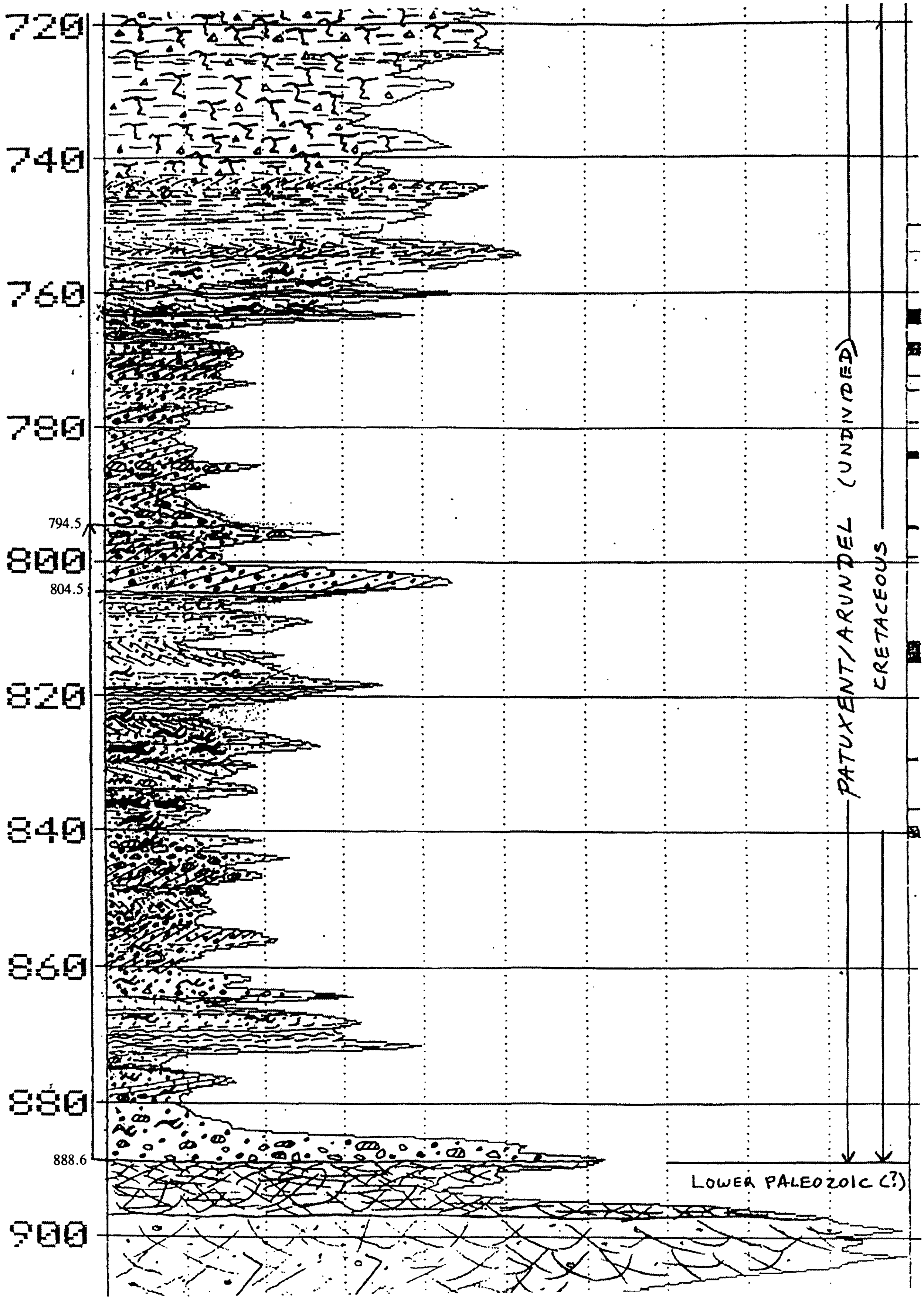
0
100
200
Fining-upwards Sequences
Black box or line = core lose
0
7.3
12.3
20
31.3
40
41.8
60
80
83.5
100
115
120
132.5
140
153
160
161.5
169.9
172.2
180
HOLOCENE
PLEISTOCENE
Not CORED
gamma-ray trace
CRETACEOUS
A1

