Test Well DO–CE 88 at Cambridge, Dorchester County, Maryland

By HENRY TRAPP, JR., LEROY L. KNOBEL, HAROLD MEISLER, and P. PATRICK LEAHY

A summary of information derived from a test well drilled to basement on the Delmarva Peninsula, Atlantic Coastal Plain

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Test Well DO-CE 88 at Cambridge, Dorchester County, Maryland

By Henry Trapp, Jr., LeRoy L. Knobel, Harold Meisler, *and* P. Patrick Leahy

Abstract

Test well DO-CE 88 at Cambridge, Maryland, penetrated 3,299 feet of unconsolidated Quaternary, Tertiary and Cretaceous sediments and bottomed in quartz-monzonite gneiss. The well was drilled to provide data for a study of the aquifer system of the northern Atlantic Coastal Plain. Twenty-one core samples were collected. Six sand zones were tested for aquifer properties and sampled for ground-water chemistry. Point-water heads were measured at seven depths. Environmental heads (which ranged from −18.33 to +44.16 feet relative to sea level) indicate an upward component of flow. A temperature log showed a maximum temperature of 41.9 degrees Celsius and a mean temperature gradient of 0.00838 degrees Celsius per foot.

The water analyses delineated the freshwater-saltwater transition zone between 2,650 and 3,100 feet. The ground water changes progressively downward from a sodium bicarbonate to a sodium chloride character. Clays in the analyzed core samples belong to the montmorillonite and kaolinite groups, and mean cation exchange capacity ranged from 8.3 to 38.9 milliequivalents per 100 grams.

Vertical and horizontal hydraulic conductivities measured in cores ranged from 1.5×10^{-6} to 1.3 feet per day and from 7.3×10^{-6} to 1.3 feet per day, respectively, but the most permeable sands were not cored. Porosity was 1.5 percent in the quartz monzonite bedrock and ranged from 22.4 to 41 percent in the overlying sediments. Transmissivities from aquifer tests ranged from 25 to 850 feet squared per day; horizontal hydraulic conductivities ranged from 2.5 to 85 feet squared per day, and intrinsic permeabilities ranged from 0.8 to 23 micrometers squared.

Fossils identified in core samples include palynomorphs, dinoflagellates, and foraminifers.

INTRODUCTION

Purpose and Scope

The U.S. Geological Survey has begun a comprehensive study to define the geology, hydrology, and geochemistry of the northern Atlantic Coastal Plain aquifer system. As part of this study, a test well was drilled to basement near Cambridge, Md., to meet the following objectives:

1. To determine the chemical character of the ground water and the position of the freshwater-saltwater transition zone at a location where control was needed for regional definition.
2. To determine the lithology, stratigraphy, and thickness of the Coastal-Plain sediments and to define the aquifers and confining beds.
3. To obtain quantitative data on aquifer and confining-bed hydraulic properties and on hydraulic heads.
4. To determine the capacity of the clays in the sedimentary section to exchange ions with the ground water.
5. To discover the nature of the basement rock.

Geographic and Geologic Setting

Test well DO-CE 88 is located near Cambridge, Dorchester County, Md., on the Delmarva Peninsula (fig. 1). It was drilled on the south bank of the Choptank River, on the grounds of the Eastern Shore Hospital Center, at latitude 38°34′01″ N., longitude 76°03′20″ W.

The Northern Atlantic Coastal Plain study area extends from New York through North Carolina and offshore to the Continental Slope. The Coastal Plain sediments form a wedge that thickens onshore from a feather edge at the Fall Line to 8,000 ft along the coast of Maryland and 10,000 ft in North Carolina. The beds dip gently seaward. The sediments are both marine and nonmarine in origin and range in age from Jurassic to Holocene. They consist largely of sand, silt, and clay and are unconsolidated except for thin cemented layers and the more deeply buried sediments. The marine sediments include significant amounts of glauconite, shell material, calcareous clay, and limestone.

Acknowledgments

The authors acknowledge Harry J. Hansen of the Maryland Geological Survey for assistance in obtaining permission to drill, preparing contract specifications, and interpreting data. Jonathan Edwards, Jr., of the

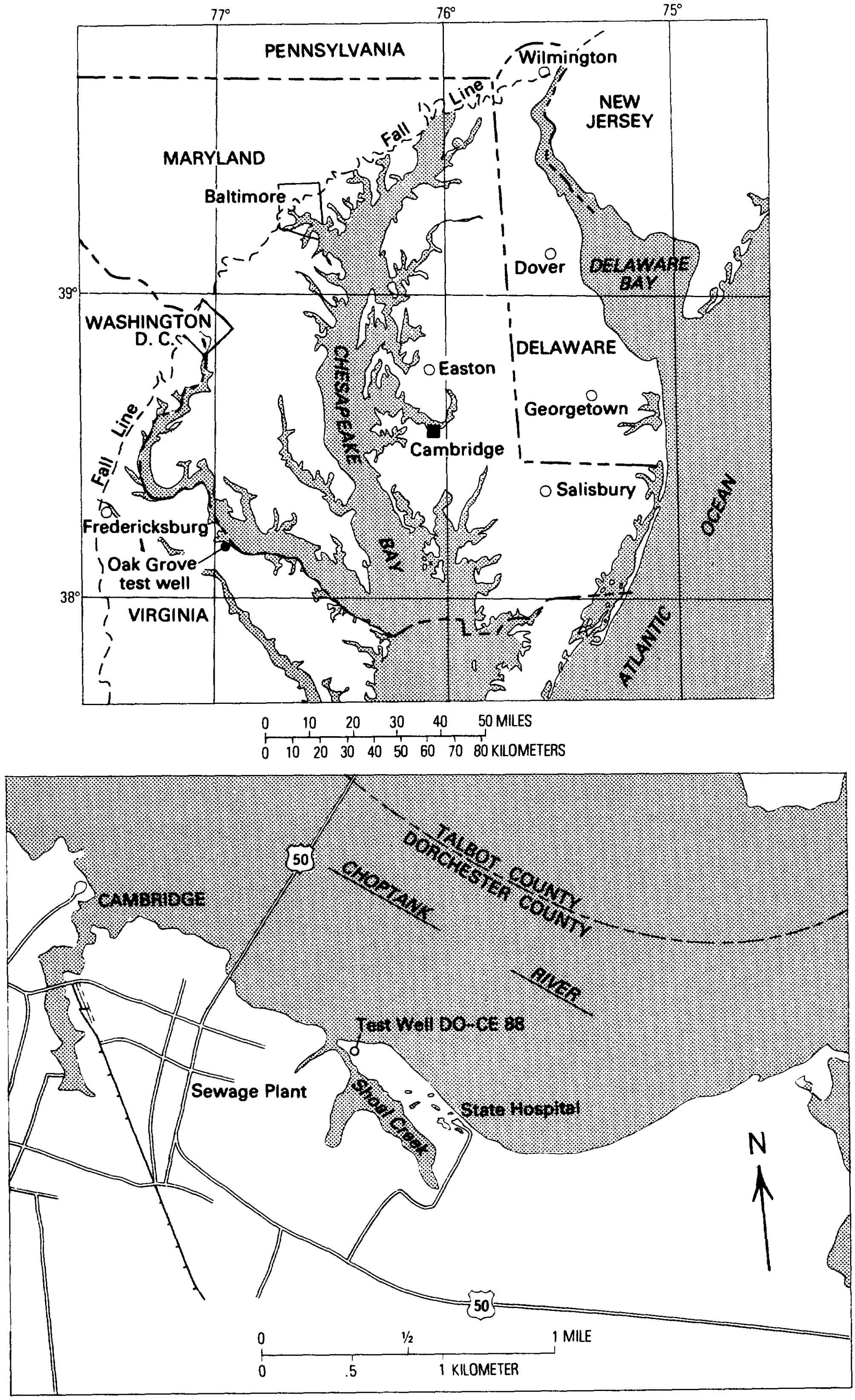


Figure 1. Location of U.S. Geological Survey test well DO–CE 88.

Maryland Geological Survey, described the petrology of the basement cores. Lowell Douglas and Pa Ho Hsu of Cook College, Rutgers University, provided laboratory space, X-ray equipment, and technical assistance for determination of clay mineralogy. Gilbert J. Brenner, State University of New York at New Paltz, identified fossil pollen in core samples and assigned them to pollen-time zonations. William H. Abbott, of Mobil Exploration and Producing Services, identified diatoms in the Tertiary cores and assigned them to time zones. Richard K. Olsson, Rutgers University, identified foraminifers in cores and assigned ages and paleoenvironments. Wilson S. McClung, Virginia Polytechnic Institute and State University, ran a temperature log of the well. Dr. H. M. English, superintendent of the Eastern Shore Hospital Center, granted permission to use the hospital grounds. David Leap, assistant superintendent, allowed access to the drill site, and Rodney Hurley, maintenance supervisor, provided logistical support. Lois Lane, of the University of Maryland, Environmental and Estuarine Studies, provided analytical support during water-sample collection. Lucy McCartan, U.S. Geological Survey, arranged for micropaleontologic studies of the cores and made helpful suggestions on presentation of the data. James P. Owens, U.S. Geological Survey, identified minerals in sedimentary-rock cores. Richard Z. Poore, U.S. Geological Survey, dated cores using planktonic foraminifers, and Lucy Edwards, U.S. Geological Survey, did the same by means of dinoflagellates. Frank T. Manheim, U.S. Geological Survey, provided core-squeezing equipment and consultation on sampling techniques. Candice M. Lane, U.S. Geological Survey, determined the water content and its chloride concentration for the bedrock core. J. Glen Blevins, U.S. Geological Survey, retired, coordinated drilling, coring, well-construction, and testing activities at the drill site. The authors wish to acknowledge the contributions of the following U.S. Geological Survey personnel for assisting during the drilling and testing phases of the operation: William B. Fleck, Franceska Wilde-Katz, Don A. Vroblesky, Daniel J. Phelan, Rene DeLisle, and Andrew A. Meng.

WELL CONSTRUCTION

Drilling and Casing Procedures

The Layne-Atlantic Company,[1] Norfolk, Va., drilled the test well by means of the hydraulic-rotary method. Datum for the well was established as the kelly bushing (KB), 5 ft above land surface, or 9.42 ft above sea level. The bottom of the 12-in. diameter surface casing was set and grouted at 108 ft below the datum. Soft-formation 8¾-in. drill bits, with provision for wire-line coring, were used from the base of the surface casing to the total depth of 3,337 ft. Commercially prepared mud, mixed with freshwater, was used in the drilling. Cuttings samples were collected at 10-ft intervals. Wire-line cores, up to 10 ft in length but usually shorter, were cut at intervals specified by the Survey's representative. Downhole rather than sidewall cores were specified in order to minimize contamination of the core samples by drilling mud. The contractor found it expedient to core, rather than drill, in bedrock (quartz monzonite gneiss), which was encountered at 3,304 ft. Geophysical logs were run at the total depth of 3,337 ft.

The well was plugged with cement from the total depth to 3,250 ft. Four-inch steel casing was set to 3,178 ft and pressure-grouted. A 4-in. telescope-size stainless-steel screen having a 0.015-in. slot was emplaced between 3,188 and 3,218 ft; blank pipe extended upward into the 4-in. casing.

[1]The use of brand or company names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Development

The well was developed by airlift for about 12 hours. An electric submersible pump was used for the aquifer test and sampling of the 3,188- to 3,218-ft zone.

Upon completion of testing and sampling of the 3,188- to 3,218-ft zone, the drill rig was replaced by a light workover rig, capable only of hoisting and lowering, for the redevelopment and testing phase.

Plugback, Perforation, and Redevelopment

The well was plugged back and the casing jet-perforated eight times in order to obtain heads, specific capacities, and water-quality data from successively shallower sand zones. These eight intervals were selected largely in the freshwater-saltwater zone of transition as well as in the deeper freshwater-bearing zones, using geophysical logs to indicate the sections having the highest effective porosity. The intended procedure was:

1. Seal off the previously developed zone and backfill to just below the next zone with sand, gravel, and cement.
2. After the cement is set, pressure-test for leaks. If a leak is indicated, reseal by dropping cement-filled bottles down the well, breaking the bottles, and tamping them with a pipe. Allow cement to set, retest, and repeat if necessary.
3. Sound top of new plug with Survey logging unit and run gamma-ray log a short section through the casing, including the prospective new zone to be per-

forated. Correlate the new section of gamma-ray log with the Schlumberger geophysical logs and adjust the interval to the Survey logger's measurements as required.
4. Jet-perforate the interval using the Survey logger. (Gearhart Industries, Inc., materials and methods were used.)
5. Set a 4-in., telescope-size, stainless-steel screen (10 ft long) inside the casing opposite the perforations by means of the rig. A tailpipe, equal in length to the interval between the base of the perforations and the top of the plug, is attached to the bottom of the screen in order to position it.
6. Redevelop the well using an air compressor, conduct an aquifer test, and collect a water sample.
7. Repeat steps 1–6 as required.

Recompletion proceeded with difficulty. Plugs frequently leaked and had to be resealed. The perforating charges appear to have torn large holes in the casing at least once, as evidenced by chunks of carbonized wood, up to 1¼ in. in diameter, blown out of the well during redevelopment by compressed air. Attempts to set screens opposite perforations were unsuccessful, either because the perforating process roughened or deformed the inside surface of the casing or because mud and aquifer material entered the casing through the perforations, impeding emplacement of the screens. The rig used during redevelopment was incapable of cleaning out or deburring the inside of the casing after perforation.

Five of the eight perforated zones listed in table 1 were developed to the point where a water sample was collected and the head measured.

HYDROGEOLOGY

A summary of the stratigraphy at the well site is shown in table 2.

Drill Cuttings

Samples of drill cuttings were collected at 10-ft depth intervals from the ditch leading from the conductor pipe on the well to the mud pits, without correction for sample lag.

Geophysical Logs

The Survey ran gamma-ray and multipoint electric logs at a drilling depth of 2,900 ft. These logs (not shown) were used in the preliminary definition of lithologic units. The spontaneous-potential log was especially useful for preliminary calculations of formation-water resistivity. These calculations, together with chloride measurements on water squeezed from cores, served as guides for the selection of zones to be perforated and sampled. The water resistivities calculated from this spontaneous-potential log correlate well with the freshwater-saltwater interface profile established through chloride determinations of water samples.

Schlumberger Limited ran dual-induction, gamma-ray, spontaneous-potential, caliper, compensated neutron-formation density, and sonic logs to total depth (figs. 2–4). These logs were useful for the delineation of lithologic units and provide a continuous record of porosity values.

Table 1. Summary of recompletion attempts

Perforated interval (ft below KB[1])	Date perforated (1981)	Plugback depth (ft below KB)	Shots	Screen (ft below KB)	Remarks
2,834 -2,844	Mar. 18	2,939	40	None	Flowed.
2,649 -2,655.6	Apr. 14	2,667	26	None	Flowed.
2,278.4–2,288.4	May 26	About 2,325	41	None	Flowed.
2,008.4–2,018.4	June 10	About 2,055	41	Abandoned, placement not checked with logger	Could not be developed.
1,822.4–1,832.4	June 16	About 1,865	42	None	Pumped turbid water.
1,605.4–1,615.4	July 7	About 1,655	42	About 1,515–1,525 (0.010 slot) recovered	Could not be developed; screen set too high.
1,469.4–1,479.4	July 21	About 1,520	21	About 1,456–1,466 (0.010 slot) abandoned	Could not be developed; screen set too high.
1,422.4–1,432.4	July 28	1,460	24	None	Pumped turbid water.

[1]KB = kelly bushing, which was 5 ft above land surface or 9.42 ft above sea level.

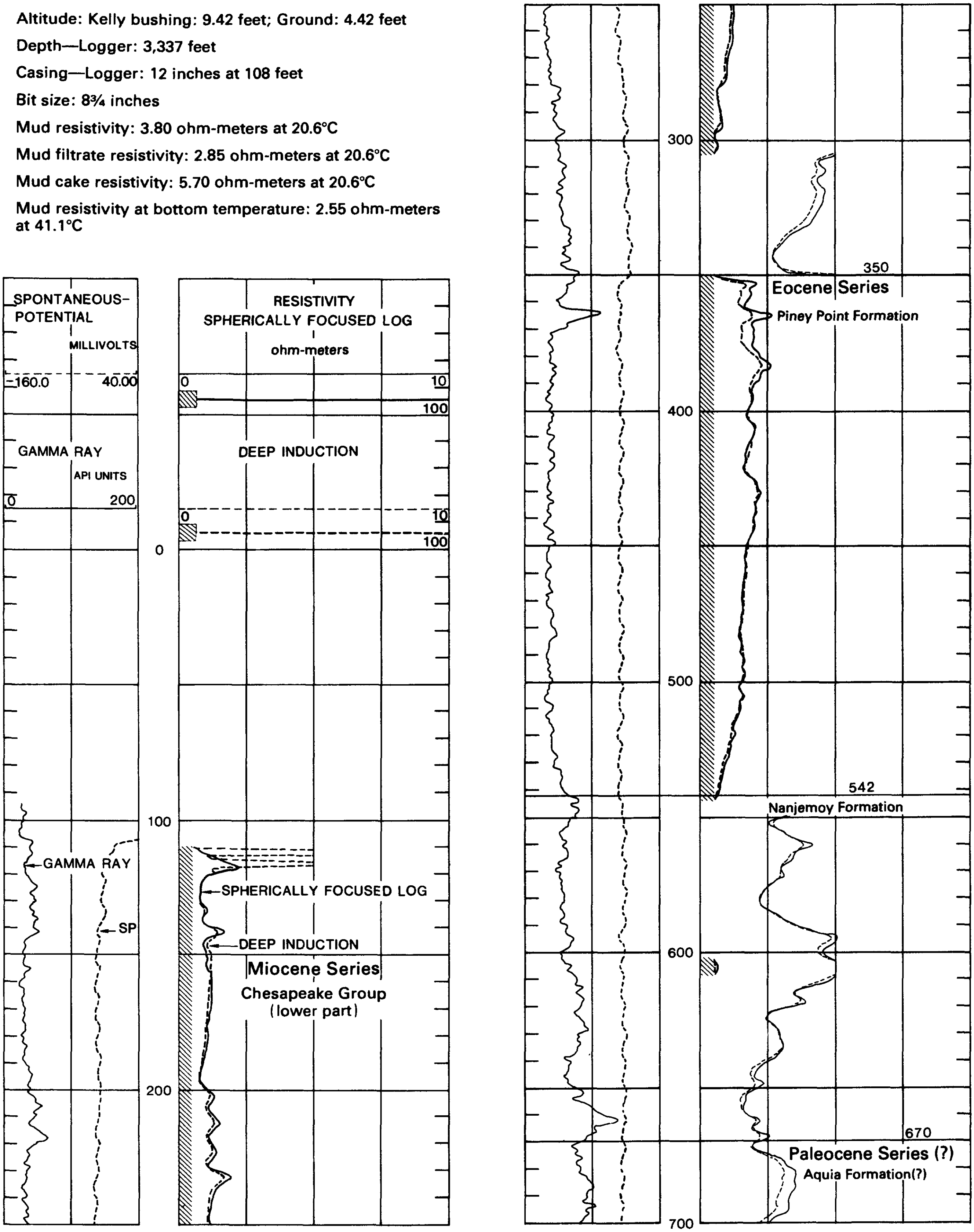


Figure 2. Dual induction with spontaneous potential and gamma-ray logs, screened and perforated zones, and formation tops.

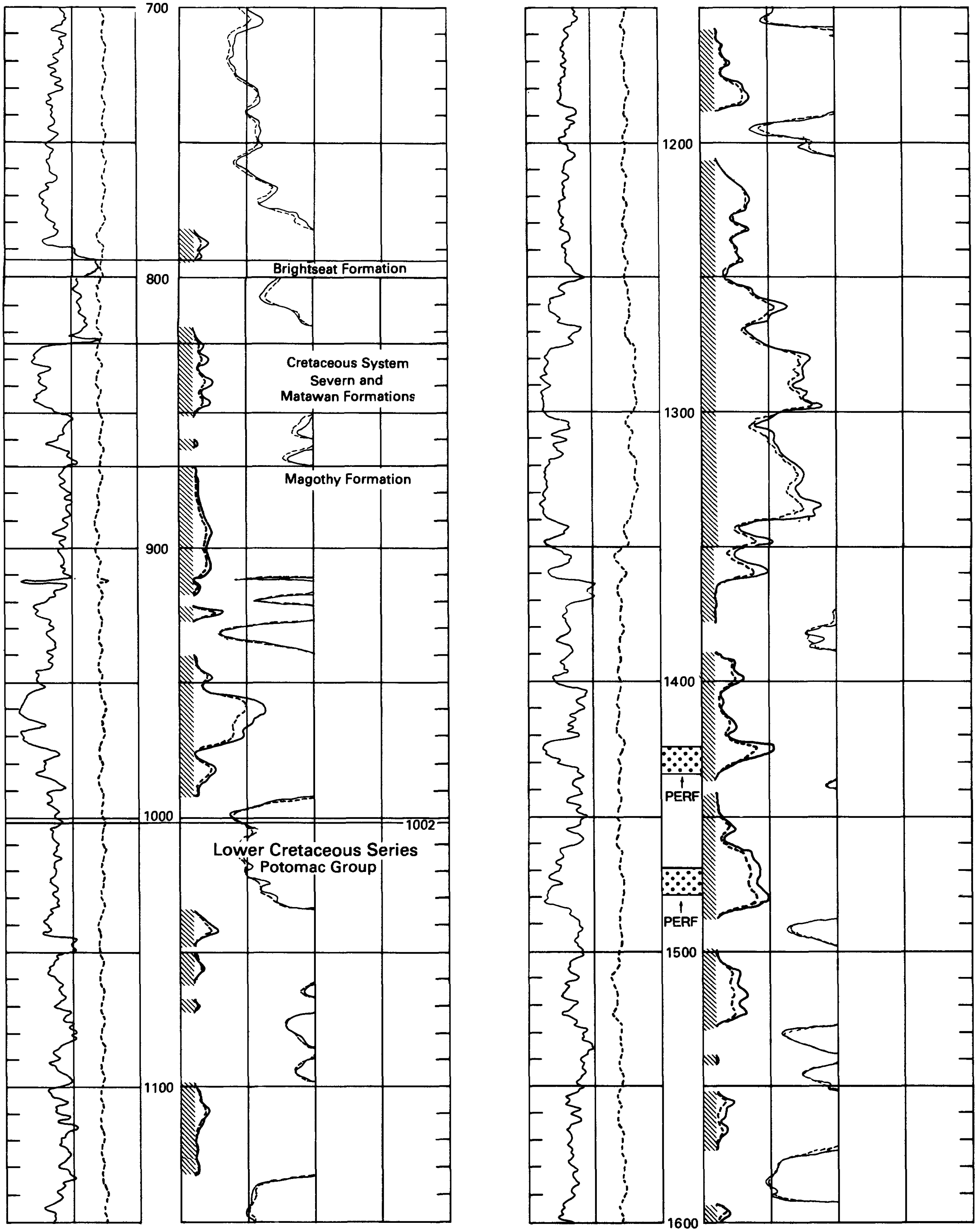
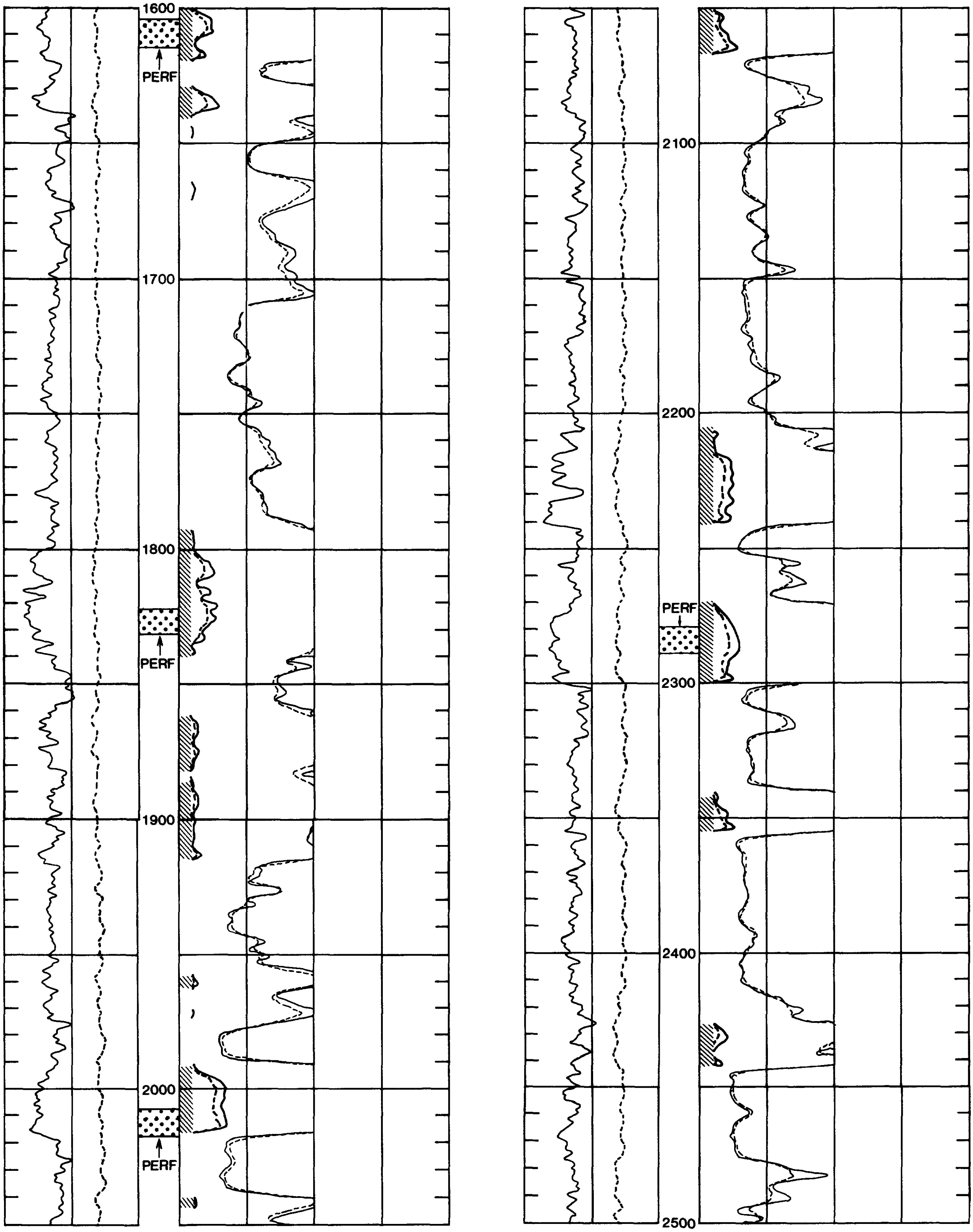


Figure 2. Dual induction with spontaneous potential and gamma-ray logs, screened and perforated zones, and formation tops—Continued.



