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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



TEST WELL DO-CE 88 AT CAMBRIDGE,
DORCHESTER COUNTY, MARYLAND

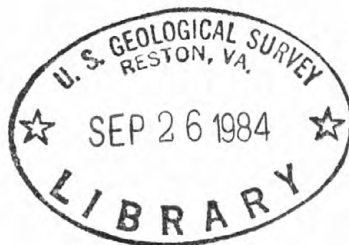
By Henry Trapp, Jr., LeRoy L. Knobel,
Harold Meisler, and P. Patrick Leahy

U.S. GEOLOGICAL SURVEY

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Open-file report
(Geological Survey
(U.S.))

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



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UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

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Metric Conversion Table

<u>Multiply inch-pound unit</u>	<u>By</u>	<u>To obtain metric (SI) unit</u>
inch (in)	25.4	millimeter (mm)
-----	2.54×10^{-6}	angstrom units (Å)
foot (ft)	.3048	meter (m)
feet per day (ft/d)	3.528×10^{-5}	meters per second (m/s)
feet squared per day (ft ² /d)	1.075×10^{-6}	meters squared per second (m ² /s)
pounds per square inch (lb/in ²)	6,894	pascals (Pa)
gallons per minute (gal/min)	0.06309	liters per second (L/s)
<hr/>		
sea level (sl)	-----	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.
kelly-bushing (KB)	-----	9.42 ft above sl or 5 ft above land surface

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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, Maryland 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, Maryland, 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 lat 38°34'01" N.; long 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 Maryland Geological Survey, described the petrology of the basement cores. Lowell Douglas and Pa Ho Hsu of

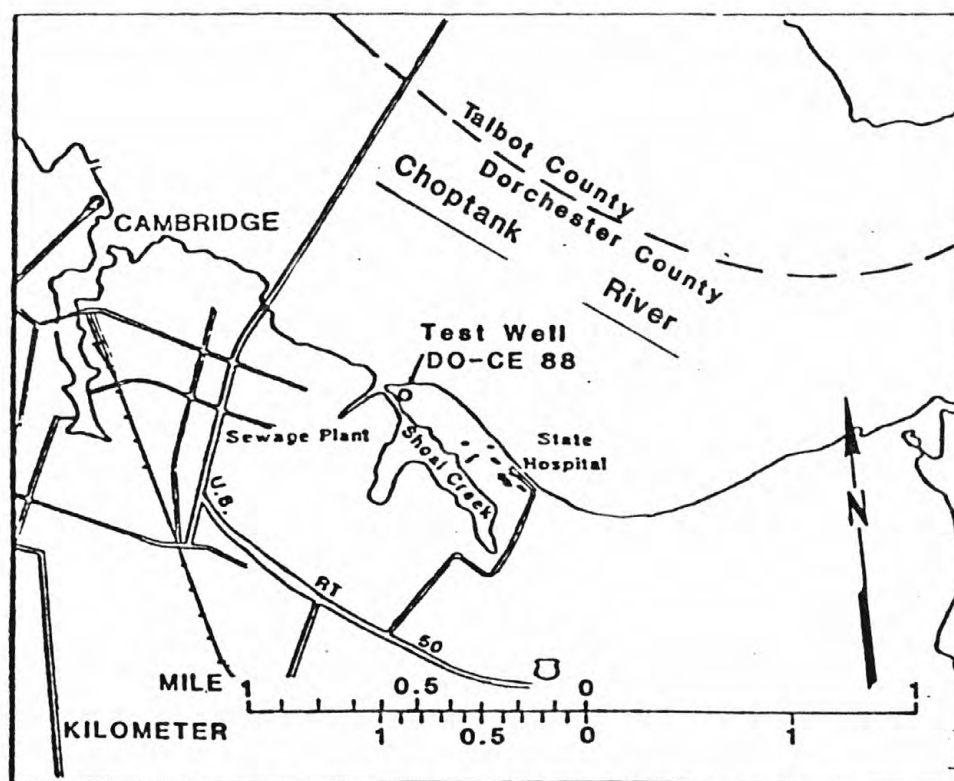
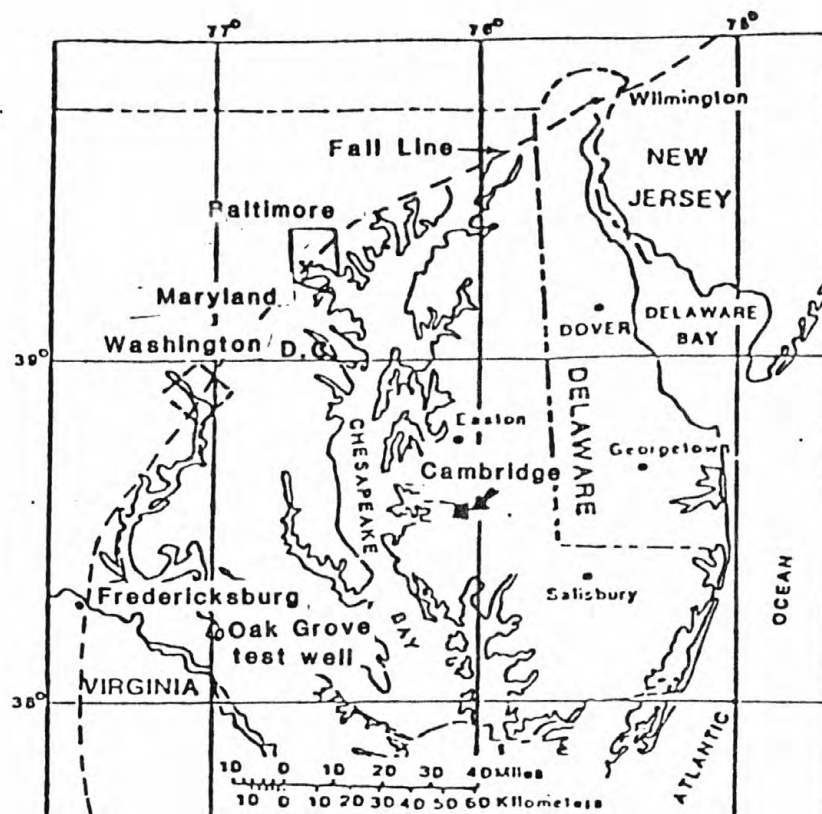