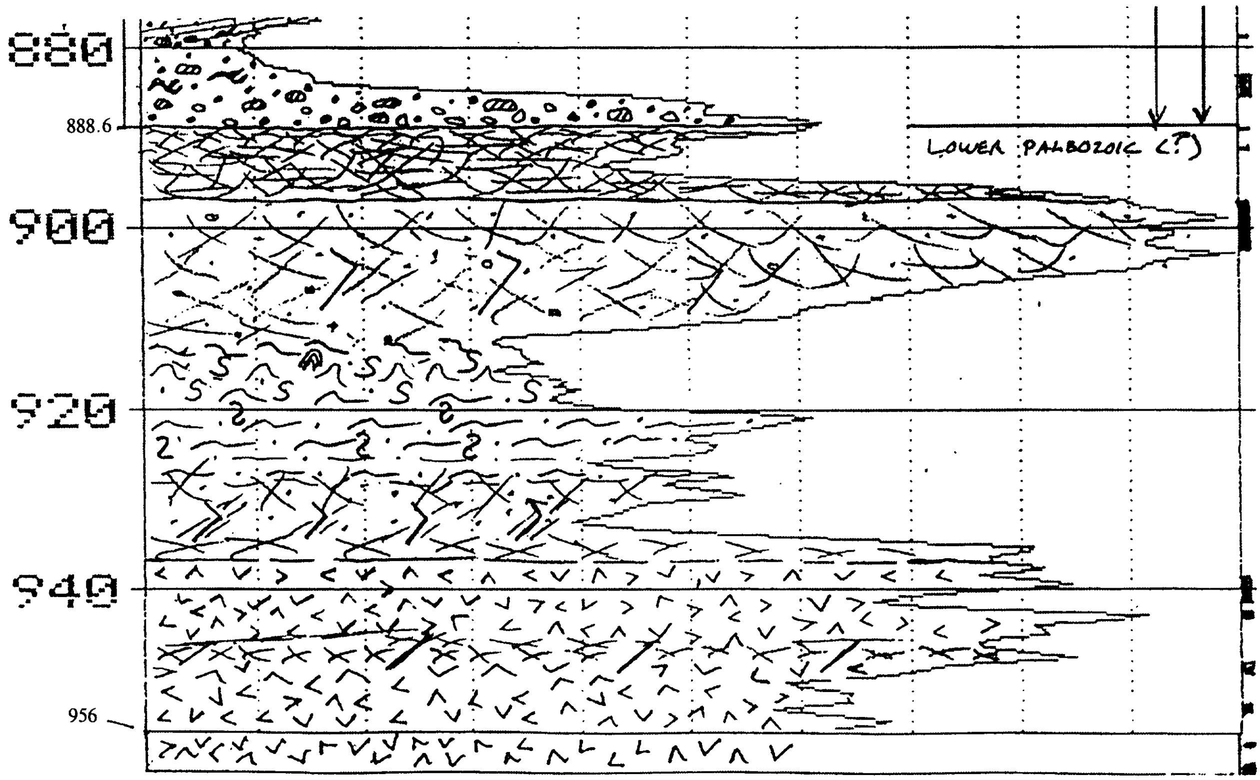

172.2
180
181.8
194
200
208.5
215.5
220
223.7
234
238.4
240
239.9
246.4
260
280
281.5
300
300.9
320
340
345.5
360
365.2
← ? paleosol
← semi-indurated
← paleosol
CRETACEOUS



360
365.2
380
well
screened
interval
392
402
400
406.6
420
438.3
440
← paleosol
CRETACEOUS
460
480
495.6
500
504.7
← concretion Fe-oxide
520
534.5
540
540.5


534.5
540
540.4
560
580
584.7
600
604.8
620
640
647.3
660
671.2
680
700
720
PATAPSCO
CRETACEOUS
PATUXENT/ARUNDEL (UNDIVIDED)
← paleosol
← semi-indurated


720
740
760
780
794.5
800
804.5
820
840
860
880
888.6
900
PATUXENT/ARUNDEL (UNDIVIDED)
CRETACEOUS
LOWER PALEOZOIC (?)