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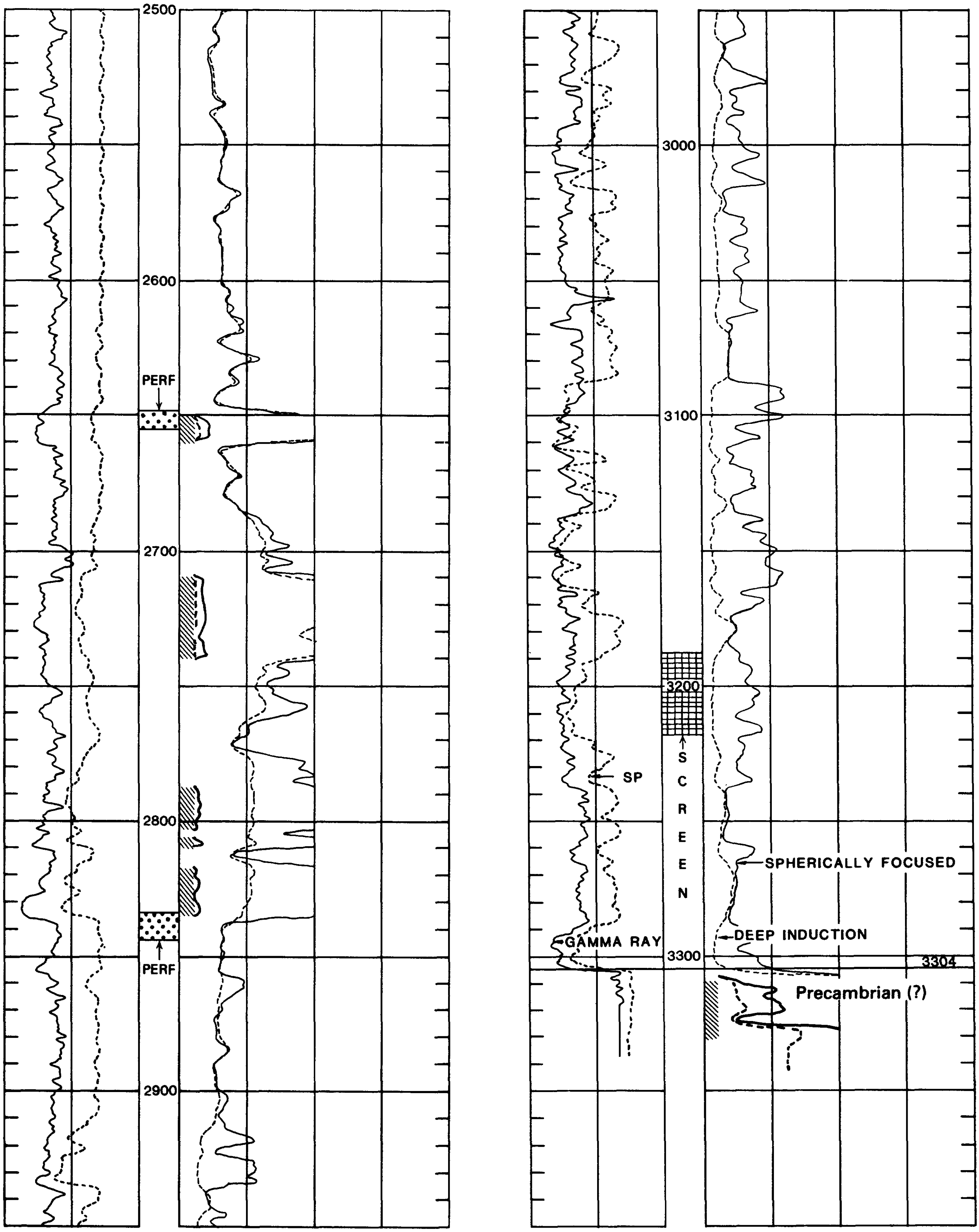


Figure 2. Dual induction with spontaneous potential and gamma-ray logs, screened and perforated zones, and formation tops—Continued.

Altitude: Kelly bushing: 9.42 feet; Ground: 4.42 feet

Depth—Logger: 3,337 feet

Casing—Logger: 12 inches at 108 feet

Bit size: 8¾ inches

Mud resistivity: 3.80 ohm-meters at 20.6°C

Mud filtrate resistivity: 2.85 ohm-meters at 20.6°C

Mud cake resistivity: 5.70 ohm-meters at 20.6°C

Mud resistivity at bottom temperature: 2.55 ohm-meters at 41.1°C

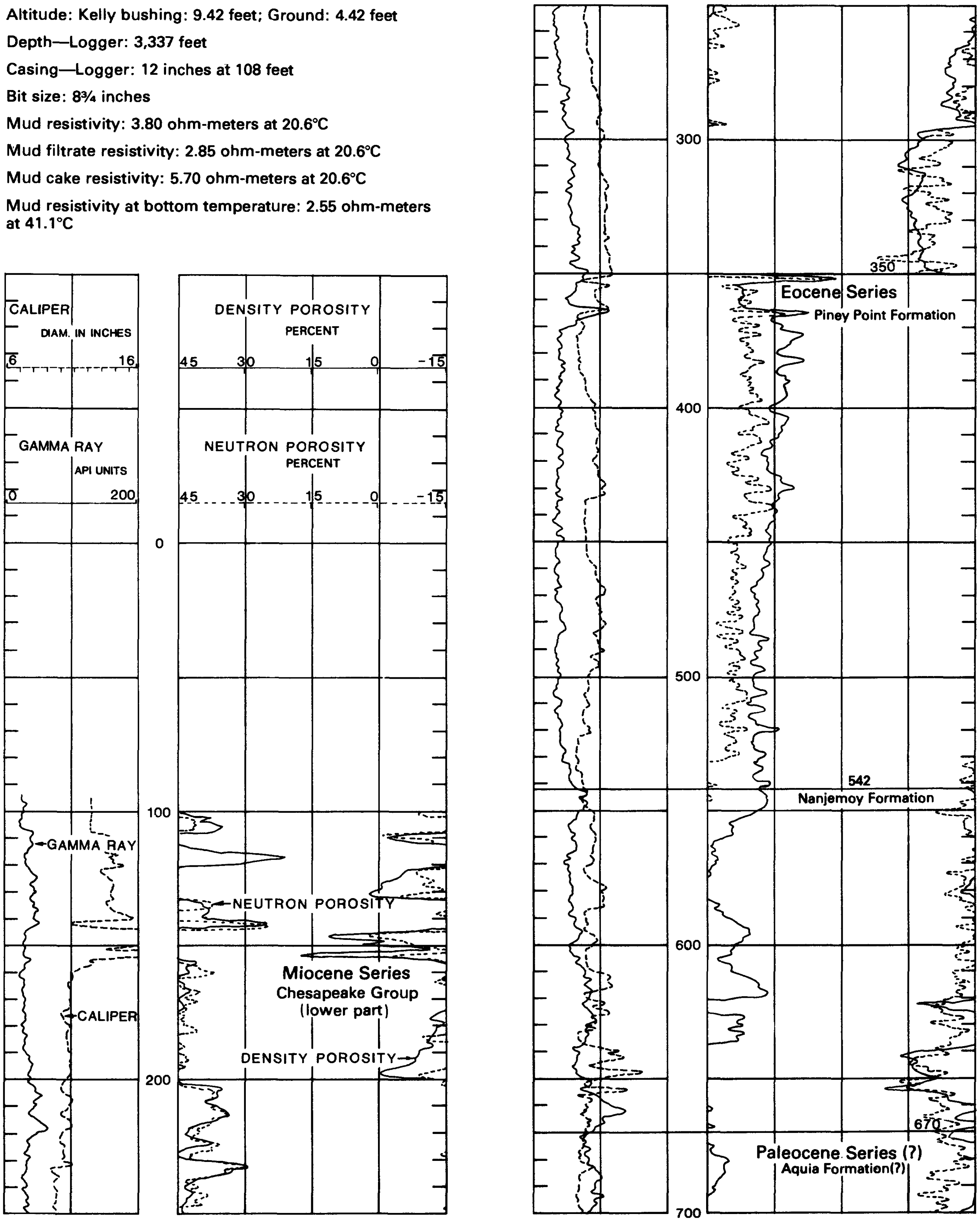
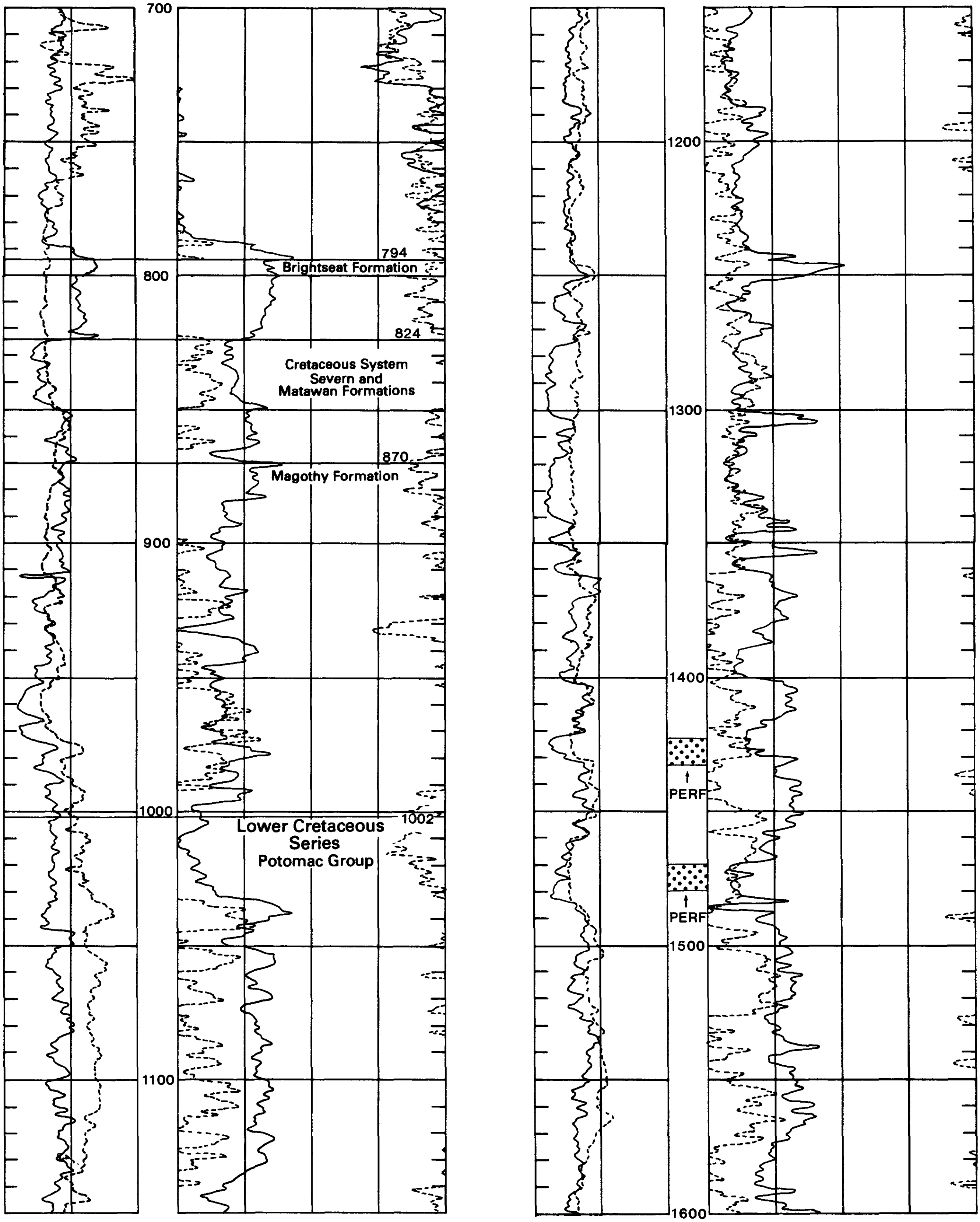


Figure 3. Simultaneous compensated neutron-formation density (expressed as porosity), with gamma-ray and caliper logs, screened and perforated zones, and formation tops.



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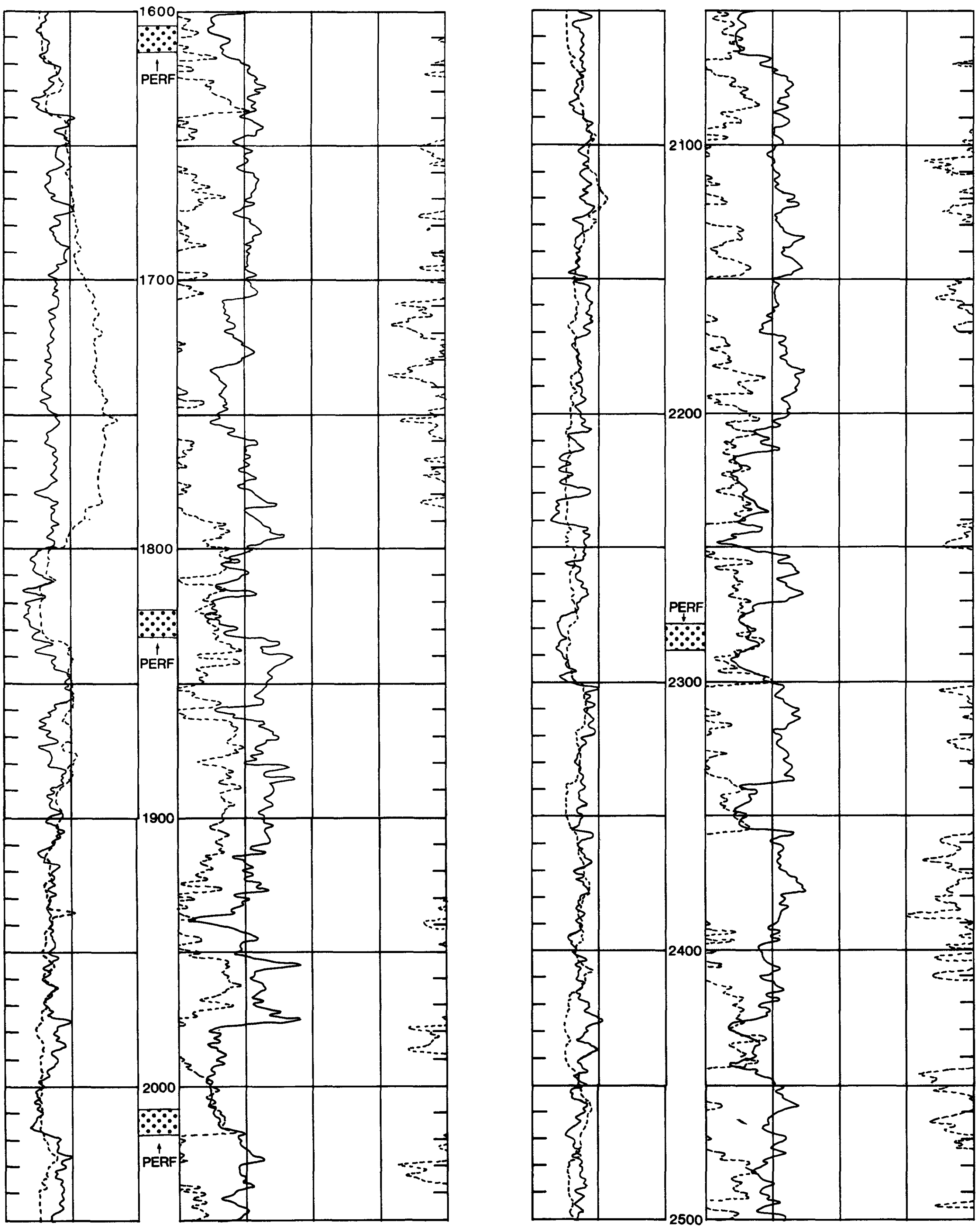

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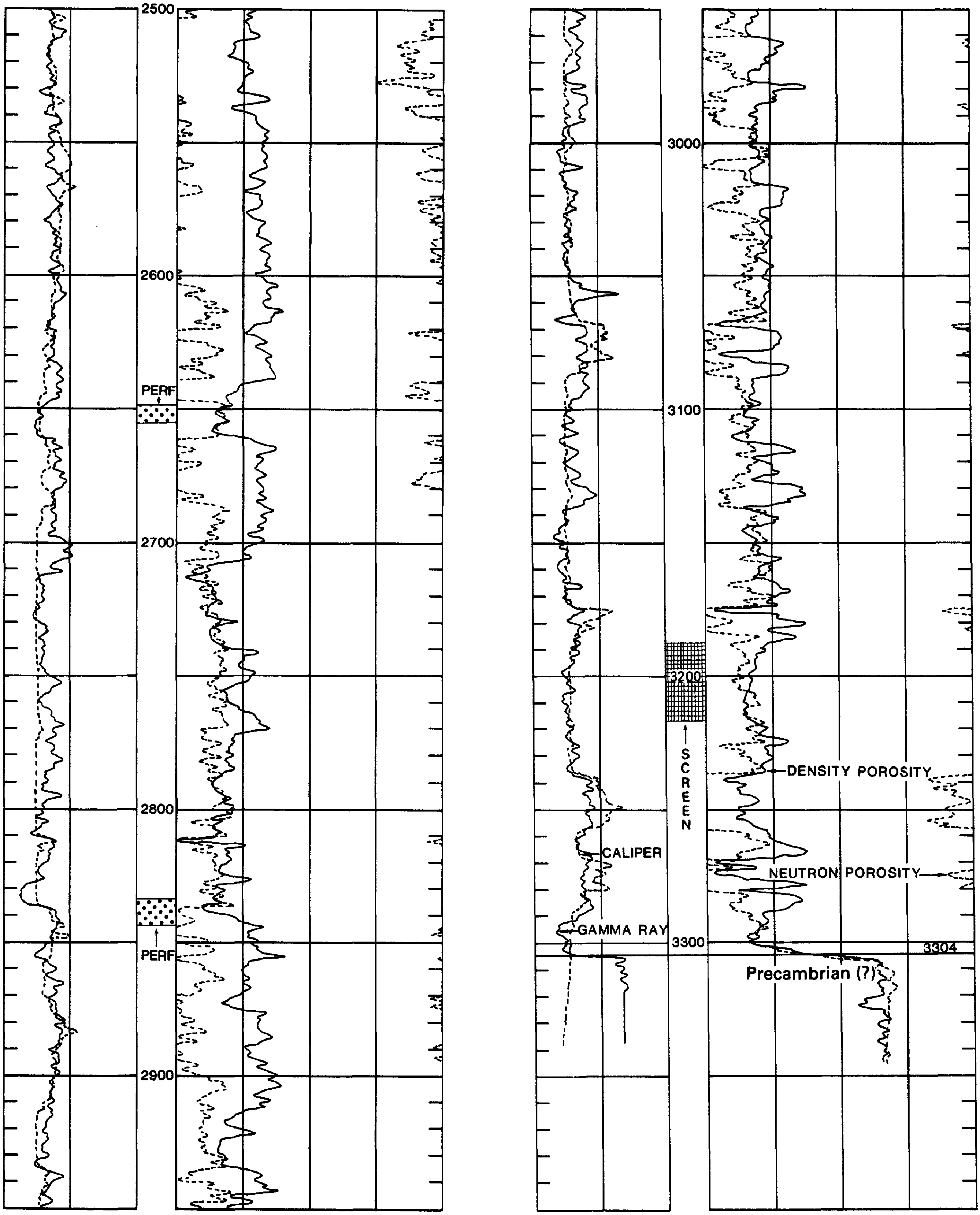

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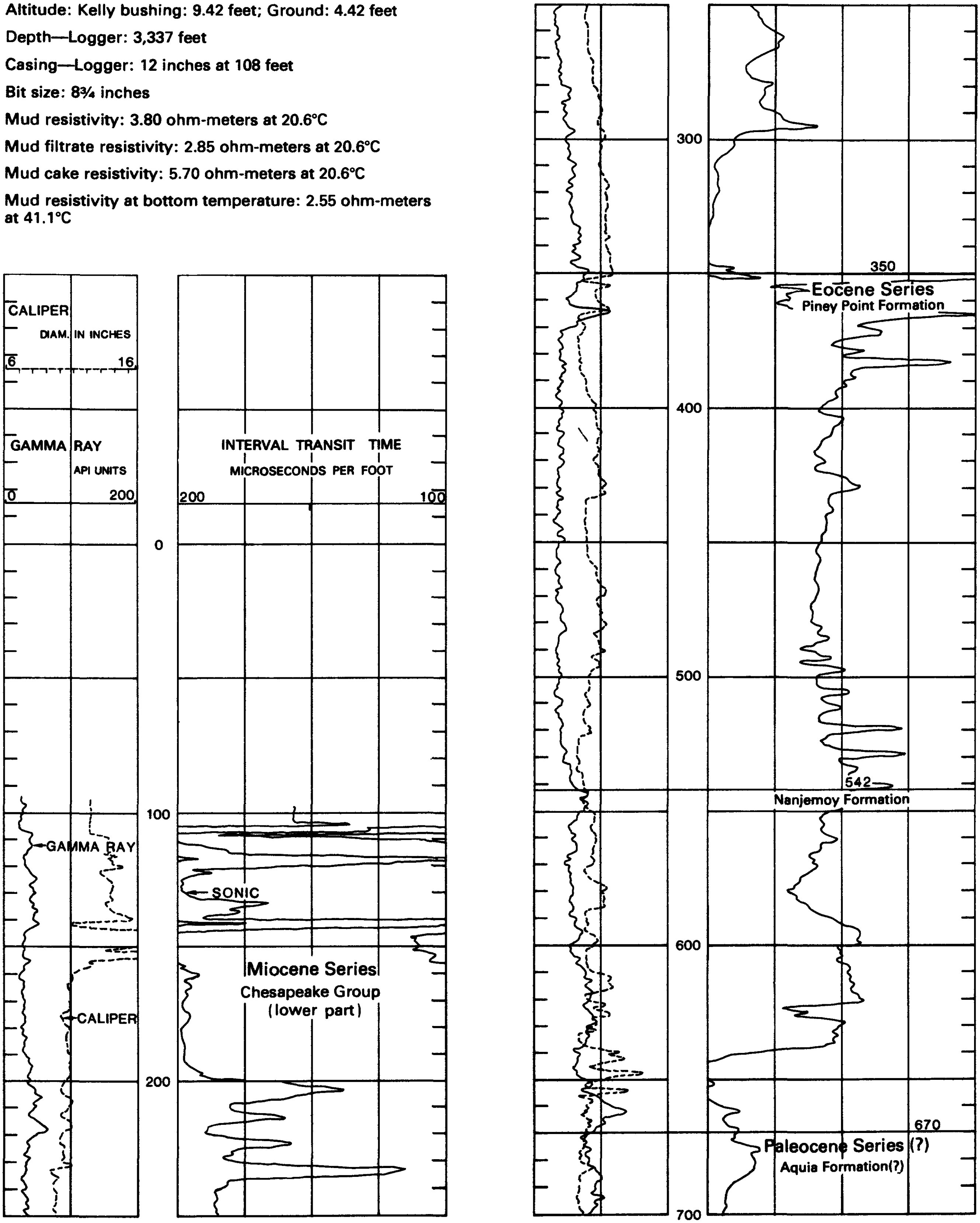


Figure 4. Borehole-compensated sonic log, with gamma-ray and caliper logs, screened and perforated zones, and formation tops.