Figure 1.--Location of U.S. Geological Survey test well DO-CE 88.

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 foraminifera 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, the 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 foraminifera. 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 Company¹, Norfolk, Virginia 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 12-in diameter surface casing was set and grouted at 108 ft below the datum. Soft-formation 8³/₄-in drill bits, with provision for wire-line coring, were used from the base of surface casing to the total depth of 3,337 ft. Commercially prepared mud, mixed with fresh water, was used in the drilling. Cuttings samples were collected

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.

at 10-ft intervals. Wireline cores, up to 10 ft in length but usually shorter, were cut at intervals specified by the Survey's representative. Down-hole 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 bed-rock (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 0.015-inch slot, 4-inch diameter, telescope stainless-steel screen was emplaced from 3,188 to 3,218 ft, with blank pipe extending upward into the 4-inch casing.

Development

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

Upon completion of testing and sampling 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 was jet-perforated eight times in order to obtain heads, specific capacities, and water-quality data from successively shallower sand zones. These 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, then break and tamp them with a pipe. Allow cement to set, retest, and repeat if necessary.
3. Sound top of new plug with Survey logging unit and gamma-ray log a short section through the casing, including the prospective new zone to be perforated. 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 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 items 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 1¹/₄-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 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 perforating.

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, which, together with chloride measurements on water squeezed from cores, served as guides for selection of zones to be perforated and sampled. The water

Table 1.--Summary of recompletion attempts

<u>Perforated interval (ft below KB¹)</u>	<u>Date perforated</u>	<u>Plug- back depth (ft below KB)</u>	<u>Shots</u>	<u>Screen (ft below KB)</u>	<u>Remarks</u>
2834-2844	March 18, 1981	2939	40	None	Flowed.
2649-2655.6	April 14, 1981	2667	26	None	Flowed.
2278.4-2288.4	May 26, 1981	About 2325	41	None	Flowed.
2008.4-2018.4	June 10, 1981	About 2055	41	Abandoned, placement not checked with logger	Could not be developed.
1822.4-1832.4	June 16, 1981	About 1865	42	None	Pumped turbid water.
1605.4-1615.4	July 7, 1981	About 1655	42	About 1515-1525 (0.010 slot) recovered	Could not be developed; screen set too high.
1469.4-1479.4	July 21, 1981	About 1520	21	About 1456-1466 (0.010 slot) abandoned	Could not be developed; screen set too high.
1422.4-1432.4	July 28, 1981	1460	24	None	Pumped turbid water.

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

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
		Piney Point Formation	Brown, very fine to coarse, glauconitic quartz sand.	192
	Eocene	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 silt.	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.	2302
Precambrian(?)		Basement complex	Quartz monzonite gneiss.	

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.