TOTAL DEPTH = 961 ft

Appendix III: *Lithologic summary for the Robins Point Corehole (JFC1)*

[Drilling depths are in feet below sea level. The lithic breaks that separate the numerous fining-upward cycles are labeled as contacts and marked with a dashed line. Colors are referenced to the Munsell Soil Color Chart (1975 edition)]

DEPTH TO BASE (feet)	THICKNESS (feet)	LITHOLOGY
0.6	0.6	SOIL, sandy clayey silt, organic-rich, dark brown (7.5YR4/2) to very dark brown (7.5YR3/2).
2.4	1.8	Clayey silty SAND, very fine to fine, dark-yellow-brown (10YR 4/6) to yellow-brown (10YR5/6).
2.7	0.3	IRON-CEMENTED SAND, concretion layer interfingered with rootlets, yellow-brown (10YR5/6).
4.6	1.9	Clayey silty SAND and CLAYEY SILT, interbedded (1.0 mm to 1.0 cm), fine to medium sand; some organic material yellow-brown (10YR5/6 to 5/8) to brown-yellow (10YR6/8), very light gray (N8) in clayey silt layers.
7.35	2.75	SAND, medium, with some coarse grains, loose, few clayey silt layers, weakly cemented iron oxide layer near base; mica flakes (1.0 to 2.0 mm); yellow-brown (5YR4/6) to brown-yellow (10YR6/6 to 6/8) with a little red (2.5YR5/8); 5.8-ft clayey silt layer includes brown-gray (10YR6/2) to strong brown (7.5YR5/8 to 4/6).
7.35	----------------------------*SHARP CONTACT*----------------------------	
8.6	1.25	CLAYEY SILT and SAND in a clayey silt matrix, interbedded, very fine to fine sand; laminated (0.5 mm) to 2.0 mm); fair amount of mica; at 8.0 ft, black pebble (2.6 cm); light gray (10YR6/1) grayish-brown (10YR5/2) to thin be light-brownish-gray (10YR6/2); top 0.3 ft weathered (oxidized) yellow-brown (10YR5/6) to red-yellow (7.5YR7/8 to 6/8) with a white 2.0-cm band at the base.
31.3	22.7	Silty SAND, fine to medium, interbedded with thin clayey silt layers, well-sorted; scattered to finely disseminated organic material increases downward; primarily frosted to clear quartz, 2-5% rose quartz angular to subrounded, few iron and chlorite-stained quartz grains with an increase in iron-stained quartz in lower 6.0 ft, 1-5% heavy minerals; mostly oxidized colors, grayish-brown (10YR5/2) to light- brown-gray (2.5Y6/2) to light-olive-brown (2.5Y6/4) to olive-yellow (2.5Y6/6) with bands of yellow-brown (10YR6/8) to red-brown (5YR5/6); 30.0 to 30.3 ft includes pebble-size, clayey silt rip-up clasts with a gradational color and lithic change (31.3 to 31.7 ft) from oxidized brownish-yellow to reduced grays.
31.3	----------------------*GRADATIONAL CONTACT = Base of Holocene ?*----------------------	
41.8	10.5	SAND, medium to coarse; abundant black grains and chips are primarily organic material (range from silt to very coarse) with light-olive-brown (2.5Y5/4) to black, (10YR2/1) organic-rich wood chips at 31.7 to 31.8 ft; dominated by frosted quartz; some clear, rare rose quartz / rock fragments/gray chert; 1-5% heavy minerals; the quartz grains are angular to subrounded with a few rounded grains; the lowest 7 ft becomes a light-gray (5Y7/1) to gray (5Y6/1), poorly sorted sand that ranges from very fine to very coarse.
41.8	----------------------------*SHARP CONTACT*----------------------------	