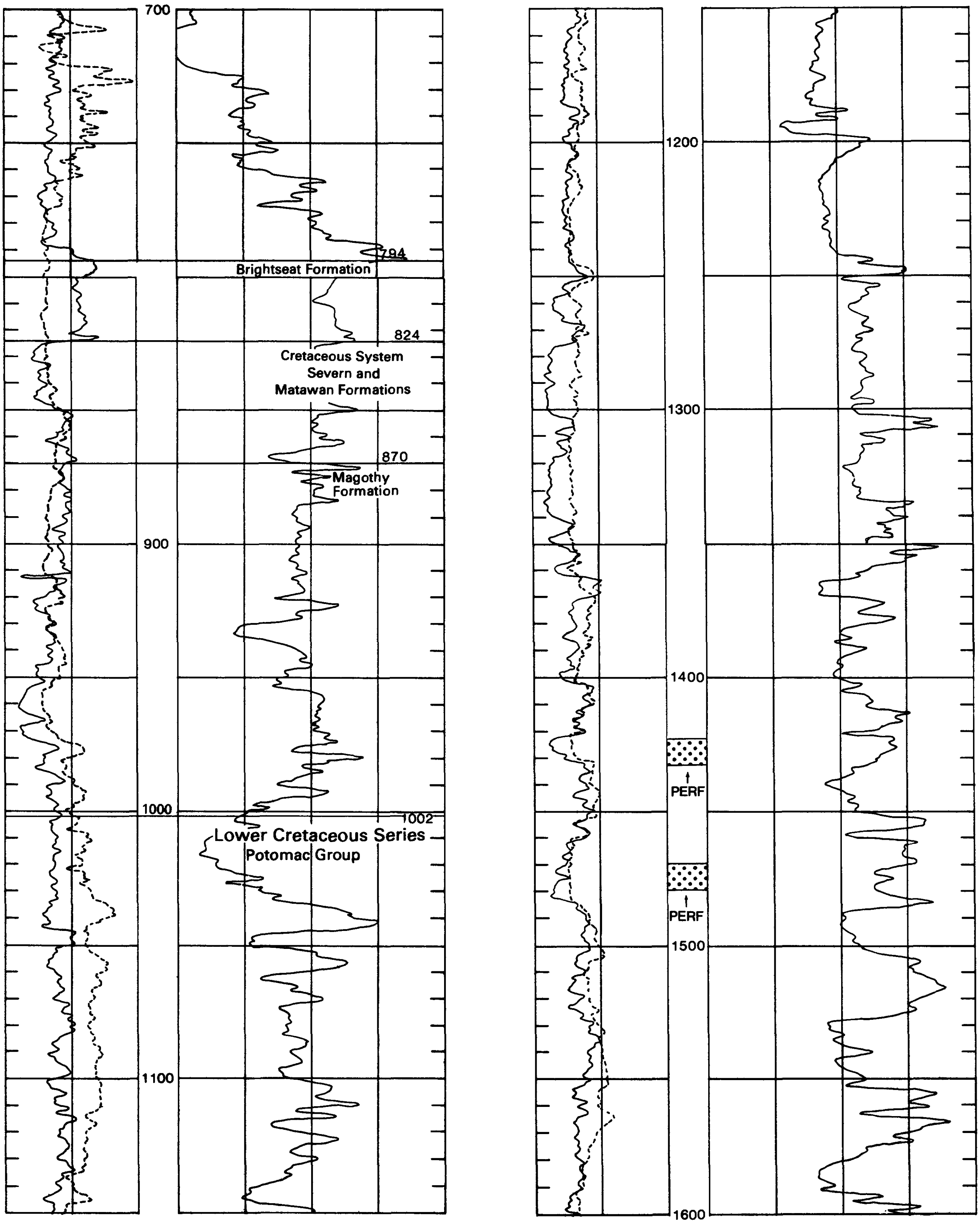
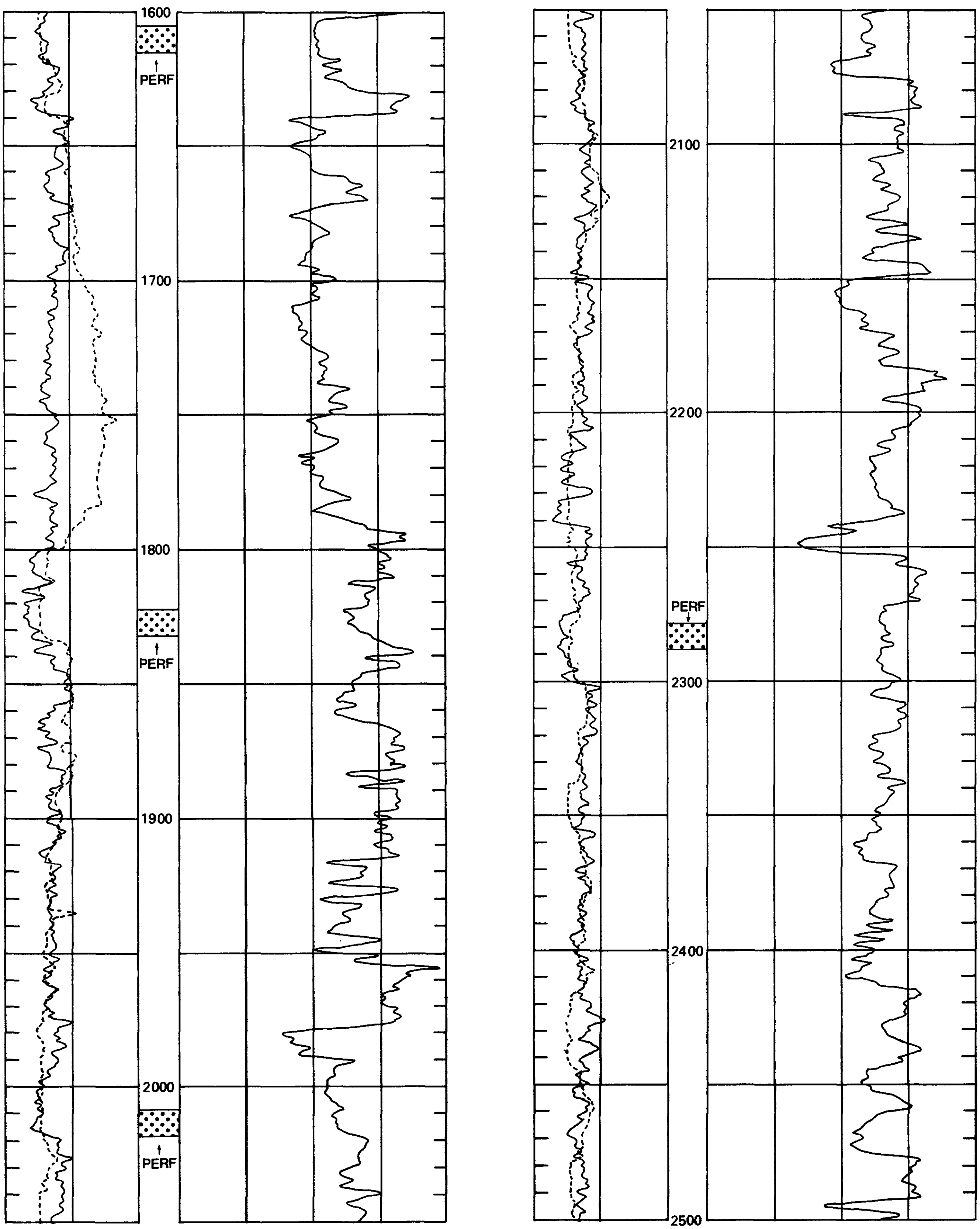


Figure 4. Borehole-compensated sonic log, with gamma-ray and caliper logs, screened and perforated zones, and formation tops—Continued.



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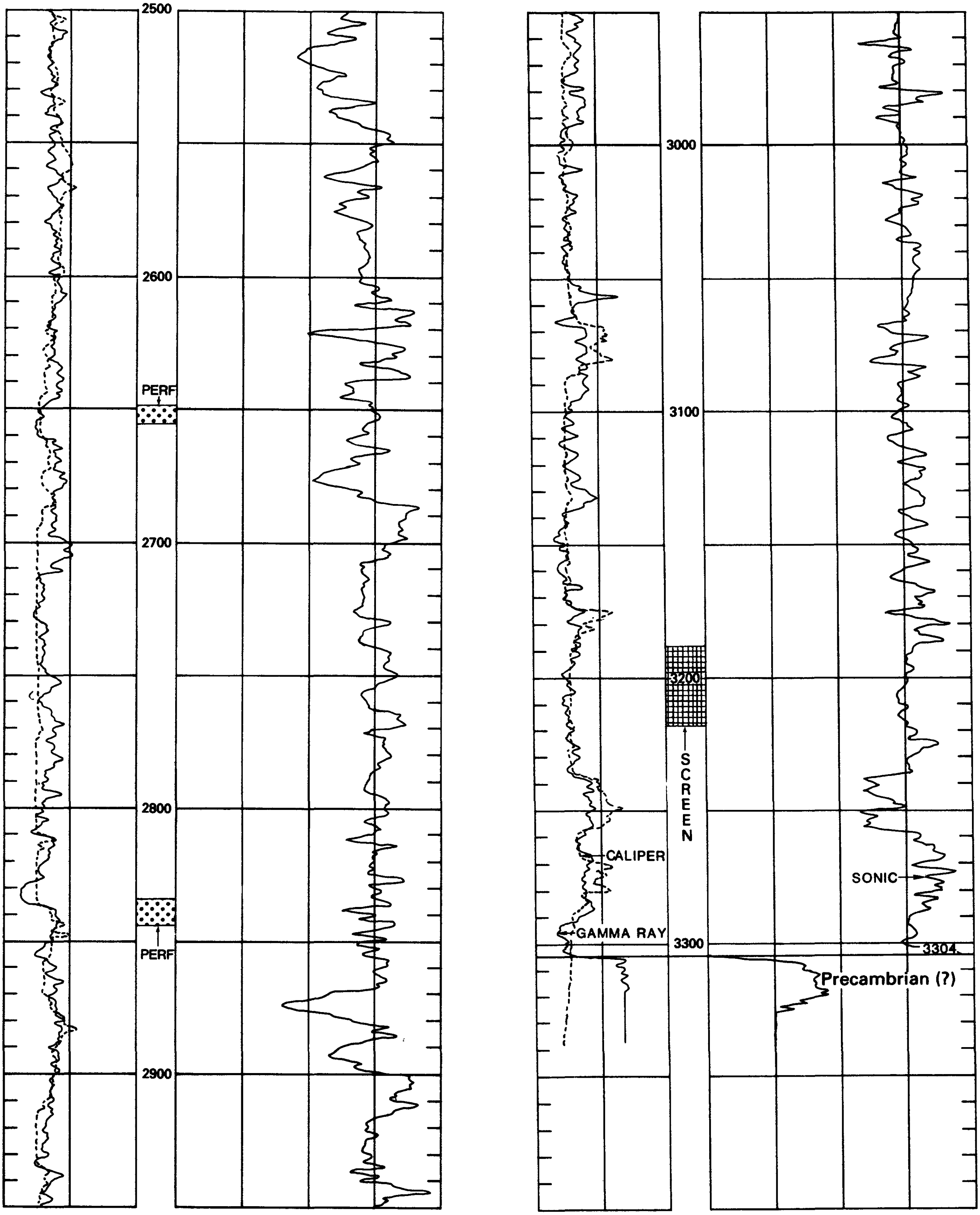

Figure 4. Borehole-compensated sonic log, with gamma-ray and caliper logs, screened and perforated zones, and formation tops—Continued.

Table 2. Stratigraphy at test well DO–CE 88

System	Series	Group or formation	Lithology	Thickness (ft)
Quaternary(?)	Pleistocene(?)		Sandy clay and brown quartz sand.	48
Tertiary	Miocene	Chesapeake Group (lower part)	Pale brown, very fine to medium quartz sand with shell fragments. Silty clay and gray silt.	297
	Eocene	Piney Point Formation	Brown, very fine to coarse, glauconitic quartz sand.	192
		Nanjemoy Formation	Very fine to medium glauconitic quartz sand. Gray, glauconitic silty clay. Grayish-green glauconitic silt.	128
	Paleocene	Aquia Formation	Greenish-black and brown glauconitic sand. Gray, silty, glauconitic, calcareous clay. Greenish-gray glauconitic silt.	124
		Brightseat Formation	Greenish-gray silty clay and greenish-black, fine glauconitic sand.	30
Cretaceous	Upper Cretaceous	Severn and Matawan Formations, undifferentiated	Fine to very coarse glauconitic and clayey sand.	46
		Magothy Formation	Very fine to very coarse glauconitic quartz clayey sand.	132
	Lower Cretaceous	Potomac Group, undifferentiated	Alternating layers of very fine to very coarse quartz sand, gray, brown, and green silt, and gray and brown silty and sandy clay.	2,302
Precambrian(?)		Basement complex	Quartz monzonite gneiss.	

The upper part of the compensated (for hole diameter) neutron-formation density log (fig. 3) reads porosity directly from both the neutron and the density readings. However, both porosity logs are based on the assumption that the matrix is predominantly limestone rather than sand and clay, as is actually the case. The porosity values based on formation density are higher than if the conversion to porosity had been based on the assumption of a sand matrix, and those based on neutron logging are lower. These effects can be adjusted for using methods given by Schlumberger Limited (1972, p. 45–47; 1977, p. 16–17). Porosity values derived from the neutron log are close to true effective porosity, after adjustment, for clean sand formations, but are too high where clay is present.

Formation-water resistivities calculated from the Schlumberger spontaneous-potential log and the reported mud-filtrate resistivity of 2.85 ohm-meters at 20.6°C were unrealistically low. The mud sample measured by Schlumberger was probably not representative of the mud in the hole. The resistivity of the mud filtrate at the time of the Survey's electric log to 2,900 ft was 9.05 ohm-meters at 20.6°C (calculated from specific conductance). Dilution of the drilling mud by salty formation water while the last 400 ft were being drilled might have lowered its resistivity; however, more reasonable water resistivities were calculated from the Schlumberger log using 9.05 ohm-meters. Formation-water resistivities calculated from the Schlumberger deep-induction log, using formation factors estimated by various methods, were in closer agreement with measured resistivities than were those calculated from the spontaneous-potential log, but are not reported here because adequate water-quality data were obtained from analyzed samples.

The Virginia Polytechnic Institute and State University ran a temperature log in the cased well to 3,030 ft below kelly-bushing datum on March 13, 1981 (fig. 5). The maximum temperature, at the base of the logged interval, was 41.9°C, and the least-squares gradient between 1,002 and 3,030 ft was 27.5°C/km, or 0.00838°C/ft (Wilson S. McClung, Virginia Polytechnic

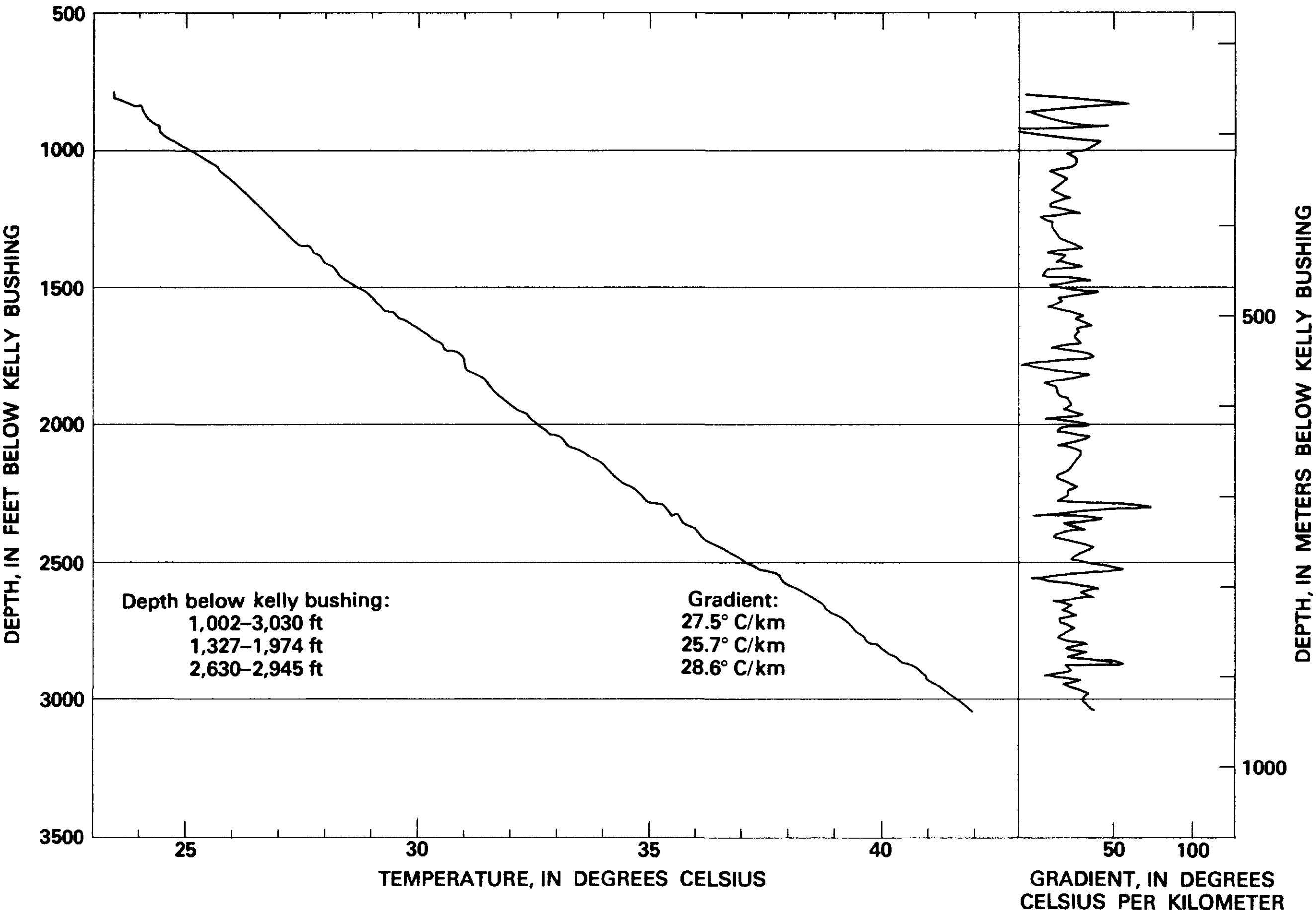

Figure 5. Temperature log.

Institute and State University, written commun., November 11, 1981). It is presumed that the log was run long enough after grouting (about February 13) and after the first pumping test (March 1) for the temperature gradient to have stabilized.

Cores

Coring Methods

Cores were taken with a 10-ft wireline core barrel. From 730 ft to total depth, an inner lining of steel tubing having an inner diameter of 1.9 in. and a wall thickness of 0.06 in. (automotive-exhaust and electric-conductor pipe) was used in the core barrel to enclose the cores. This was done to protect them from deformation, abrasion, and invasion by drilling mud. Relatively few sand cores were taken; the coring equipment was not well adapted to recovering cores of clean unconsolidated sand. The tubing was sawed into convenient lengths for examination and removal of samples for squeezing, and into 6-in. lengths, sealed with paraffin at each end, for hydraulic analysis.

Lithologic Descriptions of Cores

The lithologies of the cores, determined by hand-lens and microscopic examination and by grain-size analysis, are given in table 3.

Paleontology

The ages of the cores, based on identification of microfossils, are given in table 3. Tables 4–12 list the species identified.

Hydraulic Analysis

Core Laboratories, Inc., Houston, Tex., hydraulically analyzed 14 core samples (table 3). Porosities and vertical hydraulic conductivities ranged from 22.4 percent (at 1,111 ft) to 41 percent (at 730–732 ft), and from 1.5×10^{-6} ft/d (at 1,650–1,652 ft) to 1.3 ft/d (at 3,212 ft),

Table 3. Core data

Number and interval cut (ft below kelly bushing)	Recovery (ft)	Subinterval (ft below kelly bushing)	Lithology[1]	Paleontologic age determinations	Hydraulic analysis			Sieve analysis			Clay analysis				Chloride concentration of water[5]
												X-ray analysis			
					Porosity (pct.)	K_v[2] (ft/d)	K_h[3] (ft/d)	Grain density	Median grain size (mm)	Trask's sorting coefficient	Color[4]	Smectite 17A	Illite 10A	Kaolinite 7.2A	
1. 130–140	10	130–140	Sand, lt olive-gr (5*Y* 5/2), silt-vfg, increasingly clayey with depth.	Abbott Zone IV, Shattuck Zones 12- 13.[6] (Middle Miocene, Calvert Fm, Chesapeake Group).	—	—	—	—	—	—	Yel-gr 5*Y* 7/2	Dominant	Major	Minor	160
2. 150–160	2	150–152	Sand, lt olive-gr (5*Y* 5/2), silt-vfg, clayey at 152 ft, sparingly glauc.	Abbott Zones III-IV, Shattuck Zones 10–11[6]. (Middle Miocene, Calvert Fm, Chesapeake Group).	—	—	—	—	—	—	—	—	—	—	—
3. 340–350	3	340–343	Silt, olive-gr (5*Y* 4/1), clayey.	Abbott Zone II, Shattuck Zones 3–8.[6] (Middle Miocene, Calvert Fm, Chesapeake Group).	—	—	—	—	—	—	Yel-gr 5*Y* 7/2	Dominant	Major	Minor	99
4. 590–594	2	590–592	Clay, lt olive-gr (5*Y* 5/2), silty, v glauc, w vf dk grn-gr glauc grains.	Upper half of Middle Eocene.[7] Middle Eocene.[8] Upper lower to middle Eocene, outer shelf.[9]	—	—	—	—	—	—	Yel-gr 5*Y* 7/2	Dominant	Major	Trace	90
5. 730–740	2	730–732	Sand, dusky-brn (5*YR* 2/2), vfg, clayey, glauc, micaceous.	Middle Paleocene, inner to mid-shelf environment.[9]	41	2.4×10^{-6}	—	—	—	—	Yel-gr 5*Y* 7/2	Dominant	Trace	Trace	54
6. 805–815	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7. 815–825	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8. 863–870	2	863–863.3	Sand, grn-blk (5*GY* 2/1), vfg, silty, glauc, finely micac, clayey.	—	—	—	—	—	—	—	Pale yel-brn 10*YR* 6/2	Dominant	Minor	Major	—
		863.3–865	Silt, grn-blk, vfg sandy, clayey.	—	39	9.7×10^{-6}	1.5×10^{-5}	2.57	0.1232	1.5442	—	—	—	—	—
9. 912–915	2	912–914	Sand, olive-blk (5*Y* 2/1), vfg, glauc, clayey, micac. Trace shell fragments.	Santonian Stage, Magothy Fm, non-marine. Christopher's (1979) *Pseudoplicabpollis cuneata-semioculopollis verrucosa* zone.[10]	34.4	2.9×10^{-4}	—	—	—	—	Pale yel-brn 10*YR* 6/2	Major	Minor	Major	—
10. 970–972	0.6	970–970.6	Clay, pale brn (5*YR* 5/2), mottled lt olive-gr, silty to vfg sndy, non-calc, lignite inclusions, w tr qtz pebble.	—	25.1–28.1	4.9×10^{-6}	7.3×10^{-6}	2.60	0.0599	—	—	—	—	—	—
11. 1,111–1,114	2	1,111–1,113	Clay, moderate to olive brn (5*Y* 4/4), w dk gr silty strks, v plastic.	Barren.[10]	—	—	—	—	—	—	Lt brn 5*YR* 6/4	Trace	Major	Dominant	100
		1,111	—	—	22.4	4.9×10^{-6}	—	—	—	—	—	—	—	—	—

See footnotes at end of table.