The upper part of the compensated (for hole diameter) neutron-formation density log (fig. 3) reads porosity directly from both the neutron and 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 (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-meter 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-meter 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-meter. Formation-water resistivities calculated from the Schlumberger deep-induction log, using formation factors estimated by various methods, were in closer agreement to measured resistivities than those calculated from the spontaneous-potential log, but are not reported here because of adequate water-quality data 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 Institute and State University, written communication, November 11, 1981). The log was run presumably long enough after grouting (about February 13) and the first pumping test (March 1) for the temperature gradient to have stabilized.

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

Depth - Logger: 3337 feet

Casing - Logger: 12 inches at 108 feet

Mud resistivity: 3.80 ohm-meter
at 20.6 C

Mud filtrate resistivity: 2.85
ohm-meter at 20.6 C

Mud cake resistivity: 5.70 ohm-meter
at 20.6 C

Mud resistivity at bottom temperature:
2.55 ohm-meter at 41.1 C

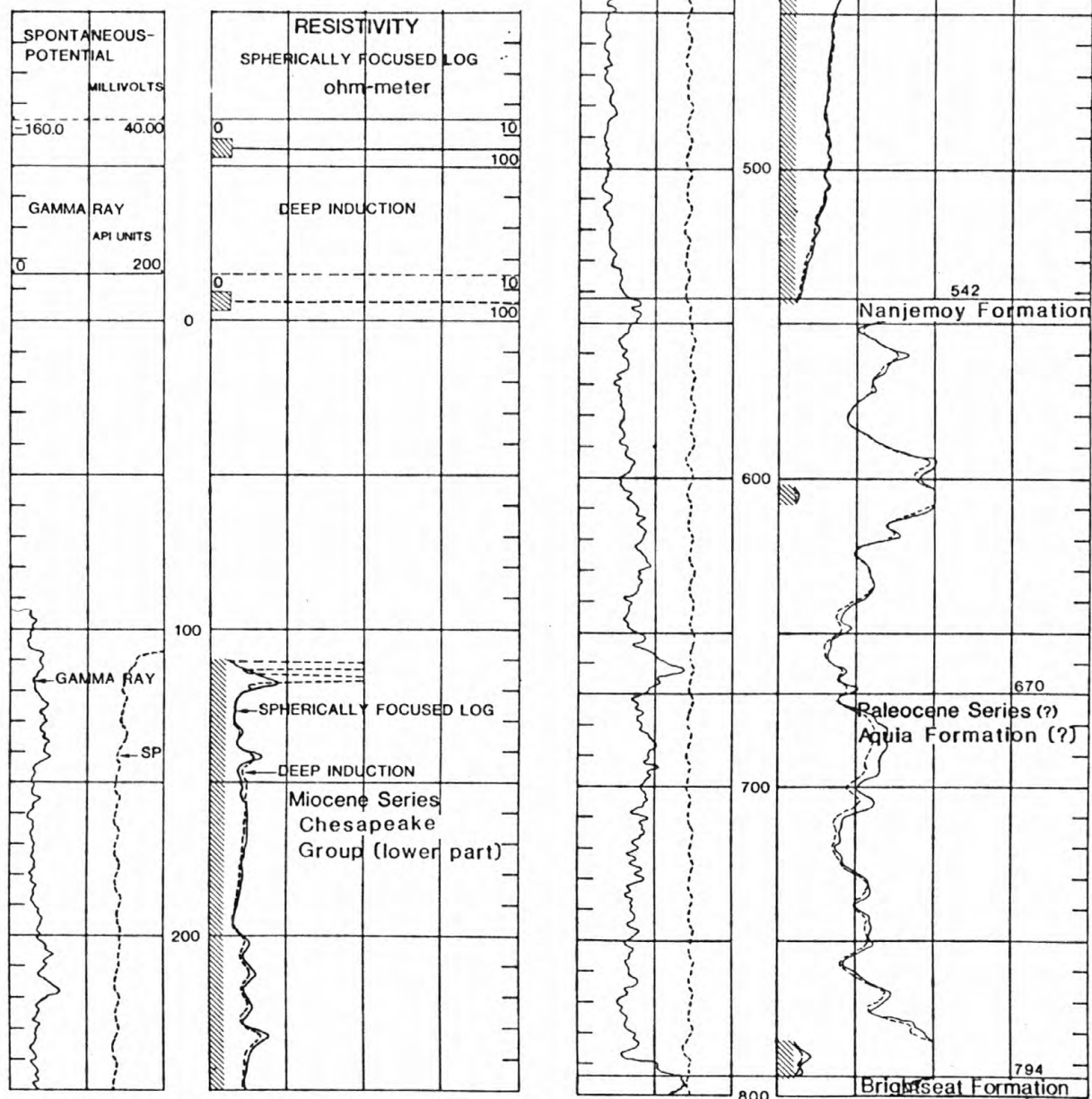


Figure 2.--Dual induction with spontaneous potential and gamma-ray logs, screened and perforated zones, and formation tops.