DEPTH TO BASE (feet)	THICKNESS (feet)	LITHOLOGY
132.7	90.9	Clayey SILT, to sandy clayey SILT to silty CLAY, alternating horizontal to slightly inclined crossbeds, fine laminations (0.25 to 1 mm), thin beds (0.5 cm) and massive intervals (due to the abundant bioturbation); burrowed locally (some clay-lined), organic-rich; 47.3 to 83.5 ft includes shells and some laminations; 83.5 to 115 ft contains abundant organic material typically concentrated in black (N1), discrete layers (finely disseminated grains to wood fragments--twigs and bark with large chunk of bored, reddish-dark-brown wood at 106.8 ft); scattered light yellow-brown (2.5Y6/4) marcasite or siderite banding (1.0 to 2.0 cm); at 100 ft depth, first appearance of grayish-blue (5PB5/2) vivianite (ferrous phosphate mineral); 115 to 132.5 ft is the finest grained (highest percentage of clay) interval in this section; lowest 0.2 ft becomes a clayey, silty, very fine to fine sand, with a few medium to granular quartz grains, dark-gray (5Y4/1 to N4) to dark-olive-gray (5Y5/2) to gray (N5).
132.7		--*SHARP CONTACT*--
161.5	28.8	Clayey SILT to SAND, fine to medium; ranges from very fine to granular, interbedded, laminated (0.25 to 1.0 mm) to thinly bedded (2.0 mm to 0.5 cm), horizontal to slightly inclined to crossbedded sand layers and numerous truncation surfaces; angular to rounded, well-sorted, quartz sand at top becomes coarser and more angular downward; organic matter scattered throughout ranges from finely disseminated to dark-reddish-brown wood chunks (up to 1.0 cm, which oxidizes immediately to black when exposed to air); little mica; few scattered rose quartz grains; dark-gray (5Y4/1 to 5YR4/1) to gray (5Y5/1); 153 ft to 156.2 ft becomes a light-gray (5Y7/1) to gray (5Y6/1) to light-gray (10YR7/2), loose pebbly(well rounded up to 2.5 cm), medium to very coarse sand; primarily clear and frosted quartz, angular to subrounded; few scattered rose to smoke quartz and chert; fair amount of iron-stained quartz grains, some scattered chlorite-stained; 2-5% heavy minerals; 156.2 ft to 161.5 ft becomes a GRAVEL, with pebbles, cobbles (>8cm), and clay rip-up clasts, with a wide variety of rock fragments, well-rounded to angular.
161.5		--*SHARP CONTACT*--
169.9	8.4	CLAY, silty, massive, with angular pebbles in clay at base (Note: pebbles could be a drilling artifact); dark-greenish-gray (5G4/1) to grayish-green (5G4/2) to dark-gray (5Y4/1) to dark-olive-gray (5Y3/2), with some light-olive-gray (5Y6/2) to olive-gray (5Y6/1) mottling.
169.9		--*SHARP CONTACT*--

Appendix III: *Lithologic summary for the Robins Point Corehole (JFC1)--Continued*