Table 3. Core data—Continued

Number and interval cut (ft below kelly bushing)	Recovery (ft)	Subinterval (ft below kelly bushing)	Lithology[1]	Paleontologic age determinations	Hydraulic analysis: Porosity (pct.)	Hydraulic analysis: K_v[2] (ft/d)	Hydraulic analysis: K_h[3] (ft/d)	Sieve analysis: Grain density	Sieve analysis: Median grain size (mm)	Sieve analysis: Trask's sorting coefficient	Clay analysis: Color[4]	Clay analysis, X-ray analysis: Smectite 17A	Clay analysis, X-ray analysis: Illite 10A	Clay analysis, X-ray analysis: Kaolinite 7.2A	Chloride concentration of water[5]
12. 1,370–1,372	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—
13. 1,436–1,439	2	1,436–1,438	Clay, varicolored gray-pk (5*R* 8/2), lt brn (5*YR* 6/4), moderate brn (5*Y* 4/4), and yel-gr (5*Y* 7/2), silty, glauc.	Barren.[10]	—	—	—	—	—	—	Moderate or-pk 10*R* 7/4	Trace	Major	Dominant	79
		1,438	—	—	26.8	2.4×10^{-6}	—	—	—	—	—	—	—	—	—
14. 1,650–1,653	2	1,650–1,652	Clay, gr-or-pk (5*YR* 7/2) and moderate yel-brn (10*YR* 5/4), somewhat silty, plastic.	—	29.9	1.5×10^{-6}	—	—	—	—	Moderate red-or 10*R* 6/6	Major	Minor	Dominant	50
15. 1,753–1,757	2	1,753–1,755	Clay, moderate brn (5*YR* 4/4), silty, waxy.	—	—	—	—	—	—	—	Gr-red 10*R* 4/2	Minor	Trace	Dominant	—
		1,754	—	—	33	2.4×10^{-6}	—	—	—	—	—	—	—	—	—
16. 1,950–1,954	2	1,950–1,950.3	Sand, gr-olive (10*Y* 4/2), fg, clayey, abundant muscovite.	—	—	—	—	—	—	—	—	—	—	—	—
		1,950.3–1,950.7	Clay, olive gr (5*Y* 3/2), silty, v finely micaceous, lignite fragments.	—	—	—	—	—	—	—	—	—	—	—	—
		1,950.7–1,952	Clay, yel-gr (5*Y* 7/2) w or mottling, silty, non-calc, waxy, interbedded w sand, med bl-gr (5*B* 5/1) to gr-red-purple (5*RP* 4/2), vfg, clayey.	Barren.[10]	—	—	—	—	—	—	Pale yel-brn 10*YR* 6/2	Dominant	Trace	Major	30
		1,951	—	—	24.6	1.2×10^{-5}	—	—	—	—	—	—	—	—	—
17. 2,004–2,006	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18. 2,094–2,096	1.5	2,094–2,095.6	Clay, gr-red-purple (5*RP* 6/2), plastic. "Poor core."	—	—	—	—	—	—	—	Pale red-or 10*R* 5/4	Major	Major	Major	57
19. 2,200–2,204	3	2,200–2,203	Sand, gr-grn (5*G* 5/2) vfg, and clay, w carb spks.	Barren.[10]	—	—	—	—	—	—	Pale olive 10*Y* 6/2	Dominant	Trace	Trace	230
		2,202.5–2,203	—	—	29–33	1.5×10^{-5}	1.8×10^{-3}	2.54	0.1321	1.6285	—	—	—	—	—
20. 2,300–2,302	0.1	2,300–2,300.1	Clay, mottled greenish-gr and dusky red, dns.	—	—	—	—	—	—	—	—	—	—	—	—
21. 2,310–2,314	0.1	2,310–2,310.1	Clay, dominantly mottled dusky red and lt gr, dns.	—	—	—	—	—	—	—	—	—	—	—	—
22. 2,319–2,322	3	2,319–2,322	Clay, dusky red (5*R* 3/4), dns, crumbly.	—	—	—	—	—	—	—	Moderate yel-brn 10*YR* 5/4	Dominant	Trace	Minor	280
23. 2,422–2,426	3	2,422–2,425	Sand, gr-grn (5*G* 5/2), vfg-fg, subang, vf	Barren.[10]	—	—	—	—	—	—	Yel-gr 5*Y* 7/2	Dominant	Trace	Minor	—

See footnotes at end of table.

Table 3. Core data—Continued

Number and interval cut (ft below kelly bushing)	Recovery (ft)	Subinterval (ft below kelly bushing)	Lithology[1]	Paleontologic age determinations	Hydraulic analysis			Sieve analysis			Clay analysis				Chloride concentration of water[5]
					Porosity (pct.)	K_v[2] (ft/d)	K_h[3] (ft/d)	Grain density	Median grain size (mm)	Trask's sorting coefficient	Color[4]	X-ray analysis: Smectite 17A	Illite 10A	Kaolinite 7.2A	
			dk grns, sli clayey.												
		2,422	---	---	---	---	---	---	---	---	---	---	---	---	28
		2,425	---	---	35-37	1.6×10^{-4}	2.2×10^{-4}	2.69	0.1058	1.3309	---	---	---	---	24, 28
24. 2,484-2,488	3	2,484-2,487	Sand, gr-grn (*10GY 5/2*), fg, subang, fn dk spks, sli clayey w clay laminae.	Barren.[10]	---	---	---	---	---	---	Dusky yel *5Y 6/4*	Dominant	Trace	Trace[11]	62
25. 2,585-2,589	3	2,585-2,588	Clay, mod brn (*5Y 3/4*), locally mottled red, gr, purple, carb frags, waxy to plastic.	---	---	---	---	---	---	---	Moderate yel-brn *10YR 5/4*	Dominant	Trace	Trace	---
26. 2,692-2,696	3	2,692-2,695	Sand, dk grn-gr (*5G 4/1*), silt-vfg, clayey, vf micac, some carb particles, dns.	Barren.[10]	---	---	---	---	---	---	Yel-gr *5Y 7/2*	Dominant	Trace	Minor	---
		2,694	---	---	---	---	---	---	---	---	---	---	---	---	440
		2,695	--	--	---	---	---	---	---	---	---	---	---	---	360
27. 2,794-2,798	0.5	2,794-2,794.5	Sand, med lt gr, vfg-fg, silty.	Barren.[10]	---	---	---	---	---	---	---	---	---	---	---
28. 2,823-2,827	0.1	2,823-2,823.1	Clay, med gr, silty, and sand, lt gr, vfg, finely laminated w dk gr clay, silty, micac.	Barren.[10]	---	---	---	---	---	---	---	---	---	---	1,200
29. 2,900-2,910	9	2,900-2,909	Silt, v clayey, w blk carb laminae and blebs, muscovitic.	Berriasian to Barremian ? Pre-Zone I to Zone I, nonmarine.[10]	---	---	---	---	---	---	---	---	---	---	10,000-11,000
30. 3,008-3,015	2.5	3,008-3,010.5	Sand, grn-gr (*5G 6/1*), fg-med, w gr clay matrix, interbedded w clay, clay increasing downward.	Neocomian to Aptian? Zone I.[10]	---	---	---	---	---	---	Yel-gr *5Y 7/2*	Dominant	Trace	Minor	12,000-17,000
		3,009.5	---	---	29-30	6.3×10^{-3}	5.0×10^{-2}	2.52	0.2288	1.8027	---	---	---	---	18,000
31. 3,110-3,116	2	3,110-3,112	Sand, dk grn-gr (*5GY 4/1*) to olive gr (*5Y 4/1*), vfg, subang; clay matrix, interbedded w clay, clay increasing downward, abund lignite frags.	? Barremian and Aptian. ? Zone I, nonmarine.[10]	---	---	---	---	---	---	---	---	---	---	---
		3,111	---	---	28-30	1.2×10^{-5}	2.2×10^{-5}	---	0.128	1.7854	---	---	---	---	---
32. 3,210-3,216	3	3,210-3,213	Sand, med gr (*N3*), fg, subang, qtz, some muscovite and lignite, clean.	---	---	---	---	---	---	---	Yel-gr *5Y 8/1*	Dominant	Trace	Minor	18,000
		3,212	---	---	32-34.8	1.3	1.3	---	0.3065	1.36	---	---	---	---	---

See footnotes at end of table.

Table 3. Core data—Continued

Number and interval cut (ft below kelly bushing)	Recovery (ft)	Subinterval (ft below kelly bushing)	Lithology[1]	Paleontologic age determinations	Hydraulic analysis: Porosity (pct.)	Hydraulic analysis: K_v[2] (ft/d)	Hydraulic analysis: K_h[3] (ft/d)	Sieve analysis: Grain density	Sieve analysis: Median grain size (mm)	Sieve analysis: Trask's sorting coefficient	Clay analysis: Color[4]	Clay analysis, X-ray analysis: Smectite 17A	Clay analysis, X-ray analysis: Illite 10A	Clay analysis, X-ray analysis: Kaolinite 7.2A	Chloride concentration of water[5]
33. 3,310–3,315	0		---	---	---	---	---	---	---	---	---	---	---	---	---
34. 3,315–3,320	0.1	3,315–3,315.1?	Gneiss	---	---	---	---	---	---	---	---	---	---	---	---
35. 3,320–3,324	4	3,320–3,324	Gneiss	---	---	---	---	---	---	---	---	---	---	---	---
36. 3,324–3,326	2	3,324–3,326	Gneiss	---	---	---	---	---	---	---	---	---	---	---	---
37. 3,331–3,336	5	3,334	Gneiss, qtz monzonite. Holo-crystalline, hypidiomorphic-granular, non-porphyritic, medium-grained. Slight gneissic fabric. Qtz 39 percent, plagioclase (oligoclase) 34 percent, microcline 18 percent, biotite 10 percent, trace apatite, zircon, leucoxene.[12]	---	---	---	---	---	---	---	---	---	---	---	---
		3,336	---	---	1.5[13]	---	---	---	---	---	---	---	---	---	6,000 7,100

[1]Colors from wet core samples, code from Geological Society of America, 1948. *Abbreviations:* abund = abundant, bl = blue, blk = black, brn = brown, carb = carbonaceous, dk = dark, dns = dense, fg = fine grained, frags = fragments, glauc = glauconitic, gr = gray, grn = green, lt = light, med = medium, micac = micaceous, mod = moderate, non-calc = non-calcareous, or = orange, pk = pink, qtz = quartz, sli = slightly, sndy = sandy, spks = specks, subang = subangular, tr = trace, v = very, vf = very fine, vfg = very fine grained, w = with, yel = yellow.

[2]Vertical hydraulic conductivity, using simulated formation water at room temperature.

[3]Horizontal hydraulic conductivity, using simulated formation water at room temperature.

[4]Colors from dry clay fractions, Geological Society of America, 1948. See footnote 1 for definition of abbreviations.

[5]In milligrams per liter. From partial analyses of water from core samples. Complete results are listed in table 14.

[6]Determination based on diatoms by William H. Abbott, Mobil Exploration and Producing Services, May 1981. Zones defined in Abbott (1978) and Shattuck (1904).

[7]Determination based on dinoflagellates by Lucy Edwards, U.S. Geological Survey, Sept. 22, 1981.

[8]Determination based on sparse, poorly preserved foraminifers by Richard Z. Poore, U.S. Geological Survey, April 20, 1981.

[9]Determination based on foraminifers by Richard K. Olsson, Rutgers University, June 10, 1981.

[10]Determination based on palynology by Gilbert J. Brenner, State University of New York at New Paltz, June 1981. Zones defined in Brenner (1963) and Doyle and Robbins (1977).

[11]X-ray analysis of clay also showed unidentified peak at 6.35A.

[12]Description by Jonathan Edwards, Jr., Maryland Geological Survey, May 6, 1981.

[13]Porosity calculated from water content of .0059.

respectively. The horizontal hydraulic conductivities of seven sandy samples ranged from 7.3×10^{-6} ft/d (at 970–970.6 ft) to 1.3 ft/d (at 3,212 ft). However, the most permeable sands penetrated by the well were not cored.

Porosity of the bedrock core (1.5 percent) was calculated from a water-content determination furnished by F. T. Manheim (U.S. Geological Survey, written commun., 1982).

Sieve Analysis

Core Laboratories ran sieve analyses on the seven sandy samples. The median grain size ranged from 0.0599 mm at a depth of 970–970.6 ft to 0.3065 mm at 3,212 ft. Trask's sorting coefficient (Krumbein and Pettijohn, 1938, p. 230–231), defined as the square root of the ratio of the grain diameter of the third quartile to the grain diameter of the first quartile (with the first quartile representing the finest material), ranged from 1.3309 at a depth of 2,425 ft to 1.8027 at 3,009.5 ft (table 3). The grain-size distribution curves are shown in figure 6.

X-Ray Analysis of Clay Fractions

The qualitative mineralogical composition of the clay fractions of 20 core samples was determined by X-ray diffractometer. The relative abundance of smectite (17A clays), illite (10A clays), and kaolinite (7.2A clays) was estimated from the heights of their respective peaks on the X-ray diffractograms. Four categories of abundance were designated: dominant, major, minor, and trace. The color of the air-dried clay fraction was determined using the Rock Color Chart (Geological Society of America, 1948).

The X-ray analyses (table 3) show that most of the clay samples belong to the montmorillonite group (smectites); however, a significant part of the section (starting with the transition sample at 912 ft and extending through

Table 4. Fossil species identified from core sample 130–140 feet

Diagnostic plant microfossils (G. J. Brenner, State University of New York at New Paltz, written commun., June 1981):

Series determination: Miocene (not above middle Miocene)
Paleoecology: Marine

	Range	Frequency
1. *Fagus* sp.	Long range	Rare.
2. *Quercus* (oak)	Paleocene to Holocene	Abundant.
3. *Periporopollenites* cf. p. sp. z Bebout, 1980	Eocene to middle Miocene	Sparse.
4. *Carya* (hickory)	---	Rare.
5. Unidentified acritarchs (marine)	---	Sparse.

Species (3) has not been found above the middle Miocene in the B-2 Outer Continental Shelf well (Bebout, 1980). An Oak-Hickory assemblage is typical of the marine Miocene of Maryland.

Dinoflagellates (Lucy E. Edwards, U.S. Geological Survey, written commun., Sept. 22, 1981):

139.5 ft:
- *Hystrichosphaeropsis obscura*
- *Lejeunecysta* sp.
- *Operculodinium centrocarpum*
- *Palaeocystodinium golzowense*
- *Tuberculodinium vancampoae*
- plus new genus, new species

135 ft:
- *Lejeunecysta* sp.
- *Palaeocystodinium golzowense*
- *Spiniferites pseudofurcatus*
- *Tuberculodinium vancampoae*

130 ft:
- *Cyclopsiella* cf. *C. elliptica*
- *Hystrichokolpoma rigaudiae*
- *Hystrichosphaeropsis obscura*
- *Lejeunecysta* sp.
- *Lingulodinium machaerophorum*
- *Operculodinium centrocarpum*
- *Palaeocystodinium* cf. *P. golzowense*
- *Spiniferites pseudofurcatus*
- *Spiniferites* sp.
- *Tectatodinium pellitum*
- *Tuberculodinium vancampoae*
- plus new genus, new species

Table 5. Fossil species identified from core sample 150–152 feet

Dinoflagellates (Lucy E. Edwards, U.S. Geological Survey, written commun., September 22, 1981):

- *Batiacasphaera sphaerica*
- *Bitectatodinium tepikiense*
- *Corrudinium* sp.
- *Hystrichokolpoma rigaudiae*
- *Hystrichosphaeropsis obscura*
- *Lejeunecysta* sp.
- *Melitasphaeridium asterium*
- *Operculodinium* cf. *O. israelianum*
- *Palaeocystodinium golzowense*
- *Pentadinium laticinctum*
- *Spiniferites* sp.
- *Systematophora placacantha*
- *Tuberculodinium vancampoae*
- plus two new genera, new species

Middle Miocene flora.

the sample at 1,753 ft) is dominated by the kaolinite group (kandites). This part of the section corresponds approximately to the Magothy Formation of Late Cretaceous age and the upper third of the Potomac Group of Early Cretaceous age.

Heavy Mineral and Feldspar Identification

Table 13 shows the occurrence of heavy minerals and feldspars as identified by James P. Owens, U.S. Geological Survey, in selected core samples. Owens (written commun., April 23, 1982) noted that epidote and igneous apatite were abundant in the sediments of the Potomac Group in DO–CE 88, but less abundant than in the U.S. Geological Survey Oak Grove test hole (fig. 1), located about 30 mi east-southeast of Fredericksburg , Va. (Reinhardt, Christopher, and Owens, 1980). The probable source of the apatite in the Oak Grove core is granite and gneiss exposed near Fredericksburg. The corresponding section in DO–CE 88

Table 6. Fossil species identified from core sample 340–343 feet

Diagnostic plant microfossils (G. J. Brenner, State University of New York at New Paltz, written commun., June 1981):

Poor recovery of palynomorphs did not allow this sample to be accurately dated. The presence of only *Quercus* grains suggests a Cenozoic age. A few fragments of circular diatoms indicate a marine environment.

Dinoflagellates (Lucy E. Edwards, U.S. Geological Survey, written commun., September 22, 1981):

Cyclopsiella cf. *C. elliptica*	*Palaeocystodinium golzowense*
Heteraulacacysta sp.	*Spiniferites* sp.
Lejeunecysta sp.	*Tuberculodinium vancampoae*
Lingulodinium machaerophorum	

Foraminifers (Richard K. Olsson, Rutgers University, written commun., June 10, 1981):

	Number of specimens
Hanzawaia cf. *concentrica*	1–10
Buliminella cf. *elongata*	1–10
Uvigerina sp.	1–10

Contains a sparse fauna with much evidence of dissolution. Age determination not restricted—Oligocene to Holocene. Environment of deposition is mid-outer shelf, a diatom-radiolarian facies.

apparently received at least part of its sediment from a northerly or northwesterly source, according to Owens.

Lithologic Log

The interpretative lithologic log in table 14 was prepared from a combination of the driller's log, the geologist's field log, microscopic examination of cuttings samples, core descriptions, and geophysical logs. Lithologic boundaries were interpreted from the geophysical logs.

Aquifer Tests

Aquifer tests were conducted at five depths to determine the transmissivity and hydraulic conductivity of the screened or perforated zones (table 15).

The initial test was of the interval screened below the casing from 3,188 to 3,218 ft below kelly-bushing datum. The well was pumped continuously at approximately 30 gal/min for 8 hours. Water levels in the pumping well were recorded during the drawdown and recovery phases of the test. Total drawdown during the drawdown phase was 71.09 ft. However, drawdown remained fairly constant following the first several minutes of the test. A plot of drawdown versus time is given in figure 7.

During the recovery phase of the test, water levels rose above the prepumping static water level of 61.9 ft below kelly-bushing datum in the first 3 min. For the remaining 27 min of measurement, water levels slowly declined toward the prepumping static level.

Ground-water temperature at the point of discharge from the well was monitored intermittently. Measured temperatures increased from 28°C at time (t) = 30 min to 35°C at t = 150 min. For the remainder of the drawdown phase of the test, the temperature at the wellhead remained constant at 35°C.

Routine straight-line aquifer-test analysis techniques (Cooper and Jacob, 1946; Lohman, 1972, p. 19, 21) do not yield an acceptable solution when applied to the observed drawdown. During the test, the increase in temperature of the pumped water caused an accompanying decrease in water density. Hence, the observed drawdowns must be temperature-corrected to analyze the test data accurately.

Figure 8 shows temperature profiles in the well at various times during the drawdown phase of the test. The profile at t = 0 min is derived from the temperature log (fig. 5) and is approximated by two straight-line segments having similar slopes. The average prepumping temperature of water in the well is 29.93°C. It was assumed that, during pumping, the temperature of the water entering the well (43.11°C) was constant through time and that the temperature profile in the well was linear at all times. Temperature profiles were constructed from measured wellhead temperatures, and an average temperature of the water in the well was computed for each profile (fig. 8).

Head is a function of water density, and density varies with temperature. Thus, density and, in turn, head must be corrected for varying temperatures. In general, the corrections required are negligible for shallow wells and are ignored; however, for deep wells, the corrections may become significant. If aquifer response is expressed in terms of pressure rather than head, as the petroleum industry uses pressure data from drill-stem tests (Bredehoeft, 1965), corrections for temperature effects on the water-column can be avoided when determining hydraulic parameters.

Pressure at the well screen is independent of the density of the fluid in a well; therefore, pressures for cold and hot water can be equated:

$$P_{cw} = P_{hw}, \quad (1)$$

where pressure (P) is defined in terms of hydraulic head (h) as $P = \varrho g(h+z)$; cw refers to cold water, hw is hot water, z is the elevation head, ϱ is the density of the water in the well, and g is the gravitational acceleration constant. Equating pressures and solving for cold-water head yields:

$$h_{cw} = \frac{\varrho_{hw}}{\varrho_{cw}}(h_{hw} + z) - z. \quad (2)$$

As the relation of water density to temperature is known, water levels can be adjusted for the increasing temperature.

The density of the water in DO-CE 88 for the 3,188- to 3,218-ft zone is 1.032 gm/mL (grams per milliliter) at 20 °C, which is approximately equivalent to a 4 percent (by weight) brine. The following linear approximation of density versus temperature in degrees Celsius (T) can be used:

$$\varrho = 1.032 + a(T-20). \quad (3)$$

The values of a used in equation 3 are interpolated from published values for a 4 percent (by weight) brine at various temperatures (INTERCOMP Resource Development and Engineering, Inc., 1976, p. 4.2-4.3). The calculated average densities of the brine in the well at various times during the drawdown phase of the pumping test are:

time (min)	*gm/mL*
0	1.0296
30	1.0281
60	1.0277
110	1.0274
>150	1.0270

Interpretation of Temperature-Corrected Drawdown

Both uncorrected and density-corrected drawdowns for the pumping test are shown in figure 7. The uncorrected drawdowns rapidly increased during the first 10 min of the test, as expected. For the remainder of the test, water levels remained approximately constant. The density-corrected drawdowns show a linear trend that is readily analyzed. The computed transmissivity of the screened zone containing brine at 29.9°C is 380 ft²/d, and its average hydraulic conductivity is 12.5 ft/d. This is a typical value for fine sand (Lohman, 1972, table 17) and, hence, is in agreement with the lithologic description of drill cuttings for this interval.

After pumping ceased, water levels rose rapidly above the prepumping static level because the well contained hotter, less dense water than before pumping began. Then, as the water in the well cooled, water levels slowly declined to the prepumping static level. During pumping, cold water in the well was replaced by hotter water from the aquifer. In contrast, during recovery, hot water in the well cooled and water levels declined. Because of the complex nature of these processes, transmissivity was not computed from recovery data.

The remaining tests were also corrected for temperature effects when necessary. Temperature measurements were insufficient to define the drawdown curve rigorously, and specific-capacity data were used to estimate transmissivity and hydraulic conductivity (Brown, 1963, p. 336). A storage coefficient and a well radius of 1×10^{-4} and 0.5 ft, respectively, were assumed. The specific capacities used in the analysis were computed from temperature-corrected drawdown near the end of the drawdown phase of each test.