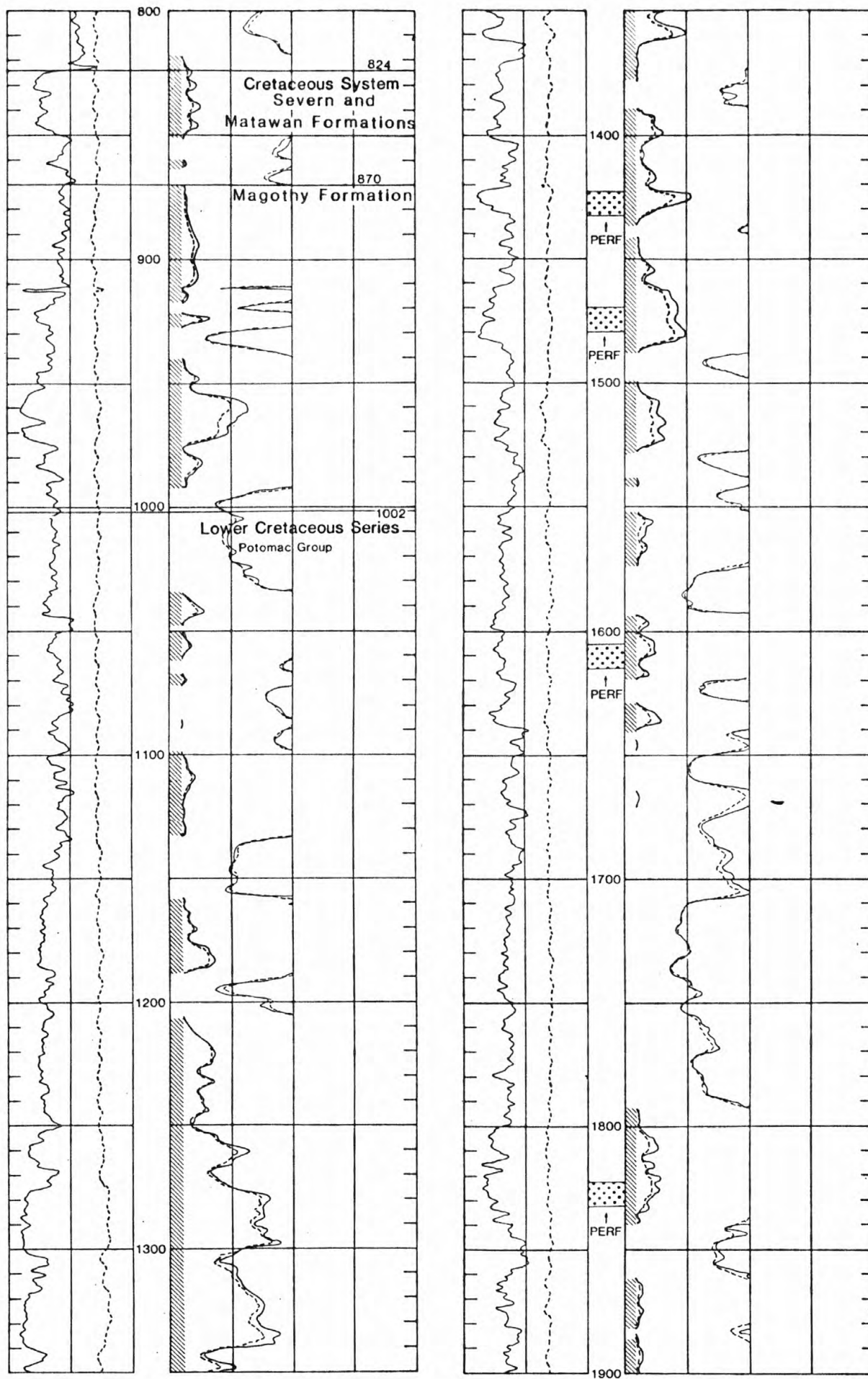


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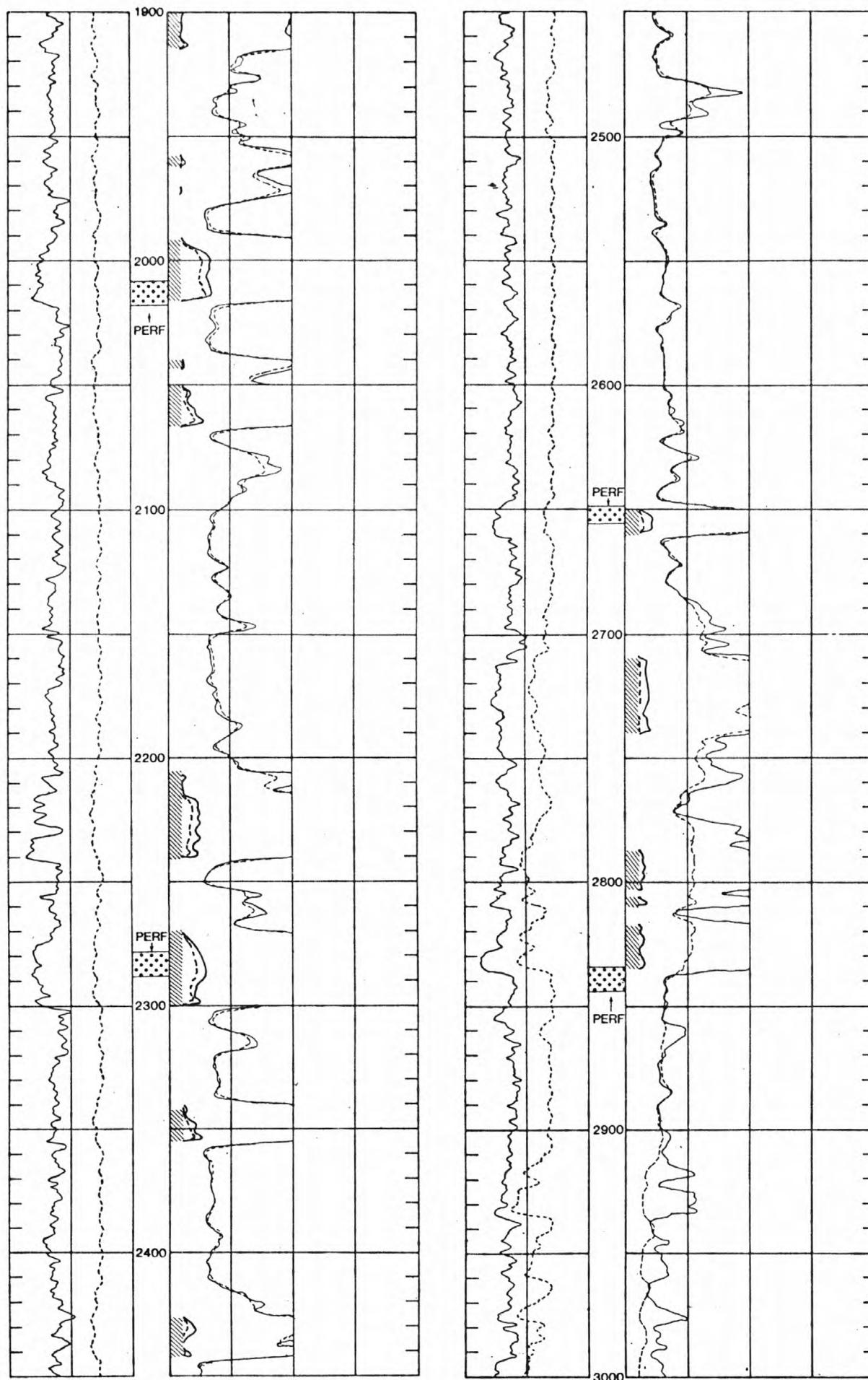