DEPTH TO BASE (feet)	THICKNESS (feet)	LITHOLOGY
177.2	7.3	SAND, medium, ranges from fine to very coarse, with a few scattered pebbles (0.5 to 0.75 cm); 2-5% heavy minerals; some mica; dark-gray (5Y4/1) to olive (5Y4/4) to light-gray (N7) to white (N9); 173.1 ft is a medium-gray (N5), clay-filled burrow or rip-up clast in a clayey, silty, fine to medium sand, with fair amount of organic material at the top; this sand coarsens down into olive-gray (5Y5/2) to grayish-brown (10YR5/2) coarses sand with the lowest 0.2 ft becoming a gravel, with pebbles (up to 3cm) angular to rounded (up to 3 cm); wide variety of rock fragments; abundant iron-stained quartz grains at contact (= very thin paleosol ?), contact possible burrowed or has 4.0 cm of relief.
177.2	---------------*SHARP CONTACT = Base of Pleistocene-------major unconformity*--------------------------------------	
181.8	4.6	Clayey SILT to silty clayey SAND to sand in a clayey silt matrix, interbedded, white to pinkish-gray; top 0.1 ft orange weathered paleosol (?); sand is primarily very fine to fine with a few medium grains; top 1.0 ft crossbedded (low angle ~10 degrees) marked with clayey (1 mm) drapes; burrowed (?); some mica; few black streaks are heavy mineral concentrations.
181.8.	---*SHARP CONTACT (0.1-ft relief)*--	
185.0	3.2	Clayey SILT to silty CLAY matrix, with a little very fine to fine sand, white to pale-light-gray.
194.0	9.0	SAND, medium, ranges from very fine to coarse, tan with some purple and yellow banding; lowest 2 ft crossbedded with 1 mm white clayey silt drapes.
194.0	--*SHARP CONTACT*--	
196.4	2.6	Clayey SILT to silty CLAY, white to pale-light-gray, with yellow and brown Lysagang banding, tight.
208.5	12.1	SAND to clayey SILT to silty, clayey SAND to sand in a clayey silt matrix, interbedded, white to light-gray, little yellowish-brown mottling; top 1.0 ft burrowed and (or) soft sediment deformation; overall coarsens downward, grading from very fine sand interbedded with clayey silt laminations (0.5 mm) to crossbedded (30 to 40 degrees) sand and clayey silt (up to 1.0 cm thick) to pale-brown to light-gray to pink, fine to medium sand, some mica (up to very coarse).
208.5	--*SHARP CONTACT*--	
210.5	2.0	Clayey SILT, laminated (0.5 to 1.0 mm) with a few interbeds of very fine to fine sand, white to light-gray with a little yellowish-brown mottling; paper-thin iron-cemented layer near top.
215.5	5.0	SAND, medium, ranges from fine to coarse, white to light-gray to yellowish-brown; top 2.0 ft interbedded with clayey silt laminations (0.5 mm); very coarse mica flakes scattered in the sands with banded heavy mineral layers.
215.5	---*SHARP CONTACT (0.1-ft relief)*--	
216.8	1.3	Silty CLAY, laminated (1.0 mm), white to light-gray.

Appendix III: *Lithologic summary for the Robins Point Corehole (JFC1)--Continued*

DEPTH TO BASE (feet)	THICKNESS (feet)	LITHOLOGY
223.7	6.9	SAND, medium, ranges from silt to very coarse, light-gray to white; a patch of yellowish-brown at 219.0 ft; 218.5 ft to 220 ft slightly inclined bedding with interbeds of thin (up to 0.5 cm) silty clay layers; coarsens downward to base becoming a coarse sand with silty clay rip-up clasts.
223.7	-------------------------*SHARP CONTACT*-------------------------	
224.2	0.5	SAND, fine, to sand in clayey silt matrix, to interbedded with clayey silt laminations (0.5 to 1.0 mm); some medium sand, light-gray to white.
234.0	9.8	SAND, fine to medium, coarsens downward to coarse, very coarse sand, light-gray to white; at 227.7 ft, clayey silt layer (1.0 cm) slightly inclined (5 degrees).
234.0	-------------------------*SHARP CONTACT*-------------------------	
235.0	1.0	SAND, fine, in a clayey SILT matrix, light-gray; ranges from very fine to medium sand.
238.4	4.4	SAND, medium, ranges from fine to coarse, light-gray, with abundant white to light-gray clay rip-up clasts (up to 5.0 cm).
239.9	1.5	CLAY- CLAST CONGLOMERATE, with a little coarse sand matrix, white to light-gray.
239.9	-------------------------*SHARP CONTACT*-------------------------	
241.0	1.1	Silty CLAY, laminated (0.5 to 5.0 mm), interbedded with very fine to fine sand; grades downward into sand in a silty clay matrix.
246.4	5.4	SAND, very fine to fine, with scattered clay rip-up clasts, white to light-gray; at 245 ft to 245.6 ft, there is a 45-degree angled, iron-oxide stained (yellow-brown), semi-cemented fracture; 245.6 to 246.4 ft grades to interbedded sand and silty clay.
246.4	-------------------------*SHARP CONTACT*-------------------------	
247.9	1.5	Silty CLAY, laminated (0.5 to 1.0 mm), white to light-gray with a little dark-brown mottling.
264.5	16.6	SAND, medium to coarse, light-gray to gray some iron-oxide yellow-brown banding, with scattered white to light-gray clay rip-up clasts (1.0 mm to 5.0 cm, angular); top 3.8 ft is gray, fine to coarse sand, with yellow-brown iron-oxides concentrated at the very top; 250.3 to 251.7 ft is semi-indurated sand with thin interbeds (0.5 to 1.0 mm); coarsens downward, becoming a medium to very coarse sand with large clay rip-up clasts at bottom 3.7 ft.
265.5	1.0	SAND in SILTY CLAY matrix, coarse to very coarse; ranges from medium to granular, white to yellow to light-gray, abundant (40 to 50%) iron-stained quartz grains.
272.8	7.3	SAND, medium to coarse, with scattered very coarse grains, interbedded with thin (0.5 to 1.0 cm) silty clay layers, some slightly inclined; 270.7 to 271.3 ft includes white clay rip-up clasts (up to 2 cm).
279.5	6.7	SAND and CLAY interbedded (4 cm to 0.5 ft); medium to coarse sand, white to gray to red and yellow.