Hydraulic properties (transmissivity and hydraulic conductivity) are dependent on both the chemical composition and temperature of the water contained in the aquifer. The results of the aquifer-test analysis may not represent in situ temperature conditions. Therefore, intrinsic permeability, which is independent of fluid properties, has been computed for each of the tests. The results are summarized in table 15.

Table 7. Fossil species identified from core sample 590–592 feet

Dinoflagellates (Lucy E. Edwards, U.S. Geological Survey, written commun., September 22, 1981):

Achilleodinium biformoides
Adnatosphaeridium sp.
Apteodinium australiense
Cordosphaeridium gracile
Corrudinium n. sp.
Deflandrea phosphoritica
Diphyes colligerum
Heteraulacacysta leptalea
Hystrichostrogylon membraniphorum
Lentinia sp.
Melitasphaeridium pseudorecurvatum
Microdinium n. sp.
Pentadinium membranaceum
Rhombodinium glabrum
Samlandia chlamydophora
Samlandia reticulifera
Spiniferites pseudofurcatus
Spiniferites ramosus var. *granomembranaceus*
Tectatodinium pellitum
Wetzeliella articulata

Age is upper half of middle Eocene.

Foraminifers (Richard K. Olsson, Rutgers University, written commun., June 10, 1981):

	Number of specimens
Gaudryina cf. *pseudocollinsi*	1– 10
Textularia sp.	1– 10
Brazilina atlantisae	+1,000
Turritilina sp.	+1,000
Bulimina cf. *subrotundata*	+1,000
Bulimina trigonalis	11– 100
Anomalinoides alazanensis	11– 100
Pullenia compressiuscula	1– 10
Cibicides westi	11– 100
Alabamina midwayensis	11– 100
Cibicidoides pippeni	11– 100
Gyroidinoides peramplus	100–1,000
Bulimina pupoides	11– 100
Lenticulina sp.	1– 10
Lagena striata	1– 10
Lagena fenestrissima	11– 100
Subbotina eocaena	100–1,000
Acarinina pentacamerata	+1,000
Morozorella spinulosa	1– 10
Stilostomella sp.	1– 10
Globulina gibba	1– 10
Morozorella spinuloinflata	11– 100
Pseudohastigerina wilcoxensis	11– 100
Truncorotaloides cf. *ruhri*	1– 10

Very rich in foraminifers. Outer shelf environment of deposition.

"Planktic foraminifers" (Richard Z. Poore, U.S. Geological Survey, written commun., April 20, 1981):

Truncorotaloides collactea (Finlay)
T. bullbrooki (Bolli)
Pseudohastigerina micra (Cole)

Age: "Middle Eocene. Planktic foraminifers are sparse and poorly preserved."

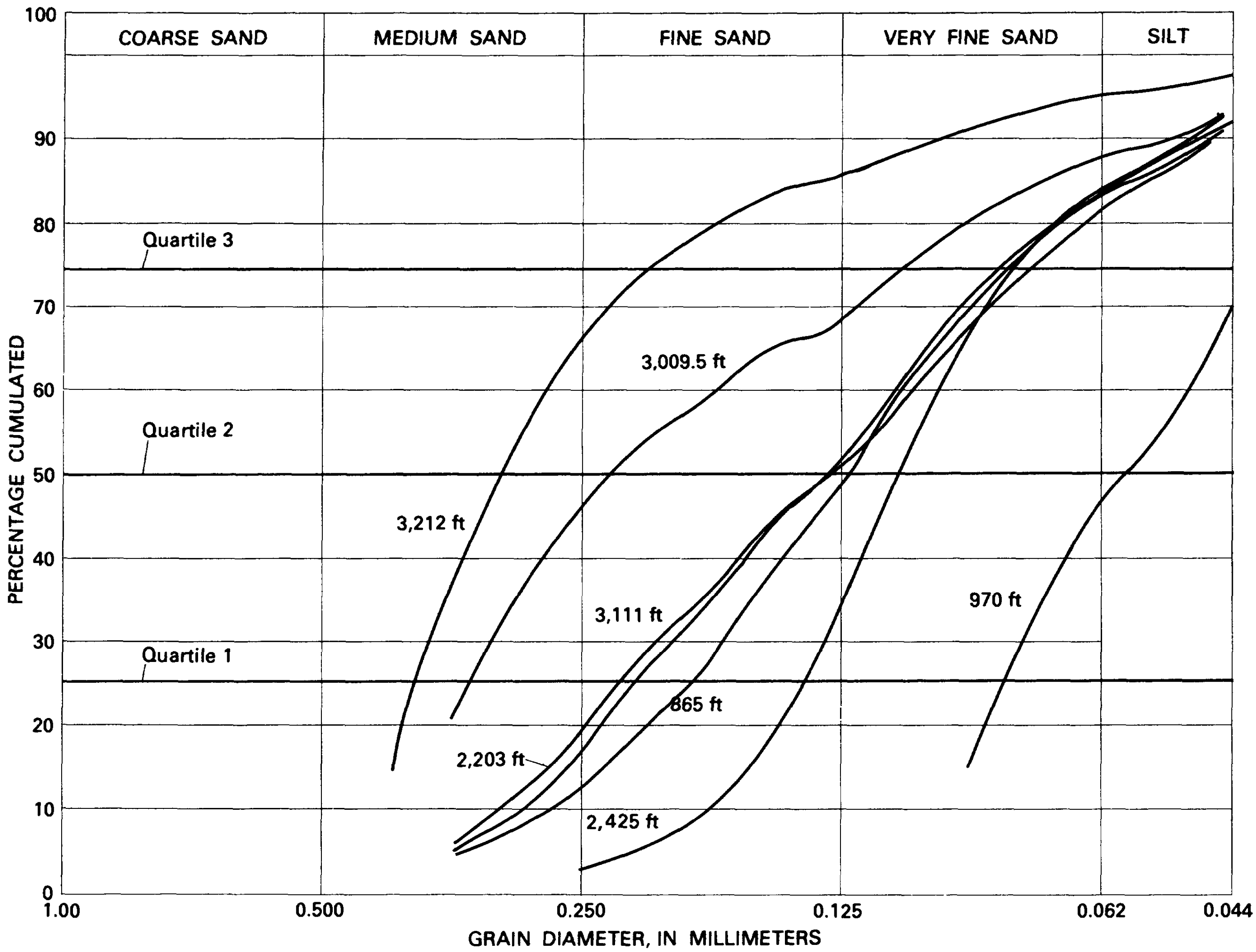

Figure 6. Grain-size distribution of core samples.

Table 8. Fossil species identified from core sample 730–732 feet

Foraminifers (Richard K. Olsson, Rutgers University, written commun., June 10, 1981):

	Number of specimens
Stilostomella paleocenica----------------	1- 10
Epistominella minata-------------------	11- 100
Bulimina cacumenata-------------------	100-1,000
Cibicides succeedens-------------------	1- 10
Bulimina quadrata---------------------	1- 10
Anomalinoides welleri------------------	1- 10
Alabamina midwayensis---------------	1- 10
Pseudouvigerina seligi-----------------	100-1,000
Acarinina sp.--------------------------	1- 10
Morozorella angulata------------------	1- 10
Subbotina triloculinoides---------------	1- 10
Dentalina sp.-------------------------	1- 10
Tappanina selmensis-------------------	1- 10
Fursenkoina sp.-----------------------	1- 10

Evidence of a fair amount of solution of foraminiferal tests. Inner to mid-shelf environment of deposition.

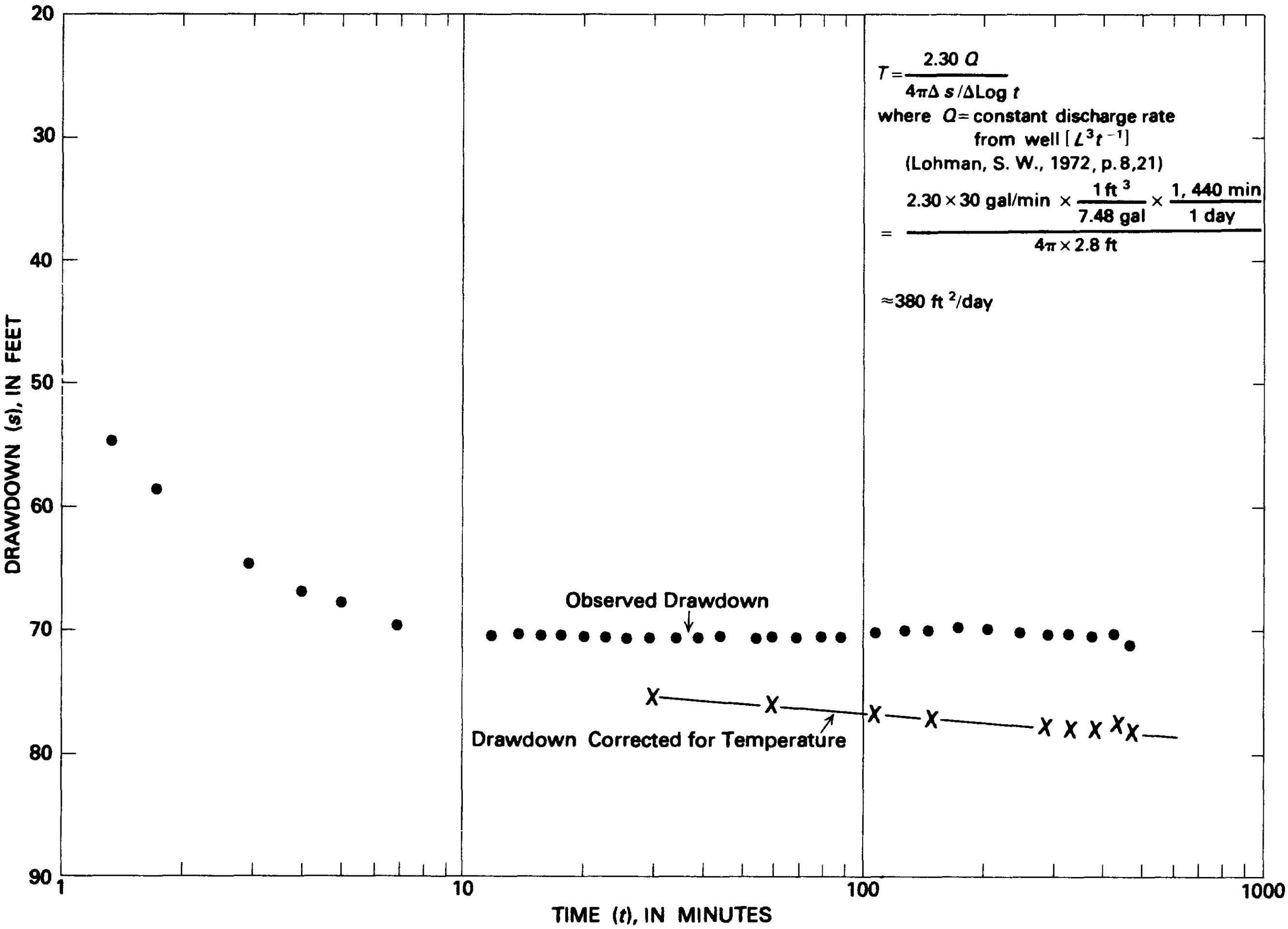

Figure 7. Computation of transmissivity (T) of screened zone 3,188 to 3,218 ft below kelly-bushing datum.

Table 9. Fossil species identified from core samples 912–915 feet

Diagnostic plant microfossils (G. J. Brenner, State University of New York at New Paltz, written commun., June 1981):

	Range (Atlantic Coastal Plain)	*Frequency*
1. *Appendicisporites tricuspidatus*	Amboy Stoneware Clay Member of Magothy Formation	Rare.
2. Genus *B* sp. *C*, Christopher, 1979	Cliffwood beds of Magothy Formation	Rare.
3. *Plicapollis* sp. *G*, Christopher, 1979	Amboy Stoneware Clay Member to Cliffwood beds of Magothy Formation	Sparse.
4. *Santalacites minor*	Amboy Stoneware Clay Member to Cliffwood beds of Magothy Formation	Rare.
5. *Semioculopollus verrucosa*	Morgan and Cliffwood beds of Magothy Formation	Rare.
6. *Stereisporites congruens*	Cenomanian to Maestrichian	Rare.
7. *Tricolporites* sp. *q*. Wolfe and Pakiser, 1971	Cliffwood beds of Magothy Formation	Sparse.
8. *Trudopollis* sp. *B*	Amboy Stoneware Clay Member to Cliffwood beds of Magothy Formation	Common.
9. *Vacuopollis* sp.	Magothy Formation	Common.

Based on the zonation of Christopher (1979), the sample at 913 feet can with confidence be placed in the *Pseudoplicabpollis cuneata-Semioculopollis verrucosa* zone of Santonian Age. Stratigraphic correlation: Magothy Formation. Paleoecology: Nonmarine.

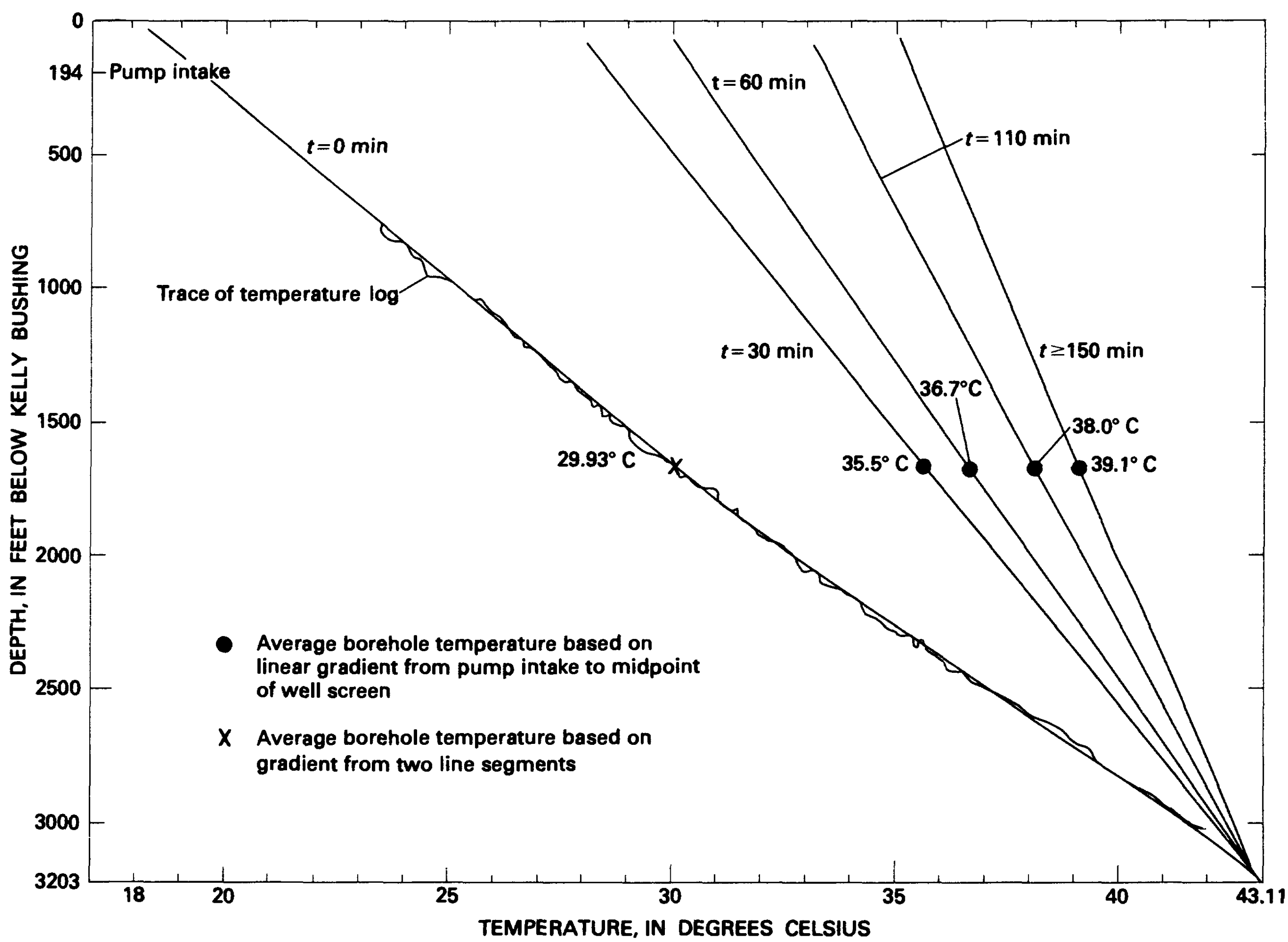

Figure 8. Temperature profiles during pumping test of screened zone 3,188 to 3,218 ft below kelly-bushing datum.

Table 10. Fossil species identified from core sample 2,900–2,909 feet

Diagnostic plant microfossils (G. J. Brenner, State University of New York at New Paltz, written commun., June 1981):

Stage determination: Berriasian to Barremian ?
Stratigraphic correlation: Pre-Zone I ? to Zone I
Paleoecology: Nonmarine

	Range	Frequency
1. *Alisporites*	Long range	Sparse.
2. *Concavissimisporites verrucatus*	Valanginian→	Rare.
3. *Klukisporites pseudoreticulatus*	Berriasian to Turonian	Rare.
4. *Leptolepidites verrucatus*	Berriasian to Albian	Rare.
5. *Lycopodiumsporites* sp.	Long range	Rare.
6. *Lycopodiacidites ambifoveolatus*	Zones I and II	Rare.
7. *Parvisaccites radiatus*	Upper Jurassic and Berriasian to Albian	Rare.
8. *Podocarpidites* sp.	Long range	Rare.

Palynomorphs not distinctive of any zone. No typical angiosperms of Zone I are present.

Table 11. Fossil species identified from core sample 3,008–3,010.5 feet

Diagnostic plant microfossils (G. J. Brenner, State University of New York at New Paltz, written commun., June 1981):

Stage determination: Neocomian to Aptian
Stratigraphic correlation: ? Zone I

The poor recovery did not allow a confident age determination. The best palynomorph with the narrowest range is a form described by Hughes and Croxton (1973) from the Dorset Wealden, listed as *Biorecord 25 CICATR B21* Berriasian to Aptian (a form of *Cicatricosisporites*). A few other palynomorphs with long Cretaceous ranges were found. These are

1. *Cicatricosisporites* sp.
2. *Appendicisporites* sp.
3. *Taurocusporites reduncus*

Table 12. Fossil species identified from core sample 3,110–3,112 feet

Diagnostic plant microfossils (G. J. Brenner, State University of New York at New Paltz, written commun., June 1981):

Stage determination: Barremian ? to Aptian
Stratigraphic correlation: ? Zone I
Paleoecology: Nonmarine

	Range	*Frequency*
1. *Klukisporites pseudoreticulatus*	Berriasian to Turonian	Rare.
2. *Perotriletes striatus*	Barremian to Albian	Rare.
3. *Pilosisporites* sp.	---	---
4. *Trilobosporites apiverrucatus*	Berriasian to Albian	Rare.

"Sample is too sparse to confidently date. However, *Perotriletes striatus* has not yet been reported from below the Barremian. In the Potomac Group, I found it much more common in the Barremian [to] Aptian, Zone I levels. I have often found it associated with megaspore *Arcellites disciformis* entrapped in the paddle-like appendages. If *P. striatus* is the microspore of this heterosporous form, then the presence of this microspore would increase the probability of the sample belonging to Zone I; since *Arcellites disciformis* first appears in the Barremian."

Table 13. Heavy minerals and feldspars in selected core samples[1]

	Percentage of light fraction					Percentage of opaque heavy-mineral fraction			Percentage of non-opaque heavy-mineral fraction											
Depth (ft below kelly bushing)	Rock frag-ments	Com-mon quartz	Polycry-stalline quartz	Potas-sium feldspar	Plagio-clase feldspar	Ilme-nite	Brown ilme-nite	Leuco-xene	Horn-blende	Epidote	Garnet	Chlori-toid	Glau-conite	Staur-olite	Kyanite	Silli-manite	Tour-maline	Rutile	Zircon	Apatite
130.5	14	81	3	3	tr[2]	—	—	—	0	8	6	4	1	0	3	15	12	3	47	0
135	10	86	1	4	tr[2]	—	—	—	0	23	5	9	0	0	3	5	5	18	32	0
139.5	2	92	0	6	tr[2]	—	—	—	0	32	12	8	0	0	0	24	4	12	8	0
150	5	92	0	3	tr[2]	—	—	—	0	2	10	4	0	0	0	17	21	2	42	0
340[3]	12	75	0	12	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
592[4]	0	70	0	30	0	—	—	—	P[5]	0	P[5]	P[5]	0	0	P[5]	0	P[5]	P[5]	0	0
913	3	80	0	13	0	87	3	10	0	26	10	15	0	8	2	0	3	11	25	0
1,951	35	63	0	2	0	49	very abundant	51	5	13	1	0	0	11	4	0	13	18	35	0
2,203	5	80	0	12	3	87	1	12	0	51	4	0	0	0	0	0	1	0	33	11
2,484	0	45	0	32	23	63	15	12	0	14	9	0	0	3	1	0	5	0	68	0
2,903	20	73	0	7	0	66	25	9	tr[2]	38	5	4	0	8	3	0	2	3	36	1
3,112	5	61	0	30	4	90	4	6	0	7	3	1	0	0	0	0	1	1	80	7
3,212	8	40	2	44	6	30	15	55	0	72	7	0	0	5	1	0	1	0	5	9

[1]The fine and very fine sand fractions > 40 microns (325 mesh) only, not the total sample.
[2]Trace, < 0.5 percent.
[3]Small sample, less accurate than other counts; heavy minerals consist of abundant diatoms replaced by pyrite, minor weathered glauconite.
[4]Mostly carbonate.
[5]Present. Heavy minerals consist mostly of opaque, green-black glauconite aggregates.

Table 14. Interpretative lithologic description, Well DO–CE 88 (USGS No. 383401076032O.01)

Owner: Eastern Shore Hospital Center
Location: Eastern Shore Hospital Center, Cambridge, Maryland
County: Dorchester
Prepared by: Henry Trapp, Jr., from microscopic examination of drill cuttings and cores adjusted to lithologic boundaries indicated by geophysical logs.
Datum: Kelly bushing of drill rig, 9.42 ft above msl = 5.0 ft above land surface

Lithology	Thickness (ft)	Depth (ft)
Quaternary (?) System *Pleistocene (?) Series*		
Clay, brown, sandy	5	10
Sand, brown, medium	11	21
Clay, blue, sandy	2	23
Sand, brown	13	36
Clay, blue, sandy	17	53
Tertiary (?) System *Miocene (?) Series* *Chesapeake (?) Group (lower part)*		
Sand and shells, interbedded[1]	62	115
Sandstone, light brown (5*YR* 6/4),[2] very fine to medium, predominantly fine, mostly angular to subangular, except for coarser grains, which are subrounded quartz. Calcareous cement contains shell fragments and fine black grains. Some porosity in fossil molds	3	118
Silt, light olive-gray (5*Y* 5/2), very fine sandy, clayey; with shell fragments and very fine black phosphatic (?) specks	14	132
Sand, light olive-gray (5*Y* 5/2), very fine to fine, very clayey, calcareous in part, with very fine black phosphatic (?) specks; grading to	4	136
Clay, light olive-gray (5*Y* 5/2), very fine sandy, calcareous in part	14	150
Sand, light olive-gray (5*Y* 5/2), silt to very fine, clayey, sparsely glauconitic; grading to	2	152
Clay, light olive-gray (5*Y* 5/2), silty and sandy	3	155
Sand, pale brown (5*YR* 5/2), very fine to fine, very clayey; trace yellow-stained quartz pebbles	25	180
Sand, pale brown (5*YR* 5/2), very fine to medium, predominantly very fine, subangular, very clayey; trace 1/2-in. subround quartz pebbles, trace fine white shell fragments	10	190
Silt, pale brown (5*YR* 5/2), scattered very fine black specks	9	199
Sand, pale brown (5*YR* 5/2), silt to medium, predominantly very fine, subangular, with very fine black specks	11	210
Sand, pale brown (5*YR* 5/2), very fine to medium, predominantly medium, subangular, with black grains	10	220
Sand, pale brown (5*YR* 5/2), very fine to coarse, predominantly medium, subangular	6	226
Sand, pale brown (5*YR* 5/2), very fine to coarse, predominantly medium, becoming finer and clayey downward	4	230
Sandstone, pale brown (5*YR* 5/2), very fine, weakly cemented, noncalcareous	4	234
Sand, pale brown (5*YR* 5/2), very fine, subangular, silty, with scattered black grains	44	278
Clay, pale brown (5*YR* 5/2), silty; interbedded with sand as above, trace white shell fragments	60	338
Silt, olive-gray (5*Y* 4/1), clayey	12	350
Eocene Series *Piney Point Formation*		
Sand, moderate brown (5*YR* 5/2), very fine to medium, predominantly fine, angular to subangular, abundant greenish-black glauconite grains and trace of shell fragments	12	362
Shell fragments, white, probably with glauconite nodules and sand	4	366
Sand, moderate brown (5*YR* 5/2), very fine to medium, predominantly fine; interbedded with very fine clayey sand	15	381
Ironstone, moderate brown (5*YR* 5/2)	3	384
Sand, moderate yellow-brown (10*YR* 5/4) with black specks, fine to coarse, predominantly medium, angular to subround, mostly quartz, with limonite and glauconite grains; trace of shell fragments	76	460
Sand as above; interbedded with gray-green (5*G* 5/2) silt	82	542
Nanjemoy Formation		
Sand, moderate, yellow-brown (10*YR* 5/4), silt to very fine, clayey; interbedded with fine to coarse, poorly sorted sand; abundant glauconite nodules and traces of shell fragments	12	554
Sand, very fine to medium, predominantly fine, clayey, abundant glauconite	19	573
Clay, light olive-gray (5*Y* 5/2), silty, very glauconitic	19	592
Sand, dark yellow-brown (10*YR* 4/2), silt to very fine, quartz, subangular, clayey,		

See footnotes at end of table.