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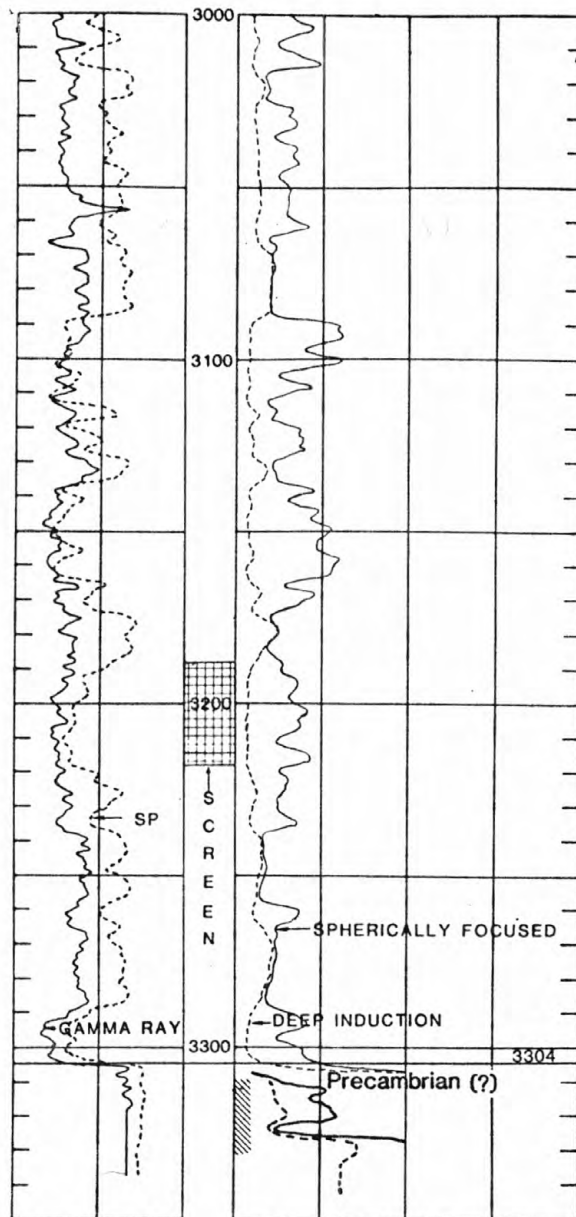