Appendix III: *Lithologic summary for the Robins Point Corehole (JFC1)--Continued*

DEPTH TO BASE (feet)	THICKNESS (feet)	LITHOLOGY
281.5	2.0	CLAY CLAST CONGLOMERATE, white clay rip-up clasts (primarily < 3 cm, up to 4 cm) floating in a red to orange (oxidized), medium to granular sand, with a few scattered fine pebbles (1.0 cm); bottom 0.1 ft thin iron-cemented layer and clayey, silty, very fine to fine sand.
281.5		-------------------*SHARP CONTACT (1.5-cm relief)*-------------------
297.5	16.0	CLAY and SAND, interbedded (0.2 to 1.2 ft), slumped and soft-sediment deformation; ranges from dark-gray laminated silty clay (0.5 to 1.0 mm) to light-gray silty very fine to fine sand, with some black, lignitic material; various burrows.
300.9	3.4	CLAY to SAND in SILTY CLAY matrix, grades downward from olive-gray, lignitic-rich, laminated clay to light-gray, very fine to fine sand, floating in a silty clay matrix, with a few sand-filled burrows and (or) fractures (40- to 50-degree angle).
300.9		-------------------*SHARP CONTACT*-------------------
345.5	44.6	CLAY, PALEOSOL, interbedded with finely laminated (0.5 mm to 1.0 cm) intervals; multicolored (iron-oxides) red, orange, brown, yellow, purple, and light-gray to white, paleosol intervals are very cracked (rootlets, burrows, fractures) and have a very intensely weathered appearance with pedogenic characteristics, such as, abundant iron-rich glaebules (nodules and concretions) and pedotubules of various shapes; 310.0 to 313.5 ft includes numerous hard, granular concretions (?goethite, siderite, limonite, hematite?) and soft, granular amber concretions (gypsum?).
345.5		-------------------*GRADATIONAL CONTACT*-------------------
365.2	19.7	Silty CLAY and SAND, interbedded (0.5 mm to 4 cm), laminated gray to dark-gray silty clay to light crossbedded very fine to fine sand, with a few medium grains; some intervals with abundant black, lignitic material (including large fragments of wood); top 2.0 ft massive gray to olive-gray clay, with abundant light-gray sand-filled burrows; 360.5 to 361.5 ft includes oxidized red-brown clay-clast conglomerate; 363.4 to 364.4 ft includes some medium and a few coarse sand grains.
406.6	41.4	SAND, fine-grading downward to medium (392 ft) to coarse (395.0 ft), white to light-gray, interbedded, crossbedded and massive, with silty clay laminae (0.5 to 1.0 mm) and layers (1.0 cm); top 19 ft scattered to abundant black, lignitic material (including fragments of wood concentrated in crossbeds), white clay rip-up clasts (up to 3 cm) scattered from 382.0 to 392.0 ft, and (up to 4 cm) in the 399.2 to 399.8-ft interval; 401.4 to 402.1 ft includes slightly inclined, thin, silty clay laminae.
406.6		-------------------*SHARP CONTACT*-------------------
414.0	7.4	CLAY, dark to medium to light-gray, laminated to thinly bedded (1.0 to 3.0 mm), sand- and clay-filled burrows; grades downward to include interbeds of very fine to fine sand (1.0 mm to 0.1 ft); a few inclined.