Table 14. Interpretative lithologic description, Well DO–CE 88—Continued

Table 14. Interpretative lithologic description, Well DO–CE 88—Continued

Lithology	Thickness (ft)	Depth (ft)
glauconitic; interbedded with light olive-gray (5*Y* 5/2), very glauconitic, silty clay with occasional shell fragments	20	612
Silt, gray-green (5*G* 5/2), very glauconitic, with shell fragments and occasional quartz pebbles	17	629
Sand, very fine to fine, mostly composed of dark greenish-black glauconite grains, about 30 percent quartz	11	640
Sand as above; interbedded with gray-green (5*G* 5/2) silty clay; trace shell fragments	10	650
Clay, gray-green, silty	10	660
Sand as in 640–650	10	670
Paleocene (?) Series ***Aquia (?) Formation***		
Sand, glauconite, as in 629–640 ft, with occasional thin layers of gray-green (5*G* 5/2) silt	28	698
Silt, gray-green (5*G* 5/2), glauconitic; interbedded with greenish-gray (5*G* 6/1) clay	11	709
Clay, greenish-gray (5*GY* 6/1) and light gray (5*GY* 8/1), silty, glauconitic, calcareous; with traces of very coarse angular quartz grains and shell fragments	18	727
Sand, dusky brown (5*YR* 2/2), very fine, clayey, glauconitic, micaceous	10	737
Clay as in 709–727 ft	3	740
Silt, greenish-gray (5*GY* 6/1), clayey, glauconitic, with trace of shell fragments	13	753
Clay as in 709–727 ft; interbedded with very fine to fine glauconite sand	22	775
Sand, greenish-black, very fine to medium, mostly medium; mostly glauconite grains with a trace of coarse subangular quartz grains	19	794
Brightseat Formation		
Clay, greenish-gray (5*GY* 6/1) and light green (5*GY* 8/1), silty, calcareous, trace shell fragments	16	810
Sand, greenish-black (5*GY* 2/1), very fine to medium, predominantly fine, composed of polylobate glauconite	14	824
Cretaceous System ***Upper Cretaceous Series*** ***Severn and Matawan Formations, undifferentiated***		
Sand, medium to very coarse, subangular to subround clear, rose, and orange-stained quartz mixed with glauconite grains as above and trace of shell fragments	26	850
Sand, greenish-black (5*GY* 2/1), fine, glauconite, clayey; interbedded with clay and quartz sand	20	870
Magothy Formation		
Sand, greenish-black (5*GY* 2/1), silt to medium, predominantly fine, about 60 percent glauconite, 40 percent quartz	23	893
Sandstone, dark yellowish-orange (10*YR* 6/6), fine to medium, mostly quartz grains, some glauconite, calcareous	2	895
Sand, greenish-black (5*GY* 2/1), silt to medium, predominantly fine, 70 percent glauconite, 30 percent quartz, with a few very coarse quartz grains and shell fragments	23	918
Clay, greenish-gray (5*G* 6/1), silty, with trace shell fragments and foraminifers	3	921
Sand as above, with trace of shell fragments	7	928
Silt, grayish-green (5*GY* 5/2), clayey, calcareous; grading to clay	8	936
Sand, fine to coarse, predominantly medium, subangular clear and rose quartz with about 20 percent glauconite grains; with thin streaks of yellowish-gray (5*Y* 7/2), light brownish-gray (5*YR* 6/1), and greenish-gray (5*GY* 6/1) slightly calcareous clay; trace of shell fragments, foraminifers, and quartz pebbles	37	973
Sand, very fine to very coarse, predominantly fine, with trace shell fragments	20	993
Silt, greenish-gray (5*G* 6/1), clayey	9	1,002
Lower Cretaceous Series ***Potomac Group, undifferentiated***		
Silt, greenish-gray (5*G* 6/1), clayey; interbedded with very fine to very coarse, predominantly very fine sand	32	1,034
Sand, very fine to coarse, predominantly very fine to fine, subangular, mostly clear quartz	10	1,044
Silt, greenish-gray (5*G* 6/1), clayey	6	1,050
Sand, as above, with a few very coarse grains	11	1,061
Clay, yellowish-gray, (5*Y* 8/1)	6	1,067
Sand, as in 1,034–1,044 ft	5	1,072
Clay, light brown (5*YR* 5/6); interbedded with sand as above	11	1,083
Sand, very fine to very coarse, poorly sorted, subangular, clear to orange-stained quartz grains, slightly clayey	11	1,094
Clay, light brown (5*YR* 5/6), sandy	6	1,100

Table 14. Interpretative lithologic description, Well DO-CE 88—Continued

Lithology	Thickness (ft)	Depth (ft)
Sand, as above, with thin streaks of clay as above	8	1,108
Sandstone, very fine grained, subangular; calcareous cement	2	1,110
Clay, moderate olive-brown (5*Y* 4/4), with dark gray silty streaks, very plastic	2	1,112
Sand, very fine to coarse, poorly sorted, subangular quartz, with thin streaks of clay as above	21	1,133
Sand, silt to very fine with trace very coarse subangular quartz grains, clayey; interbedded with pale greenish-yellow (10*Y* 8/2) and grayish-orange (10*YR* 7/4) clay	24	1,157
Sand, silt to medium, predominantly very fine to fine, subangular quartz, clear to partly iron-stained	35	1,192
Clay, mottled light gray (*N7*) and moderate red-brown (10*R* 4/6); and moderate red-brown silt	6	1,198
Sand, very fine to medium, predominantly fine to medium, angular to subangular, mostly quartz, with some limonite grains; with occasional thin layers of very fine silty sand, silt, and clay	79	1,277
Sand, very fine to very coarse, predominantly medium, subangular; with occasional thin streaks of clay as above	26	1,303
Sandstone, very fine to medium-grained, iron and calcareous cement	5	1,308
Sand, very fine to very coarse, predominantly coarse, subangular, mostly quartz, some limonite	32	1,340
Clay, sandy	6	1,346
Sand, very fine to very coarse, predominantly medium	4	1,350
Clay, sandy	6	1,356
Sand, very fine to very coarse, predominantly fine to medium	6	1,362
Silt and clay	8	1,370
Sand, very fine to very coarse, predominantly fine to medium	32	1,402
Sand, very fine to very coarse, predominantly fine to medium, clayey	19	1,421
Sand, very fine to very coarse, predominantly fine to medium, clean, with trace of quartz pebbles	10	1,431
Sand as above; interbedded with moderate yellow-brown (10*YR* 10/4) silt and moderate brown (5*YR* 4/4), light brown (5*Y* 6/4), pale greenish-yellow (10*Y* 8/2), and greenish-gray (5*GY* 6/1), silty, calcareous clay	28	1,459
Sand, very fine to very coarse, predominantly fine to medium, fairly clean	24	1,483
Sand as above; interbedded with varicolored clay as in 1,431-1,459 and moderate yellow-brown (5*YR* 5/4) to moderate brown (5*YR* 4/4), iron-cemented siltstone	19	1,502
Sand, very fine to very coarse, predominantly fine to medium, subangular, with a few thin silty and clayey streaks	18	1,520
Sand, as above but predominantly very fine, with silty and clayey streaks	8	1,528
Clay, pale greenish-yellow (10*Y* 8/2) and greenish-gray (5*GY* 6/1), silty	8	1,536
Sand, very fine to very coarse, predominantly very fine	6	1,542
Clay, as above	6	1,548
Sand, light brown (5*YR* 5/6), silt to very fine, clayey	4	1,552
Sand, very fine to very coarse, predominantly fine to medium, with thin clayey and silty streaks, trace of quartz pebbles	22	1,574
Sand, very fine to fine, clayey and silty	18	1,592
Sand, very fine to coarse, predominantly fine to medium; with thin layers of moderate brown (5*YR* 4/4) iron-cemented siltstone	28	1,620
Sand, very fine to fine, clayey and silty	8	1,628
Sand, very fine to coarse, predominantly fine to medium	12	1,640
Sand, very fine to coarse, predominantly very fine to fine, silty	9	1,644
Clay, grayish-orange-pink (5*YR* 7/2) and moderate yellowish-brown (10*YR* 5/4), silty, plastic	13	1,662
Sand, very fine to coarse, predominantly fine, slightly clayey	12	1,674
Sand, very fine to coarse, predominantly very fine, silty, clayey	14	1,688
Silt, light brown (5*YR* 5/6)	20	1,708
Silt, moderate brown (5*Y* 4/4); interbedded with moderate brown and pale greenish-yellow (10*Y* 8/2), silty, waxy clay and very clayey sand	82	1,790
Sand, very fine to coarse, predominantly very fine to fine, subangular	10	1,800
Sand, very fine to coarse, predominantly fine to medium, angular to subangular, mostly quartz grains, and some limonite; with a few thin beds of light greenish-gray (5*GY* 8/1) clay and light brown (5*YR* 5/5), yellowish-gray (5*Y* 7/2), and grayish-green (10*GY* 10/2), iron- and silica-cemented siltstone	20	1,820
Sand, very fine to very coarse, predominantly medium, angular to subangular	20	1,840
Sand as above; grading downward into pale olive (10*Y* 6/2) silt to very fine, clayey sand; interbedded with light greenish-gray		

Table 14. Interpretative lithologic description, Well DO–CE 88—Continued

Lithology	Thickness (ft)	Depth (ft)
(5*GY* 8/1) clay	18	1,858
Sand, very fine to very coarse, predominantly fine to medium; with 1-ft layer of siltstone, as in 1,800–1,820, at 1,871 ft; trace lignite	24	1,882
Clay, moderate red (5*R* 4/6) and light greenish-gray (5*G* 6/1); interbedded with very fine clayey sand; trace lignite	6	1,888
Sand, very fine to very coarse, predominantly fine, mostly clean but with clayey streaks, trace of lignite	28	1,916
Clay, olive-gray (5*Y* 3/2), yellowish-gray (5*Y* 7/2), partly with orange mottling, silty, partly micaceous, partly waxy; interbedded with grayish-olive (10*Y* 4/2), fine, clayey, micaceous sand and light brown (5*YR* 5/6) silt; trace of lignite	39	1,955
Sand, very fine to coarse, predominantly fine, slightly clayey	19	1,974
Clay, varicolored as in 1,916–1,955 ft, silty to sandy; interbedded with very fine clayey sand and silt	16	1,990
Sand, very fine to very coarse, predominantly fine to medium, fairly clean	27	2,017
Clay interbedded with silt	22	2,039
Sand, very fine to very coarse, predominantly fine to medium, fairly clean	5	2,044
Silt	7	2,051
Sand, very fine to very coarse, predominantly medium, angular to subangular	17	2,068
Clay and silt, interbedded	8	2,076
Sand, as above	12	2,088
Silt, light brown (5*YR* 5/6), moderate brown (5*YR* 4/4) and grayish-brown (5*YR* 3/2); interbedded with moderate brown, grayish-red-purple (5*RP* 6/2) and pale greenish-yellow (10*Y* 8/2) clay. Clay increasing downward	14	2,102
Clay as above; interbedded with silt	18	2,120
Sand, very fine to very coarse, predominantly very fine, clayey; interbedded with light brown (5*YR* 5/6) silt and clay	30	2,150
Clay, light brown (5*YR* 5/6), silty; interbedded with light brown silt and fine to medium clayey sand, with trace of subangular quartz pebbles	21	2,171
Sand, moderate brown (5*YR* 4/4), silt to medium, predominantly very fine, clayey, slightly calcareous	22	2,193
Clay, pale yellow-brown (10*YR* 6/2), very silty and very fine sandy, slightly calcareous	4	2,197
Sand, grayish-green (5*G* 5/2), with dark specks, very fine, clayey	9	2,206
Sand, very fine to very coarse, predominantly		

Table 14. Interpretative lithologic description, Well DO–CE 88—Continued

Lithology	Thickness (ft)	Depth (ft)
medium to coarse, angular to subangular quartz	6	2,212
Clay, pale yellow-brown (10*YR* 6/2), silty and sandy	2	2,214
Sand as above	27	2,241
Clay, moderate reddish-brown (10*R* 4/6), moderate yellowish-brown (10*YR* 5/4), grayish yellowish-green (5*GY* 7/2), and dark greenish-gray (5*G* 4/1), silty, sandy, slightly calcareous in part	12	2,253
Sand, very fine to very coarse, predominantly medium to coarse, clayey	12	2,265
Clay as above	5	2,270
Sand, very fine to very coarse, predominantly medium to coarse, angular to subangular, quartz, clean	30	2,300
Clay, light brown (5*YR* 5/6), grayish-green (10*G* 4/2), mottled greenish-gray (5*GY* 6/1), and dusky red (5*R* 3/4), silty, mostly non-calcareous, non-swelling	10	2,310
Silt, light brown (5*YR* 5/6)	8	2,318
Clay, dusky red (5*R* 3/4), dense, crumbly, and light brown (5*YR* 5/6), moderate brown (5*YR* 4/4), and light greenish-gray (5*G* 6/1), trace lignite and pyrite	21	2,339
Sand, very fine to very coarse, predominantly coarse, subangular quartz, slightly clayey	17	2,356
Clay, varicolored as in 2,318–2,339 ft; interbedded with very fine clayey sand and silt	60	2,416
Sand, grayish-green (5*G* 5/2), very fine to fine, subangular, with very fine dark grains, slightly clayey	10	2,426
Sand, very fine to very coarse, predominantly fine to medium, subangular	10	2,436
Clay, sandy	2	2,438
Sand as above	5	2,443
Clay interbedded with silt	35	2,478
Sand, grayish-green (10*GY* 5/2), fine, subangular with fine dark specks, slightly clayey, with clay laminae	16	2,494
Clay, moderate brown (5*YR* 4/4), moderate orange-pink (10*R* 7/4), pale greenish-yellow (10*Y* 8/2), dark greenish-gray (5*GY* 4/1), and medium brown (5*YR* 3/4), locally mottled red, gray, and purple; with thin layers of fine to poorly sorted sand and yellow-gray (5*Y* 7/2), light brown (5*YR* 5/6), pale brown (5*YR* 5/2), and dusky yellow (5*Y* 6/4), slightly calcareous silt	154	2,648
Sand, very fine to very coarse, predominantly medium to coarse, subangular, clean	12	2,660
Clay, varicolored as in 2,494–2,648 ft; interbedded with moderate reddish-brown		

Table 14. Interpretative lithologic description, Well DO-CE 88—Continued

Lithology	Thickness (ft)	Depth (ft)
(10*R* 4/6) silt	25	2,685
Sand, dark greenish-gray (5*G* 4/1), silt to very fine, clayey, very finely micaceous, fine lignitic particles, dense; with streaks varicolored clay and silt	25	2,710
Sand, very fine to very coarse, predominantly medium to coarse, subangular, clear to light bluish-gray (5*B* 7/1), grayish-purple (5*RB* 4/2), and very pale orange (10*YR* 8/2) quartz grains	30	2,740
Sand, predominantly very fine to medium, clayey, becoming finer and more clayey downward; interbedded with sandy clay and silt	47	2,787
Sand, very fine to fine, generally clean except for thin silty and clayey streaks	23	2,810
Clay	6	2,816
Sand, very fine to very coarse, predominantly medium to coarse, generally clean except for a few thin silty and clayey streaks; trace lignite and quartz pebbles	20	2,836
Clay, interbedded with silt and clayey sand	64	2,900
Silt, moderate brown (5*YR* 4/4) and dark greenish-gray, clayey, muscovitic, with black carbonaceous laminae	15	2,915
Sand, moderate yellow-brown (10*YR* 6/4), very fine, silty, clayey, with carbonaceous specks	5	2,920
Silt, greenish-gray (5*GY* 6/1), slightly calcareous	4	2,924
Sand, very fine to coarse, predominantly fine to medium, slightly clayey	21	2,945
Clay, pale green (5*G* 7/2) and moderate red-orange (10*R* 6/6), swelling; interbedded with medium reddish-brown (10*R* 4/6) and pale yellowish-brown (10*YR* 6/2) silt and medium yellowish-brown (10*YR* 5/4), very fine silty, clayey sand; trace of lignite	28	2,973
Sand, moderate yellow-brown (10*YR* 5/4), very fine to medium, predominantly very fine, silty, subangular	5	2,978
Clay, as in 2,945–2,973 ft; with thin layers of sand as above and silt	14	2,992
Sand, grayish-green (5*G* 6/1), fine to medium, somewhat clayey	15	3,007
Clay, gray; interbedded with sand as above	3	3,010
Sand, very fine to very coarse, predominantly medium, angular to subangular, becoming clayey downward	7	3,017

Table 14. Interpretative lithologic description, Well DO-CE 88—Continued

Lithology	Thickness (ft)	Depth (ft)
Silt, moderate yellow-brown (10*YR* 5/4) and gray-green (5*G* 5/2), with trace of lignite	8	3,025
Sand, very fine to very coarse, predominantly fine, slightly clayey, with trace of lignite	27	3,052
Sand as above; interbedded with greenish-gray (5*G* 6/1), grayish-green (10*GY* 5/2), very pale green (10*G* 8/2), and light olive-brown (5*Y* 5/6), silty, slightly calcareous clay, and dark yellowish-green (10*GY* 4/4), sandy, slightly calcareous silt, with traces of lignite	40	3,092
Silt, light olive-gray (5*Y* 5/2), very fine sandy, clayey, calcareous	16	3,108
Sand, dark greenish-gray (5*GY* 4/1) to olive-gray (5*Y* 4/1), very fine, subangular, somewhat clayey, becoming increasingly clayey downward	20	3,128
Silt, light olive-gray (5*Y* 5/2), very fine sandy, clayey, calcareous	8	3,136
Sand, very fine to very coarse, predominantly very fine to fine	10	3,146
Sand, very fine to very coarse, predominantly fine to medium, angular to subangular quartz	28	3,174
Silt, dusky yellowish-green (10*GY* 3/2), clayey, slightly calcareous, swells; with thin streaks of clay	16	3,190
Sand, medium gray (*N*3), very fine to medium, predominantly fine, subangular quartz, with traces of muscovite and lignite, clean	28	3,218
Sand, very fine to very coarse, predominantly very fine to fine, angular to subangular quartz; with thin layers of silt and clay	18	3,236
Silt, dusky yellowish-green (10*GY* 3/2), clayey, slightly calcareous, swells	22	3,258
Sand as in 3,218–3,236 ft	5	3,263
Silt as in 3,236–3,258 ft	27	3,290
Sand, very fine to very coarse, predominantly fine to medium, angular to subangular quartz, clean	14	3,304
Precambrian (?) basement		
Gneiss, quartz monzonite, biotitic	33	3,337

[1]Description from surface to 115 ft based on driller's log adjusted to U.S. Geological Survey gamma-ray log.

[2]Colors described from wet samples. Code from Geological Society of America, 1948.

Table 15. Transmissivities, hydraulic conductivities and intrinsic permeabilities based on aquifer-test analyses

Date of test	Perforated interval (feet below KB)[1]	T[2]	K_h[3]	k[4]	Remarks
2/28/81--------	3,188-3,218[5]	380	12.5	4	Temperature corrected for brackish water; Cooper and Jacob (1946), straight-line analyses; T=29.9°C.
3/31/81--------	2,834-2,844	275-300	27-30	9	Temperature corrected. Specific capacity at t=452 min; T=38.3°C.
4/16/81--------	2,649-2,655.6	525	75	18	Temperature corrected. Specific capacity at t=240 min; T=38.0°C.
5/28/81--------	2,278.4-2,288.4	850	85	23	Temperature corrected. Specific capacity at t=217 min; T=34.0°C.
7/31/81--------	1,422.4-1,432.4	25	2.5	0.8	No temperature correction required. Specific capacity at t=152 min and straight line analyses (Cooper and Jacob, 1946); T=25.5°C.

[1]Kelly bushing datum (KB) is 9.42 ft above sea level and 5 ft above land surface.
[2]Transmissivity, in feet squared per day.
[3]Horizontal hydraulic conductivity, in feet per day.
[4]Intrinsic permeability, in micrometers squared. Viscosity of pure water used for all tests except the February 28, 1981, test. The dynamic viscosity used for that test was .8647 cP (centipoises) at 29.9°C.
[5]Screened interval.

Heads

Heads were measured at seven depths. Table 16 lists point-water heads, environmental heads, and freshwater heads. Lusczynski (1961) defines the various heads that can be used to represent pressure conditions in ground waters of variable density. "Point-water head" is generally defined as the water level, relative to a given datum, in a piezometer (a tightly cased well used to measure hydraulic head at a point) filled with water from the zone tapped by the piezometer. "Freshwater head" is the water level in a piezometer filled with freshwater. If the water in the aquifer were fresh, the point-water and freshwater heads would be identical. "Environmental-water head" is the water level in a piezometer filled with water having the same depth-integrated density as the column of ground water in the saturated section penetrated by the piezometer. Freshwater heads are useful in determining the rate and direction of horizontal groundwater flow, whereas environmental heads are useful for analyzing vertical flow.

Figure 9 shows the vertical distribution of point-water heads, environmental heads, freshwater heads, and fluid densities. The vertical profile of environmental heads shows a generalized vertical hydraulic gradient that is causing an upward component of ground-water flow. The upward movement of ground water may be a natural component of the regional prepumping flow

Table 16. Summary of fluid-head measurements

Date	Time	Perforation interval (ft) below KB[1]	Measuring point (ft) relative to sl	Point-water heads (ft) relative to KB	Point-water heads (ft) relative to sl	Environmental-water heads (ft) relative to sl[2]	Freshwater heads (ft) relative to sl[3]
2/27/81------	1215	3,188 -3,218	9.52	-63.17	-53.75	+44.16	+53.22
3/25/81------	0857	2,834 -2,844	6.35	+18.64	+28.06	+40.11	+42.38
4/16/81------	---	2,649 -2,655.6	7.05	+25.52	+34.94	Approximately equal to point-water head	Approximately equal to point-water head
5/27/81------	About 1800	2,278.4-2,288.4	do	+11.53	+20.95	do	do.
6/23/81------	---	1,822.4-1,832.4	do	+5.13	+14.55	do	do.
7/27/81------	---	1,469.4-1,479.4	do	-25.50	-16.08	do	do.
7/31/81------	0915	1,422.4-1,432.4	do	-27.75	-18.33	do	do.