Figure 2.--Continued

Altitude: Kelly bushing: 9.42 feet
Ground: 4.42 feet

Depth - Logger: 3337 feet

Mud resistivity: 3.80 ohm-meter at
20.6 C

Mud filtrate resistivity: 2.85
ohm-meter at 20.6 C

Mud cake resistivity: 5.70 ohm-
meter at 20.6 C

Mud resistivity at bottom tempera-
ture: 2.55 ohm-meter at 41.1 C

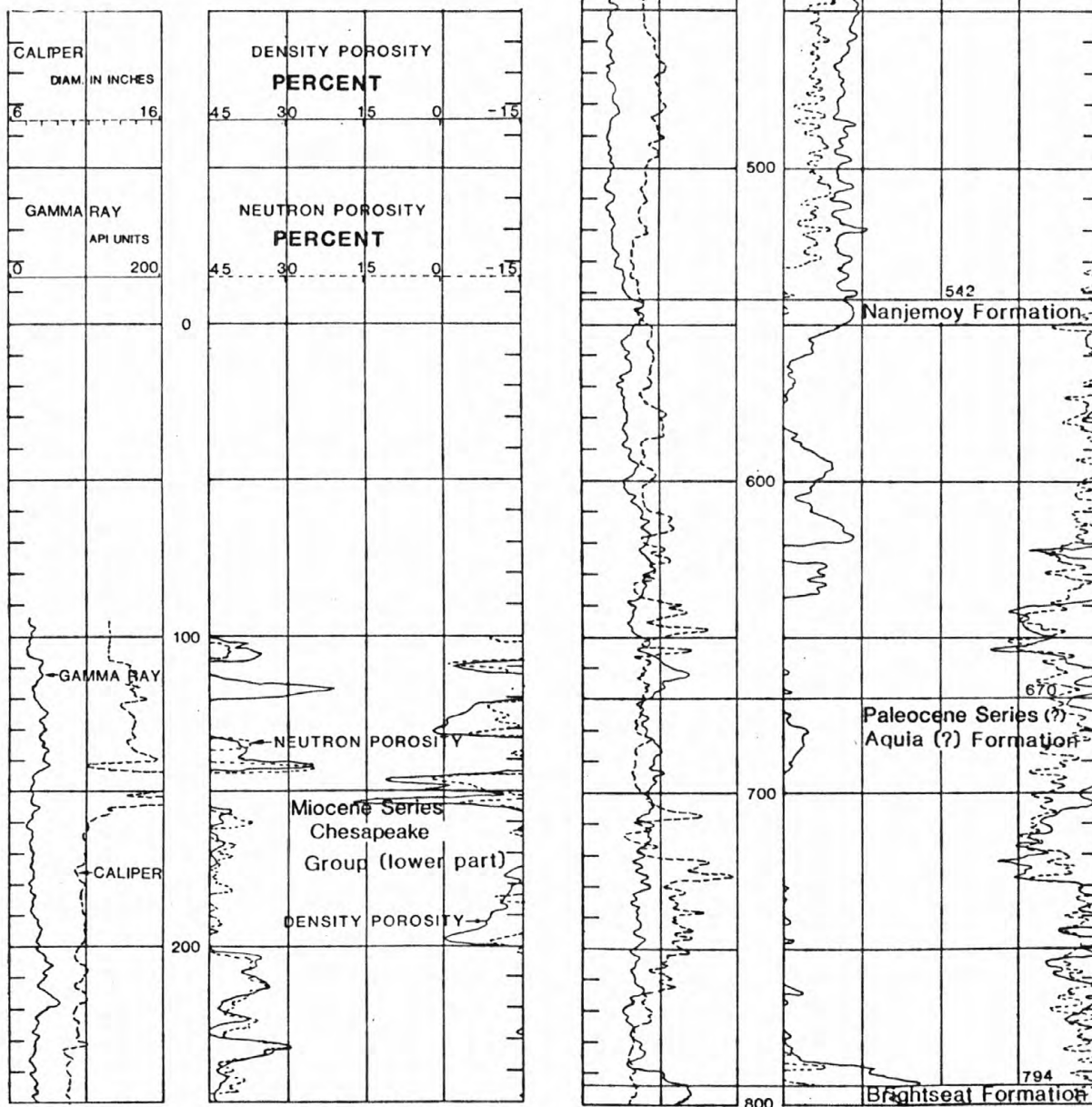


Figure 3.--Simultaneous compensated neutron-formation density (expressed as porosity), with gamma-ray and caliper logs, screened and perforated zones, and formation tons.