Appendix III: *Lithologic summary for the Robins Point Corehole (JFC1)--Continued*

DEPTH TO BASE (feet)	THICKNESS (feet)	LITHOLOGY
422.2	8.2	SAND and CLAY interbedded, grades downward to a clay-clast conglomerate, light-gray to white very fine to fine sand, with some medium to coarse grains and abundant white clay rip-up clasts; some crossbedded laminated (0.5 to 1.0 mm) clay and sand.
438.3	16.1	SAND, fine to medium grades downward to medium coarse to pebbly (up to 1.5 cm), coarse to very coarse sand, light-gray to white; with red-brown (iron oxide) mottling at 433.2 to 433.7 ft; top 8.0 ft crossbedded, with white silty clay laminae (1.0 mm); lower 8.0 ft massive sand with clay rip-up clasts (up to 5.0 cm); lowest 0.3-ft clay-clast conglomerate in a clayey silt matrix.
438.3	-----------------------------------*SHARP CONTACT*--------*(= Base of Upper Patapsco = "Elk Neck Beds")*----------------	
495.6	57.3	CLAY, PALEOSOLS interbedded with laminated clays (0.5 to 1.0 mm), multicolored (iron-oxides) brown, red, olive-green, pink, purple, yellow, white, and light-gray; top 6.0 ft white with brown mottling; various intervals of scattered to abundant iron-rich glaebules (hard and soft granular concretions that crush by knife = ? gypsum or jarrosite ?).
504.7	9.1	SAND, fine, grades downward to medium to coarse sand, ranges from very fine to granules, pink-brown; lowest 1.0 ft contains light-gray, clay layers or ? clay rip-up clasts; bottom 0.2 ft is indurated sand.
504.7	--*SHARP CONTACT*--	
529.6	24.9	CLAY to clayey SILT to SAND, interbedded, very fine to fine, dark- to light-gray to pastel-lavender, laminated (0.5 to 1.0 mm) to thinly bedded (2.0 mm to 1cm); burrowed throughout; scattered black, lignitic material (large fragment of wood at 520.0 ft).
534.5	4.9	SAND, coarse to very coarse. ranges from medium to granules, with scattered pebbles (up to 1.0 cm) and light- to dark-gray clay rip-up clasts (up to cobble size).
534.5	------------------------------------*SHARP CONTACT (0.1-ft relief, ? burrowed)*---	
540.0	5.5	CLAY to sandy, clayey SILT, interbedded, dark- to light-gray to pastel-lavender; burrowed.
540.4	0.4	SAND, coarse to very coarse with pebbles (up to 1.0 cm), medium-gray; includes dark-gray clay rip-up clasts and black, lignitic wood fragments.
540.4	--*SHARP CONTACT (1.0-cm relief)*---------------------------------	
584.7	44.3	SAND and CLAY interbedded, white to dark- to light-gray to lavender; overall fining-upwards sequence, crossbedded, burrowed; lower 10.0 ft becomes medium to very coarse sand, with pebbles (up to 1.0 cm), black, lignitic fragments of wood and dark-gray, clay rip-up clasts (both to cobble size).
584.7	--*SHARP CONTACT (0.1-ft relief)*--	
594.7	10.0	CLAY, laminated (0.5 to 1.0 mm) and thin-layered (2.0 mm to 1.0 cm), wavy to convoluted to inclined angle, with a few black, lignitic fragments, burrowed; lower 5.0 ft interbedded with thin, light-gray, very fine sand layers and burrows.