[1]Kelly bushing datum (KB) is 9.42 ft above sea level (sl), or 5 ft above land surface.
[2]Environmental-water heads are not compensated for an increasing temperature with depth. Heads would further increase with depth if the temperature compensation were incorporated.
[3]Freshwater heads computed using density of 0.998 g/ml at 20°C. This density was measured for water from the 1,422.4-1,432.4 ft perforation interval.

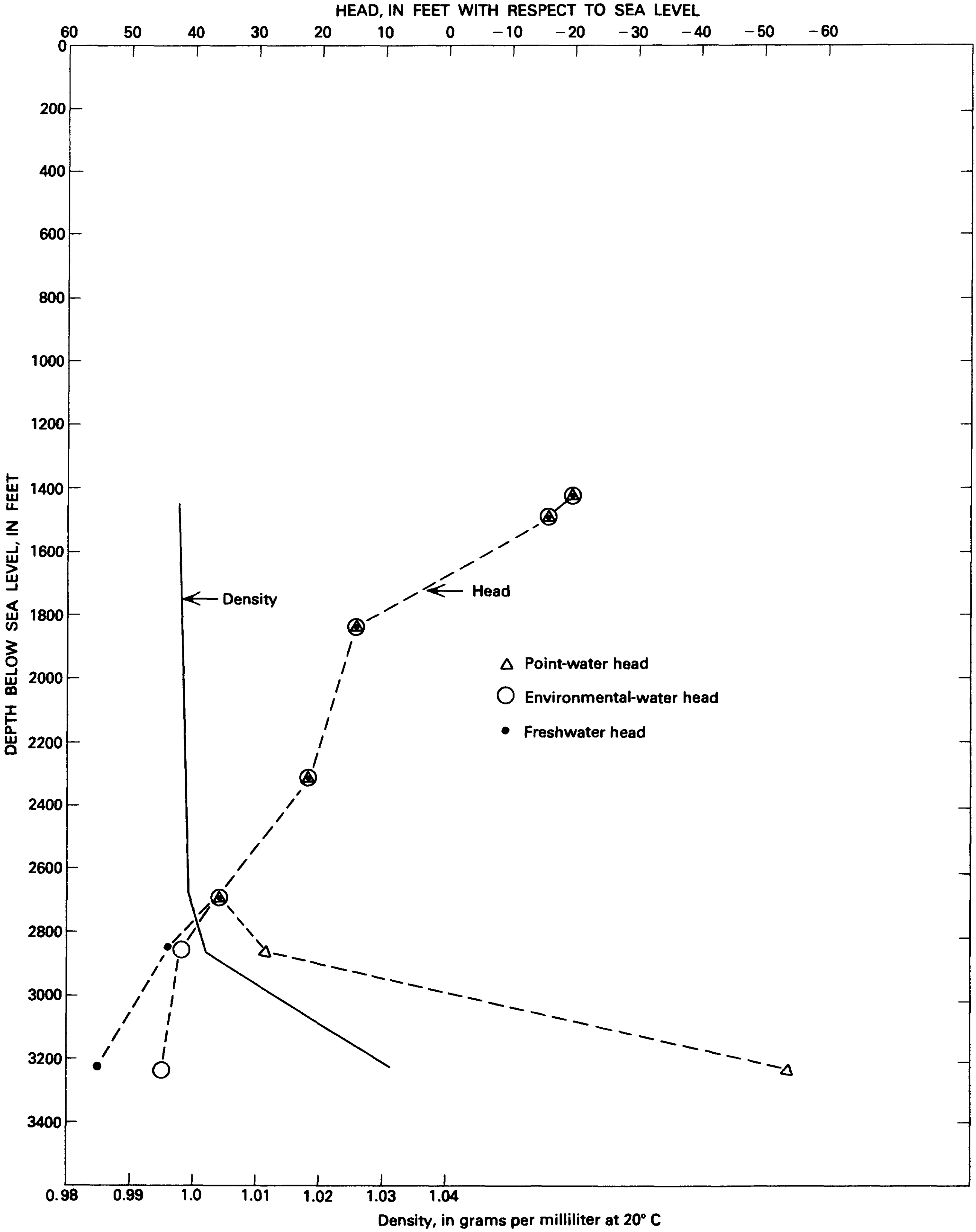

Figure 9. Head and density profile.

Table 17. Principal dissolved chemical constituents of water samples from cores in U.S. Geological Survey test well DO–CE 88 and of selected other samples

Depth (ft below kelly bushing in DO–CE 88; in other wells, reported depth in ft)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Lithium (ug/L as Li)	Sodium (mg/L as Na)	Silica (mg/L as SiO_2)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)
139	48	26	50	310	48	66	160
343	41	21	20	190	46	68	99
397[1]	4.0[1]	3.4[1]	---	177[1]	20[1]	11[1]	5.1[1]
592	12	1.9	20	280	34	71	90
732	3.2	2.3	20	290	16	57	54
955[1]	3.2[1]	2.4[1]	---	139[1]	18[1]	14[1]	6.8[1]
1,113	12	1.9	20	200	11	80	100
1,333[1]	0.4[1]	0.1[1]	---	57[1]	12[1]	18[1]	1.7[1]
1,423[2]	0.6[2]	0.5[2]	---	95[2]	14[2]	16[2]	2.3[2]
1,438	11	1.3	<20	170	17	56	79
1,652	8.6	0.1	<60	180	17	26	50
1,823[2]	1.5[2]	0.6[2]	---	240[2]	15[2]	35[2]	2.8[2]
1,952	5.3	1.9	<20	300	47	47	30
2,094	15	2.7	<100	230	12	110	57
2,203	48	23	<60	960	7.4	1,400	230
2,279[2]	2[2]	0.4[2]	---	260[2]	18[2]	35[2]	120[2]
2,319	36	21	<80	660	10	490	280
2,425	11	1.3	<60	270	8.1	150	28
do	4.6	3.5	<20	400	110	130	28
2,484	9.4	4.6	<50	430	22	330	62
2,649[2]	1.1[2]	0.4[2]	---	230[2]	19[2]	28[2]	140[2]
2,694	16	3.5	<100	570	3.8	230	440
2,695	6.9	0.3	<60	480	93	74	360
2,823	73	10	<80	1,200	17	370	1,200
2,834[2]	44[2]	7.7[2]	---	1,400[2]	19[2]	38[2]	2,200[2]
2,900	1,000	180	<600	6,300	1.3	860	10,000
do	---	---	---	---	---	720	11,000
3,010	1,300	200	200	7,600	1.1	660	12,000
do	---	---	---	---	---	310	17,000
3,110	2,000	350	500	11,000	7.7	390	18,000
do	---	---	---	---	---	360	---
3,188[2]	2,900[2]	490[2]	---	14,000[2]	14[2]	665[2]	27,800[2]
3,210	2,100	320	900	9,500	3.8	460	18,000
3,210	2,200	400	2,000	9,100	5.5	200	18,000
3,336	---	---	---	---	---	---	6,600
do	---	---	---	---	---	---	7,100

[1]Analyses from wellhead water samples from nearby wells; shown for comparison with core samples from DO–CE 88.
[2]Analyses of wellhead water samples from DO–CE 88; shown for comparison with core samples.

system, or it may be, in part, induced by the withdrawal of ground water from shallower aquifers in the Cambridge area.

A continuous water-level recorder monitored water levels in the 3,188- to 3,218-ft screened zone March 4–7, 1981. During this period, tidal fluctuations of approximately 0.8 ft were observed in the well, with peaks about every 12.5 hours. In addition, the observed water level responded to longer term changes in atmospheric pressure.

GEOCHEMISTRY

Water Analyses

Water samples for chemical analysis were obtained from two principal sources: water that flowed or was pumped from screened or perforated zones (wellhead samples) and water from cores.

Water from Cores

Water samples were squeezed from sediment cores in a stainless steel hydraulic squeezer described by Manheim (1966, p. C256–C260). The chemical analyses are given in table 17. Generally, 25 to 50 grams of sediment, obtained from the inner part of the core (to lessen the possibility of contamination from drilling fluid), were placed in the squeezer. Pressures used to extract the interstitial water ranged from about 4,000 to 20,000 lb/in^2. The lower pressures were adequate to squeeze water from cores obtained at depths of less than 1,700 ft and from the sandy cores at any depth. The higher pressures were required for the deeper, nonsandy materials. Water samples ranged in volume from about 0.5 mL to more than 3 mL, the shallower and sandier materials generally yielding more water. Analyses were performed in the U.S. Geological Survey National Water Quality Laboratory, Atlanta, Ga., using ion chromatography and argon plasma emission spectrometry.

Chloride concentrations of interstitial water were determined from basement cores obtained at 3,336 ft (Manheim, F. T., 1982, written commun.). Nine grams of the inner part of the core were ground to submicron size in a tungsten carbide mill, diluted with 70 grams of distilled water, and centrifuged in an ultra centrifuge at 40,000 rpm for up to 1 hour. Analyses were performed at the Branch of Atlantic–Gulf of Mexico Geology, Woods Hole, Mass., using a Coulometric Buchler chloridometer.

The zone of transition from freshwater downward to saltwater that is roughly equivalent to seawater, as indicated by chloride concentrations in both the squeezed and wellhead samples (also shown in table 17), occurs between 2,650 and 3,100 ft. In this zone and in the highly saline zone below, the water is principally of a sodium chloride character (terminology of Back, 1966), although significant concentrations of calcium occur below 2,900 ft. In the freshwater section, above 2,650 ft, the water is of a sodium bicarbonate character in the wellhead samples and probably in all but one of the squeezed samples. However, the squeezed samples from 2,094 to 2,900 ft contain much higher concentrations of sulfate than do wellhead samples from similar depths. Also, concentrations of calcium, magnesium, sodium, and, most notably, chloride in the freshwater section are generally higher in the squeezed samples than in the wellhead samples.

Water Produced from Well

Wellhead samples from six zones were analyzed by the U.S. Geological Survey National Water Quality Laboratory in Atlanta. The samples were collected after the specific conductance, temperature, and pH of the water pumped or flowing from the well had stabilized. Standard U.S. Geological Survey techniques were used to collect the water samples; temperature, pH, specific conductance, and alkalinity were measured in the field.

Table 18 shows the results of the analyses for the six zones sampled. The variation of concentration with depth is shown graphically in figure 10 for the major cations and in figure 11 for the major anions and silica. Three additional chemical analyses from nearby wells (DO-CE 2, DO-CE 3, DO-CE 82), which were screened

Table 18. Chemical analyses of wellhead water samples

Parameter	Depth to top of sampled interval below kelly-bushing, in feet[1]					
	1423	1823	2279	2649	2834	3188
Date	7/31/81	6/23/81	5/28/81	4/16/81	3/26/81	2/28/81
Time	1200	0900	1345	1900	1330	1745
Geologic unit code[2]	217 PPSC	217 PPSC	217 ARDL	217 ARDL	217 PTXN	217 PTXN
Discharge, gal/min	7	10	52	57	30	32
Temperature, °C	22.5	21.5	33.0	37.0	34.0	35.5
Specific conductance, field[3]	410	760	996	920	6,500	58,500
Specific conductance, lab[3]	394	828	1,060	1,010	7,250	64,300
Density, g/mL	.998	.999	.999	1.000	1.003	1.032
Field pH, units	8.5	8.6	8.4	8.7	7.8	7.6
Lab pH, units	8.5	8.5	8.6	8.8	8.2	6.2
Saturation index (calcite)	−.89	−.13	−.13	−.12	.15	.74
Turbidity[4]	200	260	.65	4.6	7.1	.00
Calcium, dissolved	.6	1.5	2.0	1.1	44	2,900
Magnesium, dissolved	.5	.6	.4	.4	7.7	490
Potassium, dissolved	5.0	3.5	1.9	1.5	8.9	48
Sodium, dissolved	95	240	260	230	1,400	14,000
Alkalinity (as $CaCO_3$), dissolved[5]	172	425	341	276	150	48
Sulfate, dissolved	16	35	35	28	38	665

See footnotes at end of table.

Table 18. Chemical analyses of wellhead water samples—Continued

Parameter	Depth to top of sampled interval below kelly-bushing, in feet[1]					
	1423	1823	2279	2649	2834	3188
Date	7/31/81	6/23/81	5/28/81	4/16/81	3/26/81	2/28/81
Time	1200	0900	1345	1900	1330	1745
Chloride, dissolved	2.3	2.8	120	140	2,200	27,800
Fluoride, dissolved	1.4	2.3	1.3	1.0	.4	.3
Silica, dissolved	14	15	18	19	19	14
Phosphorus (as P), dissolved	.21	—	.13	—	—	—
Phosphorus (as P), total	.69	—	.11	—	—	—
Nitrogen, ammonia (as N), dissolved	.05	—	.09	—	—	—
Nitrogen, ammonia (as N), total	.60	—	.08	—	—	—
Solids, residue at 180 °C, dissolved	255	575	631	594	3,910	45,500
Solids, sum of constituents, dissolved	250	560	637	596	3,820	47,200
Hardness (as $CaCO_3$)	4	6	7	4	140	9,300
Aluminum, dissolved[6]	120	410	10	70	30	10
Arsenic, dissolved[6]	1	1	1	0	0	1
Arsenic, suspended[6]	0	8	1	0	0	0
Barium, dissolved[6]	30	50	40	20	400	—
Barium, suspended[6]	400	300	60	80	0	—
Boron, dissolved[6]	400	780	360	400	560	—
Bromide, dissolved	.018	.016	.8	.9	19	—
Cadmium, dissolved[6]	1	2	<1	1	1	0
Cadmium, suspended[6]	0	—	—	0	2	0
Chromium, dissolved[6]	10	<10	20	10	20	50
Chromium, suspended[6]	210	—	0	10	10	0
Cobalt, dissolved[6]	<1	<1	2	4	1	1
Cobalt, suspended[6]	—	—	0	0	0	0
Copper, dissolved[6]	2	2	1	0	0	2
Copper, suspended[6]	68	150	5	2	1	0
Iron, dissolved[6]	350	140	310	100	710	7,200
Iron, suspended[6]	48,000	39,000	130	1,300	1,100	5,800
Lead, dissolved[6]	6	1	0	1	0	0
Lead, suspended[6]	22	32	1	1	1	11
Manganese, dissolved[6]	7	20	30	10	280	8,600
Manganese, suspended[6]	410	470	0	20	0	400
Mercury, dissolved[6]	<.1	.2	.2	.3	1.4	3.0
Mercury, suspended[6]	—	.2	.0	.1	.8	.0
Nickel, dissolved[6]	<1	2	1	0	0	1
Nickel, suspended[6]	—	47	9	8	9	2
Potassium 40 (as K40), dissolved[7]	3.7	—	1.4	1.1	6.6	37
Selenium, dissolved[6]	<1	<1	0	0	0	0
Selenium, suspended[6]	—	—	0	0	0	0
Silver, dissolved[6]	<1	<1	0	0	0	0
Silver, suspended[6]	—	—	0	0	0	0
Sodium adsorption ratio	22	46	44	48	51	63
Sodium percent	95	98	98	99	95	77
Zinc, dissolved[6]	10	<4	<4	<4	10	40
Zinc, suspended[6]	100	—	—	—	20	200

[1]Concentrations in milligrams per liter unless otherwise indicated.

[2]217 PPSC designates Patapsco Fm., 217 PTXN designates Patuxent Fm. and 217 ARDL designates Arundel Fm.; upper, lower, and middle parts, respectively, of the Potomac Group.

[3]Micromhos per centimeter at 25°C.

[4]Nephelometric turbidity units.

[5]Field measurement.

[6]Micrograms per liter. One milligram equals 1,000 micrograms.

[7]Picocuries per liter.

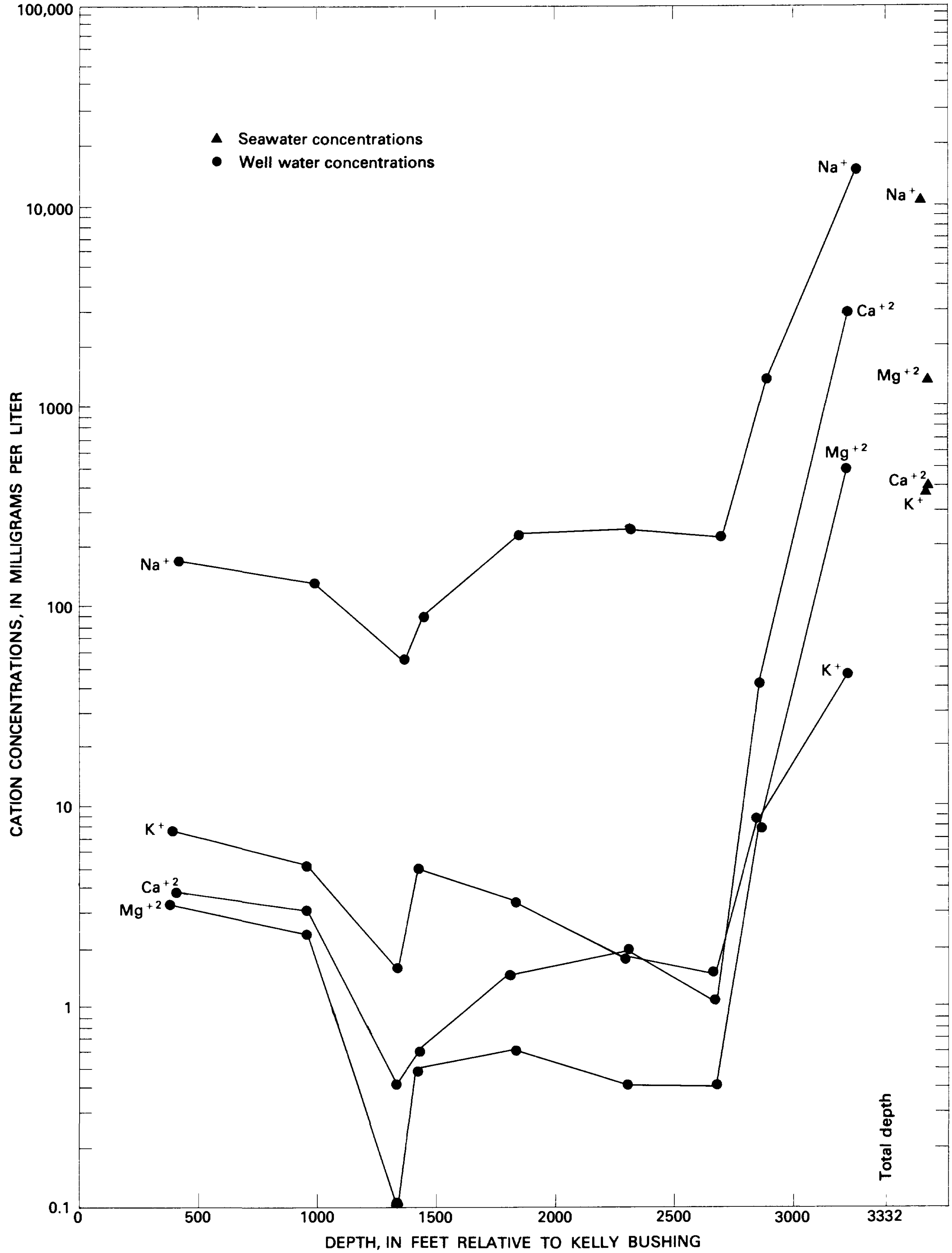

Figure 10. Variation in concentration of major cations with depth.

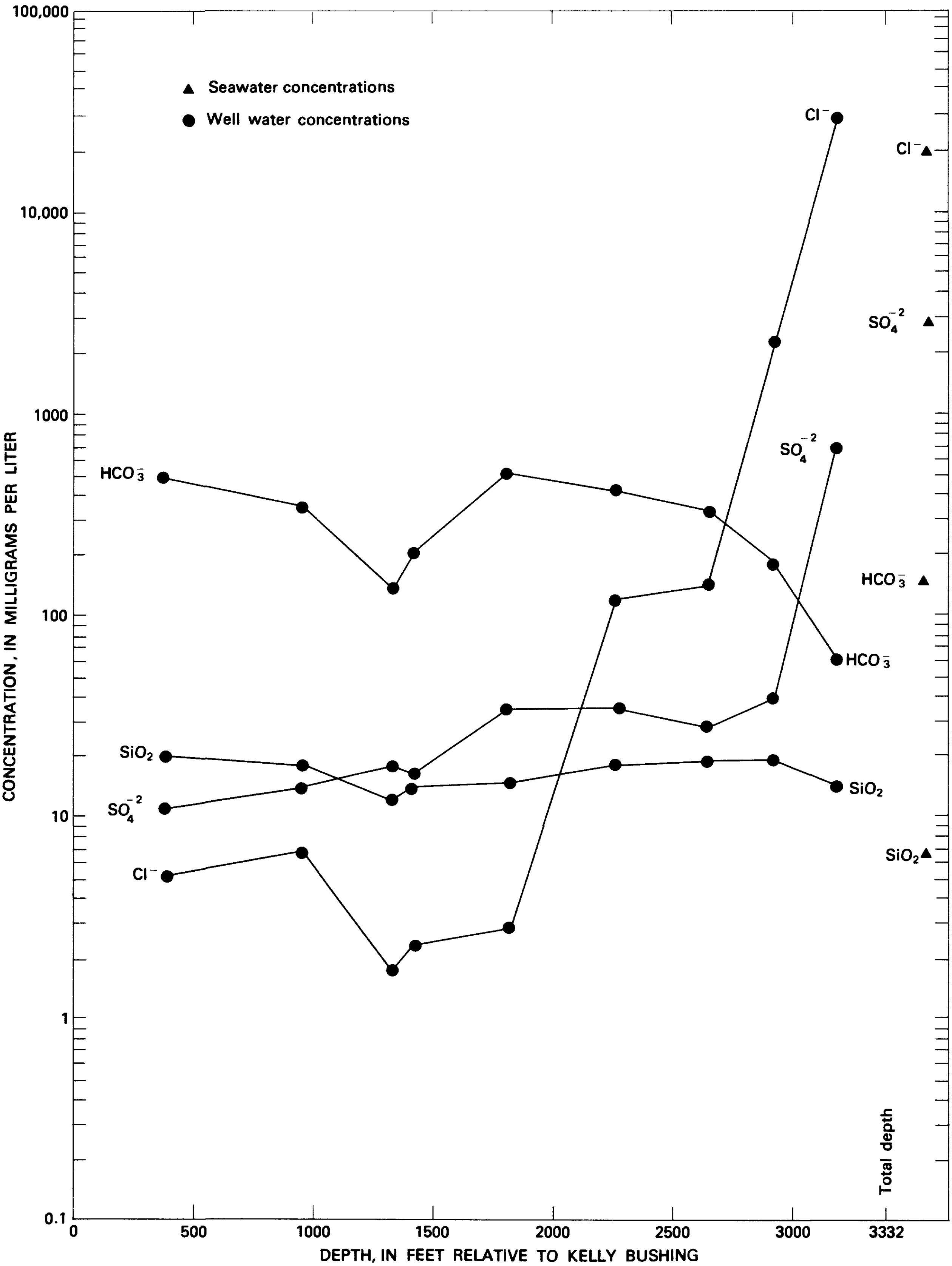

Figure 11. Variation in concentration of major anions and silica with depth.

at shallower depths (Woll, 1978), are included in figures 10 and 11. Seawater concentrations (Hem, 1970, p. 11) are also plotted for comparison.

As shown in figure 10, calcium (Ca^{+2}) and magnesium (Mg^{+2}) decrease in concentration by about an order of magnitude between 397 and 1,333 ft. Potassium (K^{+}) and sodium (Na^{+}) decrease, but by less than an order of magnitude. From 1,333 to 1,418 ft, the concentrations of the ions increase to levels somewhat lower than in the sample at 397 ft. Between 2,649 and 3,188 ft, the concentrations of the cations increase sharply to their maximum levels. The water at 3,188 ft is a brine having total dissolved solids concentration 1.4 times that of seawater. The concentrations of Na^{+} and Ca^{+2} are higher in the brine sample than in seawater, whereas the concentrations of Mg^{+2} and K^{+} are lower.

Figure 11 shows that chloride (Cl^{-}) and sulfate (SO_4^{-2}) concentrations vary with depth in a manner roughly similar to that of the cations. Alkalinity (as HCO_3^{-}) concentrations vary with depth in a manner nearly identical to that of Na^{+} in the freshwater section above 2,649 ft. However, beginning at 2,649 ft, alkalinity decreases sharply downward to a minimum at 3,188 ft. Silica (SiO_2) concentrations are relatively constant in the freshwater section and somewhat higher than seawater. Alkalinity and SO_4^{-2} concentrations in the brine at 3,188 ft are lower and the Cl^{-} and SiO_2 concentrations are higher than in seawater.