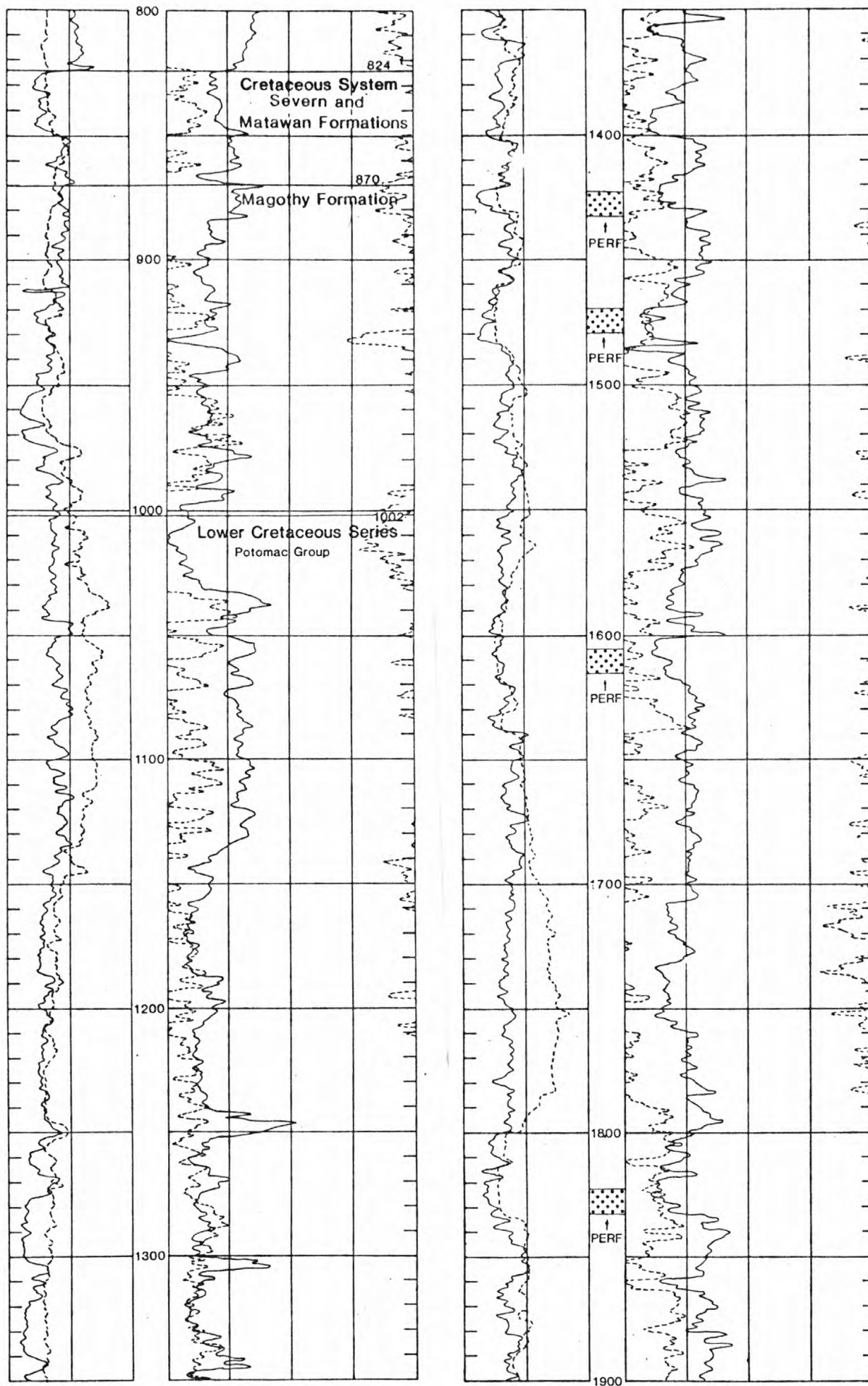


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