Appendix III: *Lithologic summary for the Robins Point Corehole (JFC1)--Continued*

DEPTH TO BASE (feet)	THICKNESS (feet)	LITHOLOGY
604.8	10.1	SAND, coarse to very coarse, ranges from medium to granules, with pebbles (up to 1.0 cm) and few white to medium-gray clay rip-up clasts, scattered black, lignitic material throughout; wood fragments in lower 5 ft; some crossbedding; top 4.0 ft finer-grained sand interbedded with white to dark-gray, laminated to thinly bedded clay layers.
604.8		----------SHARP CONTACT (2.0-cm relief)----------
611.3	6.5	CLAY, to clayey silt, soft-sediment deformation, dark- to light-gray, abundant black, lignitic material (including wood fragments); ? burrowed.
620.3	9.0	Silty CLAY to clayey, silty sand, very fine, light-gray, burrowed; coarsens downward to primarily a very fine sand, grades into clay below.
624.5	4.,2	CLAY, laminated to massive, maroon to lavender to gray; burrowed.
633.8	9.3	CLAY, PALEOSOL, multicolored maroon, burgundy, light- to medium-gray, olive-gray, brown, interbedded with laminated intervals, burrowed and rootlets (cracks).
636.2	2.4	SAND, slumped and (or) faulted interval, 45-degree angle contacts at the top, and a conjugate set 1.0 ft below (this one includes a 0.5-cm clay ? gouge) separates light-brown (? white), well-sorted, fine sand from brown, medium to very coarse sand with pebbles (up to 1.5 cm) at base.
647.3	11.1	CLAY and SAND, very fine to fine, slumped and (or) faulted, soft-sediment deformation, dark- to light-gray to white to pastel lavender; large (cobble size) fragment of black lignitic wood at 638.2 ft; interbedded; burrowed ?.
647.3		----------SHARP CONTACT--------(= Base of Patapsco Formation)----------
665.7	18.4	CLAY, PALEOSOL, brick red to brown to some light-gray to yellow to pastel-lavender,marbled or beef-steak appearance.
671.2	5.5	Clayey, silty SAND, light-gray to white, fine sand; top 1.2-ft sandstone cemented concretions (cobble to boulder size); lowest 1.0 ft crossbedded.
671.2		----------SHARP CONTACT (0.1-ft relief)----------
742.2	71.0	CLAY, PALEOSOL, multicolored, intervals of abundant iron-rich glaebules (hard granular concretions-goethite, siderit limonite, and hematite ? and soft granular concretions (gypsum ?); grades down into the interbedded clay and sand unit below.
762.2	20.0	CLAY and SAND, interbedded laminated (0.5 to 1.0 mm) to thin (1.0 cm) beds, occasionally crossbedded clayey sand; sand grades upward from a fine (ranges from very fine to medium) to very fine sand, dark- to medium-to light-gray; scattered black, lignitic wood fragments; burrowed; base marked with abundant wood fragments and pyrite concretions.
767.4	5.2	CLAY and clayey, silty SAND, interbedded, laminated, white to light to medium-gray.
794.5	27.1	SAND, medium, ranges from fine to coarse, coarsens downward to coarse to very coarse pebbly (up to 3.0 cm) sand, crossbedded with clay rip-up clasts and black, lignitic wood fragments.

Appendix III: *Lithologic summary for the Robins Point Corehole (JFC1)--Continued*

DEPTH TO BASE (feet)	THICKNESS (feet)	LITHOLOGY
794.5		--*SHARP CONTACT (1.0-cm relief)*--
804.5	10.0	SAND, medium to coarse, ranges from fine to very coarse; top is finer grained and includes clayey silt laminae (0.5 to 1.0 mm); some clay rip-up clasts and scattered black, lignitic material.
888.6	84.1	SAND, overall fining-upward sequence; top 4.0 ft primarily a laminated clay, with silty, very fine burrows and (or) lenses; rest of section is crossbedded, with abundant mica (up to very coarse), clay rip-up clasts, and black,lignitic wood fragments; ranges from very fine sand to pebbles (primarily 1.0 cm, up to 1.5 cm, rough subangular to subrounded).
438.3		------------------------------------*SHARP CONTACT*---------*Base of Cretaceous = major unconformity*---
961.0	72.4	BASEMENT-weathered rock and saprolite, consisting of metamorphosed, predominantly mafic igneous complex with crosscutting dikes and faults, with the very bottom being a weathered metadiorite (?). This interval can be divided into three units which are, in ascending order: 12.4 ft of highly weathered metadiorite(?) 36.6 ft of highly weathered-rock saprolite, and 23.4 ft of clayey saprolite.