Figure 12 is a diagram showing the hydrochemical facies of the test-well water samples and of the three analyses reported by Woll (1978). The diagram is of a type originated by Durov (1948) and described by Zaporozec (1972). The Durov diagram permits the plotting of two parameters in addition to relative concentrations of common ions. In figure 12, these parameters are depth relative to kelly bushing and the saturation index (SI) of the water with respect to calcite.

Figure 12 indicates that the cation facies is of the sodium type while the anion facies is of either the bicarbonate type or the chloride type. Combination of the cation and anion facies indicates water of a sodium bicarbonate character or a sodium chloride character. The figure also shows that the ground water changes progressively with depth from a sodium bicarbonate character to a sodium chloride character.

SI was determined for the analyses by the computer program WATEQF (Plummer and others, 1976) and is defined as

$$SI = \log \frac{IAP}{K},$$

where IAP = ion activity product and K = the equilibrium constant for the reaction.

An SI of 0 indicates that the water is in equilibrium with respect to a reaction. A negative SI indicates that the water is undersaturated, and a positive SI indicates that the water is supersaturated.

The saturation indices indicate that the analyses from the freshwater section are undersaturated (negative) with respect to calcite ($CaCO_3$). The more negative a number, the more undersaturated the water. The most undersaturated water is at 1,333 ft, which corresponds to the abrupt decrease in concentrations of Ca^{+2} and HCO_3^{-} shown on figure 10 and figure 11, respectively. The two analyses from deeper saline sections are supersaturated with respect to $CaCO_3$. The saturation indices for the wellhead samples are also given in table 16.

Cation Exchange Capacities and Concentrations of Exchangeable Cations

Samples of 20 cores were analyzed for cation exchange capacities (CEC), by means of standard techniques (Hesse, 1972), at the U.S. Geological Survey National Water Quality Laboratory in Denver. The CEC of colloidal material is defined by Van Olphen (1963) as the excess of counter ions (ions on the surface of a colloidal particle) in the zone adjacent to the charged surface or layer that can be exchanged for other cations. CEC is normally expressed as the number of milliequivalents of cations that can be exchanged per 100 grams of dry sample (meq/100g). The results of the cation exchange capacity analyses are listed in table 19 for triplicate samples.

Table 19. Cation exchange capacities from core samples, in milliequivalents per 100 grams

Depth[1]	Primary	Duplicate	Triplicate	Mean
130	12.4	9.6	12.0	11.3
340	26.4	26.4	24.0	25.6
590	29.6	24.8	32.8	29.1
730	28.0	23.2	27.2	26.1
863	18.4	16.4	16.0	16.9
912	16.0	11.6	15.2	14.3
1,111	13.6	12.4	16.4	14.1
1,436	14.4	11.2	12.0	12.5
1,650	21.6	20.0	24.0	21.9
1,753	16.4	14.4	10.4	13.7
1,950	31.2	28.0	28.4	29.2
2,094	22.4	20.0	23.2	21.9
2,200	21.6	20.0	20.8	20.8
2,319	34.4	32.8	35.2	34.1
2,422	16.8	13.6	17.2	15.9
2,484	16.0	13.6	18.4	16.0
2,585	37.6	37.6	41.6	38.9
2,692	20.8	16.4	16.8	18.0
3,008	14.4	11.2	13.6	13.1
3,210	8.0	7.2	9.6	8.3

[1]Feet below kelly bushing.

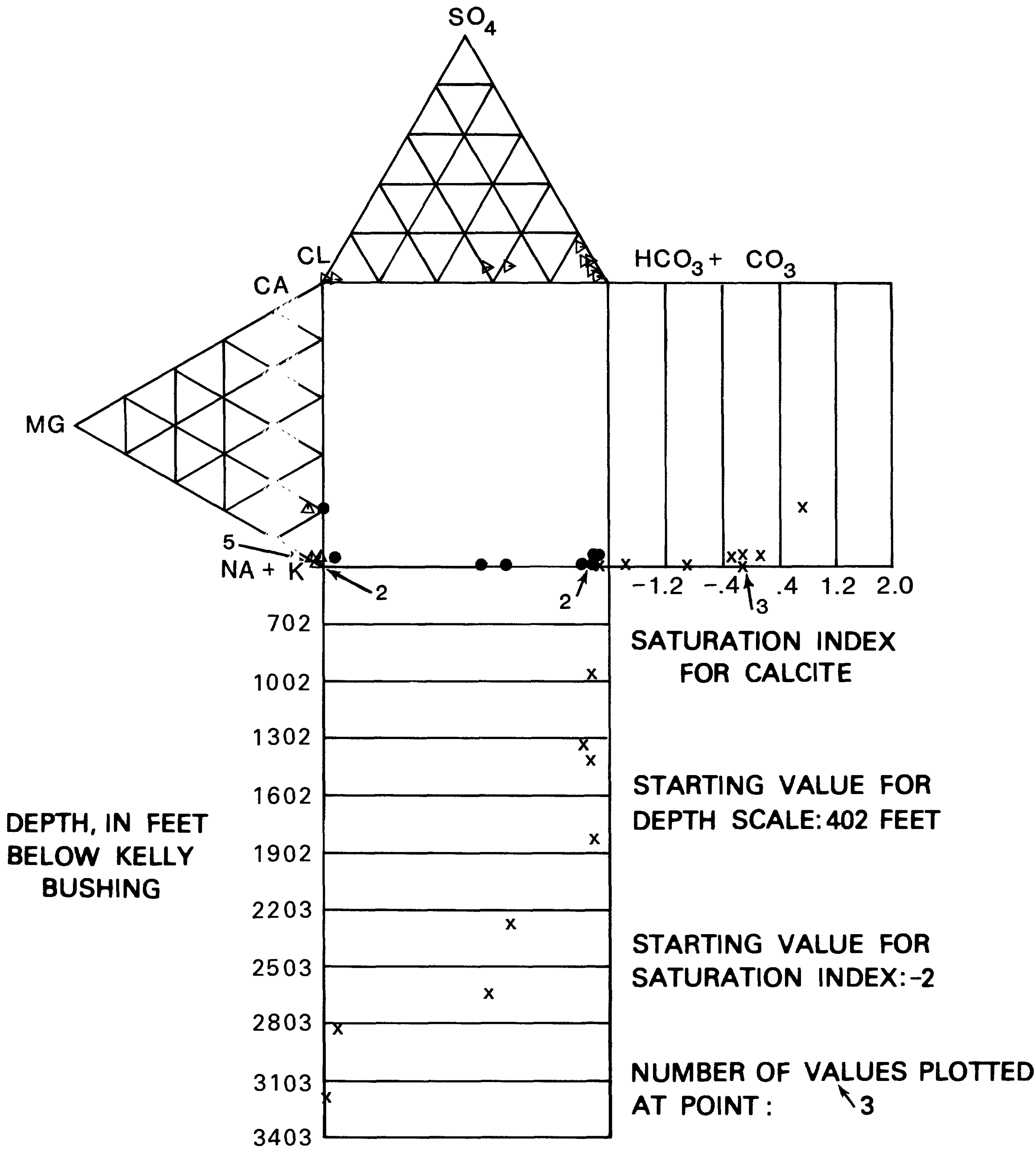

Figure 12. The hydrochemical facies of ground water from test well DO-CE 88 and other nearby wells.

The same samples were also analyzed for concentrations of exchangeable cations. Exchangeable cations are cations that can be expected to enter or leave the layer of counter ions on the colloidal surface. The samples were successively leached three times with ammonium acetate buffer. The leachates were then analyzed by atomic absorption spectrophotometry for calcium, magnesium, potassium, and sodium (Delora Boyle, U.S. Geological Survey, written commun., October 23, 1981). Table 20 shows the exchangeable cations in milligrams per gram (mg/g) for duplicate samples.

The data in table 20 were converted to millimoles

Table 20. Exchangeable cations from core samples, in milligrams per gram

	Calcium			Magnesium			Potassium			Sodium		
Depth[1]	Primary	Duplicate	Mean	Primary	Duplicate	Mean	Primary	Duplicate	Mean	Primary	Duplicate	Mean
130	2.85	2.70	2.78	.80	.86	.83	.33	.32	.33	.34	.35	.35
340	10.35	10.75	10.55	2.33	2.61	2.47	1.17	1.38	1.28	1.06	1.08	1.07
590	45.00	58.50	51.75	1.25	1.61	1.43	7.99	6.97	7.48	5.04	5.22	5.13
730	22.80	24.20	23.50	1.22	1.32	1.27	2.91	2.79	2.85	2.60	2.31	2.46
863	8.95	8.85	8.90	1.24	1.49	1.37	1.11	1.24	1.18	1.52	1.47	1.50
912	2.28	2.64	2.46	1.25	1.46	1.36	.35	.42	.39	.93	.94	.94
1,111	1.74	2.32	2.03	.69	.82	.76	.62	.65	.64	.90	.89	.90
1,436	1.05	1.10	1.08	.47	.59	.53	.37	.44	.41	.89	.89	.89
1,650	2.31	2.42	2.37	.87	.95	.91	.48	.62	.55	2.59	2.34	2.47
1,753	1.27	1.36	1.32	.61	.69	.65	.33	.39	.36	1.66	1.56	1.61
1,950	3.05	3.02	3.04	1.22	1.38	1.30	.49	.62	.56	4.27	4.43	4.35
2,094	2.74	2.49	2.62	.70	.77	.74	.50	.50	.50	1.79	2.24	2.02
2,200	2.50	2.89	2.70	.71	.73	.72	.33	.42	.38	3.14	2.75	2.95
2,319	4.65	4.97	4.81	.95	1.12	1.04	.51	.56	.54	4.46	5.65	5.06
2,422	1.61	1.54	1.58	.41	.47	.44	.22	.32	.27	1.86	1.78	1.82
2,484	1.61	1.73	1.67	.41	.53	.47	.24	.32	.28	1.66	1.52	1.59
2,585	4.56	5.18	4.87	.92	1.16	1.04	.48	.53	.51	4.46	5.15	4.81
2,692	1.65	1.81	1.73	.53	.65	.59	.20	.32	.26	1.53	1.48	1.51
3,008	1.76	1.85	1.81	.19	.24	.22	.25	.35	.30	2.82	2.37	2.60
3,210	1.24	1.29	1.27	.17	.21	.19	.09	.20	.15	1.89	1.44	1.67

[1]Feet below kelly bushing.

per 20 grams and plotted in figure 13 to show the variations with depth for the exchangeable cations. Also plotted in figure 13 are the mean CEC data given in table 19.

SUMMARY AND CONCLUSIONS

Test well DO-CE 88 penetrated 3,299 ft of Quaternary, Tertiary, and Cretaceous unconsolidated Coastal Plain sediments, chiefly clay and sand, and 33 ft of quartz monzonite gneiss bedrock. Twenty-one core samples were collected to determine interstitial water chemistry, mineralogy, lithology, hydraulic properties, paleontologic age, and cation exchange properties. In addition, six sand zones were tested for aquifer properties and sampled to determine ground-water chemistry. Point-water heads were measured at seven depths. A temperature log showed a maximum temperature of 41.9°C and a mean temperature gradient of 0.00838°C/ft.

The analyses of water samples indicate that the zone of freshwater-saltwater transition occurs between 2,650 and 3,100 ft. Also, the ground water changes progressively with depth from a sodium bicarbonate to a sodium chloride character.

Most of the clays in the analyzed core samples belong to the montmorillonite group. However, the clays in the Upper Cretaceous Magothy Formation and the upper third of the Lower Cretaceous Potomac Group, undifferentiated, belong predominately to the kaolinite group. Mean cation exchange capacity ranged from 8.3 to 38.9 meq/100g in core samples.

Vertical and horizontal hydraulic conductivities measured in cores ranged from 1.5×10^{-6} to 1.3 ft/d and from 7.3×10^{-6} to 1.3 ft/d, respectively, but the most permeable sands were not cored. Porosity was 1.5 percent in the quartz monzonite bedrock and ranged from 22.4 to 41 percent in the overlying sediments.

Fossils identified in core samples include palynomorphs, dinoflagellates, and foraminifers.

In aquifer tests of five zones between depths of 1,422 and 3,218 ft, transmissivities ranged from 25 to 850 ft^2/d, horizontal hydraulic conductivities ranged from 2.5 to 85 ft/d, and intrinsic permeabilities ranged from 0.8 to 23 $(\mu m)^2$. Observed water levels used to analyze the aquifer tests were corrected for increasing water temperature. The increasing temperature caused the density of the water in the well to decrease during discharge.

Calculated environmental heads ranged from −18.33 to +44.16 ft relative to sea level, indicating an upward component of flow. This upward movement of water may be a natural component of the regional prepumping flow system, or it may be, in part, induced by withdrawal of ground water from shallower aquifers.

SELECTED REFERENCES

Abbott, W. H., 1978, Correlation and zonation of Miocene strata along the Atlantic margin of North America using diatoms and silicoflagellates: Marine Micropaleontology, v. 3, p. 15–34.

Armentrout, J. A., and Abbott, W. H., eds., North American Cenozoic biostratigraphy, symposium volume: Elsevier Press (in press).

Back, William, 1966, Hydrochemical facies and ground-water flow patterns in northern part of Atlantic Coastal Plain: U.S. Geological Survey Professional Paper 498–A, 42 p.

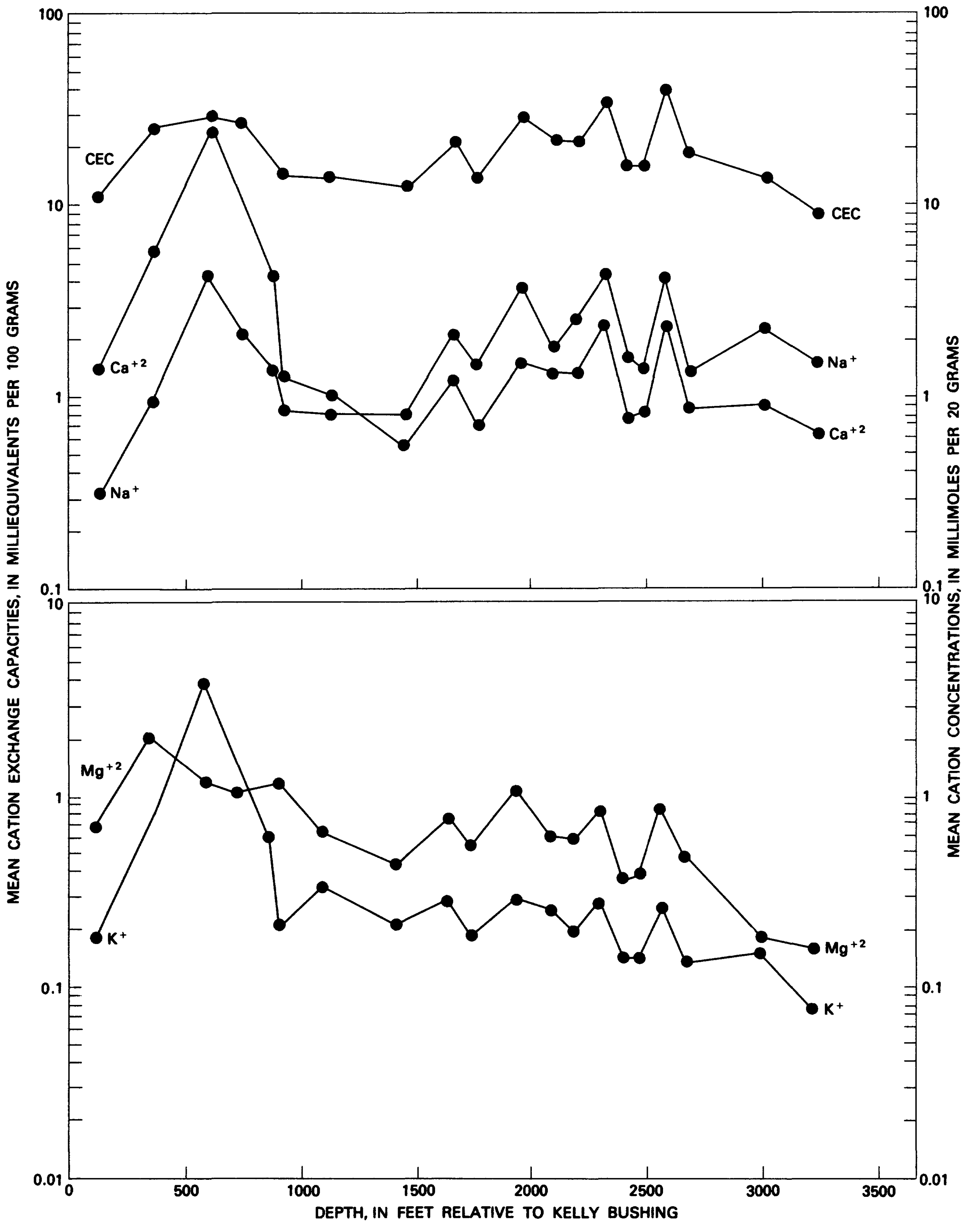

Figure 13. Cation exchange capacities and exchangeable cation concentrations.

Bebout, J. W., 1980, Observed stratigraphic distribution of spores, pollen, and Incertae Sedis palynomorphs in the Tertiary section of the COST No. B-2 well, Baltimore Canyon, Atlantic Outer Continental Shelf: Palynology, v. 4, p. 181–196.

Bredehoeft, J. D., 1965, The drill-stem test: The petroleum industry's deep-well pumping test: Ground Water, v. 3, no. 3, p. 31–36.

Brenner, G. J., 1963, The spores and pollen of the Potomac Group of Maryland: Maryland Department of Geology, Mines and Water Resources Bulletin, v. 27, 215 p.

Brown, R. H., 1963, Estimating the transmissivity of an artesian aquifer from the specific capacity of a well, *in* Bentall, Ray, compiler, Methods of determining permeability, transmissibility and drawdown: U.S. Geological Survey Water-Supply Paper 1536-I, p. 336–338.

Christopher, R. A., 1979, Normapolles and triporate pollen assemblages from the Raritan and Magothy Formations (Upper Cretaceous) of New Jersey: Palynology, v. 3, p. 73–121.

Cooper, H. H., Jr., and Jacob, C. E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: American Geophysical Union Transactions, v. 27, no. 4, p. 526–534.

Cushing, E. M., Kantrowitz, I. H., and Taylor, K. R., 1973, Water resources of the Delmarva Peninsula: U.S. Geological Survey Professional Paper 822, 58 p., 12 pl.

Dörhöfer, Gunter, 1977, Palynologie und Stratigraphie der Bukeberg-Formation (Berriasium-Valanginium) in der Hilsmulde (NW-Deutschland): Geologische Jahrbuch, ser. A, no. 42, p. 3–122, 15 pls., 8 figs., 3 tabs.

Doyle, J. A., and Robbins, E. A., 1977, Angiosperm pollen zonation of the continental Cretaceous of the Atlantic Coastal Plain and its application to deep wells in the Salisbury Embayment: American Association of Stratigraphic Palynologists, Inc., 8th annual meeting, Houston, 1975, Proceedings, v. I, Palynology, p. 43–78.

Durov, S. A., 1948, Klassifikacija prirodnych vod i graficeskoje izobrazenie ich sostava. [Classification of natural waters and graphic representation of their composition]: Doklady Ak. Nauk SSSR, v. 59, no. 1, p. 87–90.

Freeze, R. A., and Cherry, J. A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Geological Society of America, 1948, Rock color chart: Reprinted 1963, The Netherlands, Huyskes-Enschede.

Gibson, T. G., and others, 1980, Biostratigraphy of the Tertiary strata of the core, *in* Geology of the Oak Grove core: Virginia Division of Mineral Resources Publication 20, pt. 2, 88 p.

Hansen, Harry J., 1978, Upper Cretaceous (Senonian) and Paleocene (Danian) pinchouts on the south flank of the Salisbury Embayment, Maryland, and their relationship to antecedent basement structures: Maryland Geological Survey Report of Investigations, no. 29, 36 p.

______1981, Stratigraphic discussion in support of a major unconformity separating the Columbia Group from the underlying upper Miocene aquifer complex in eastern Maryland: Southeastern Geology, v. 22, no. 3, p. 123–137.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water, 2nd ed.: U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Hesse, P. R., 1972, A textbook of soil chemical analysis: New York, Chemical Publishing Co., 520 p.

Hughes, N. F., and Croxton, C. A., 1973, Palynologic correlation of the Dorset "Wealden": Paleontology, v. 16, no. 3, p. 567–601.

INTERCOMP Resource Development and Engineering, Inc., 1976, A model for calculating effects of liquid waste disposal in deep saline aquifers: U.S. Geological Survey Water-Resources Investigations 76-61, 252 p.

Krumbein, W. C., and Pettijohn, F. J., 1938, Manual of sedimentary petrography: New York, London, Appleton-Century-Crofts, 549 p.

Lohman, S. W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 69 p., 9 pl.

Lusczynski, N. J., 1961, Head and flow of ground water of variable density: Journal of Geophysical Research, v. 66, no. 12, p. 4247–4256.

Mack, F. K., Webb, W. E., and Gardner, R. A., 1971, Water resources of Dorchester and Talbot Counties, Maryland, with special emphasis on the ground-water potential of the Cambridge and Easton areas: Maryland Geological Survey Report of Investigations, no. 17, 107 p.

Manheim, F. T., 1966, A hydraulic squeezer for obtaining interstitial water from consolidated and unconsolidated sediments, *in* Geological Survey Research 1966: U.S. Geological Survey Professional Paper 550-C, C256–C261.

Plummer, L. N., Jones, B. F., and Truesdell, A. H., 1976, WATEQF--A FORTRAN IV version of WATEQ, a computer program for calculating chemical equilibrium of natural waters: U.S. Geological Survey Water Resources Investigations 76-13, 61 p. (Reprinted 1978).

Reinhardt, Juergen, Christopher, R. A., and Owens, J. P., 1980, Lower Cretaceous stratigraphy of the core, *in* Geology of the Oak Grove core: Virginia Division of Mineral Resources Publication 20, pt. 3, 88 p.

Reinhardt, Juergen, Newell, W. L., and Mixon, R. B., 1980, Tertiary lithostratigraphy of the core, *in* Geology of the Oak Grove core, Virginia Division of Mineral Resources Publication 20, pt. 1, 88 p.

Schlumberger Limited, 1972, Log interpretation principles: New York, 113 p.

______1977, Log interpretation, charts: New York, 83 p.

Shattuck, G. B., 1904, Geologic and paleontologic relations with a review of earlier investigations, *in* Clark, W. B., Shattuck, G. B., and Dall, W. H., eds., The Miocene deposits of Maryland: Maryland Geological Survey, Miocene Volume, p. xxxiii–xciv.

Van Olphen, H., 1963, An introduction to colloid chemistry: New York, Wiley Interscience, 301 p.

Wolfe, J. A., and Pakiser, H. M., 1971, Stratigraphic interpretations of some Cretaceous microfossil floras of the Middle Atlantic States, *in* Geological Survey Research 1971: U.S. Geological Survey Professional Paper 750, p. B35–B47.

Woll, R. S., 1978, Maryland ground-water information: Chemical quality data: Maryland Geological Survey Water Resources Basic-Data Report, no. 10, 126 p.

Zaporozec, Alexander, 1972, Graphical interpretation of water quality data: Ground Water, no. 10, p. 32–43.

Metric Conversion Factors

Multiply inch-pound unit	By	To obtain metric (SI) unit
in. (inch)	25.4	mm (millimeter)
in. (inch)	2.54×10^{-8}	A (angstrom units)
ft (foot)	.3048	m (meter)
ft/d (feet per day)	3.528×10^{-5}	m/s (meters per second)
ft^2/d (feet squared per day)	1.075×10^{-6}	m^2/s (meters squared per second)
lb/in^2 (pounds per square inch)	6,894	Pa (pascals)
gal/min (gallons per minute)	0.06309	L/s (liters per second)
sl (sea level)	---	National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.
KB (kelly-bushing)	---	9.42 ft above sl or 5 ft above land surface