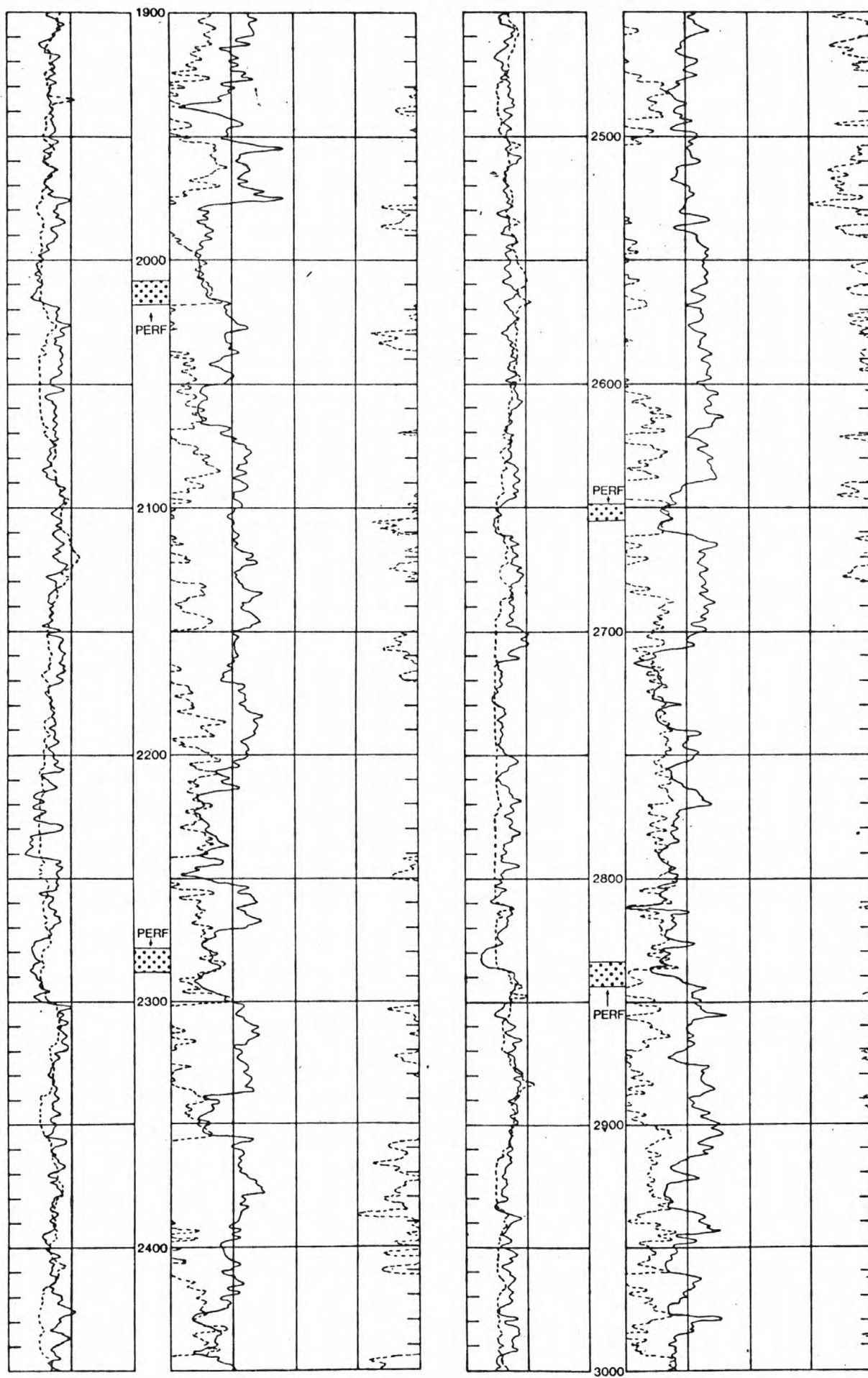


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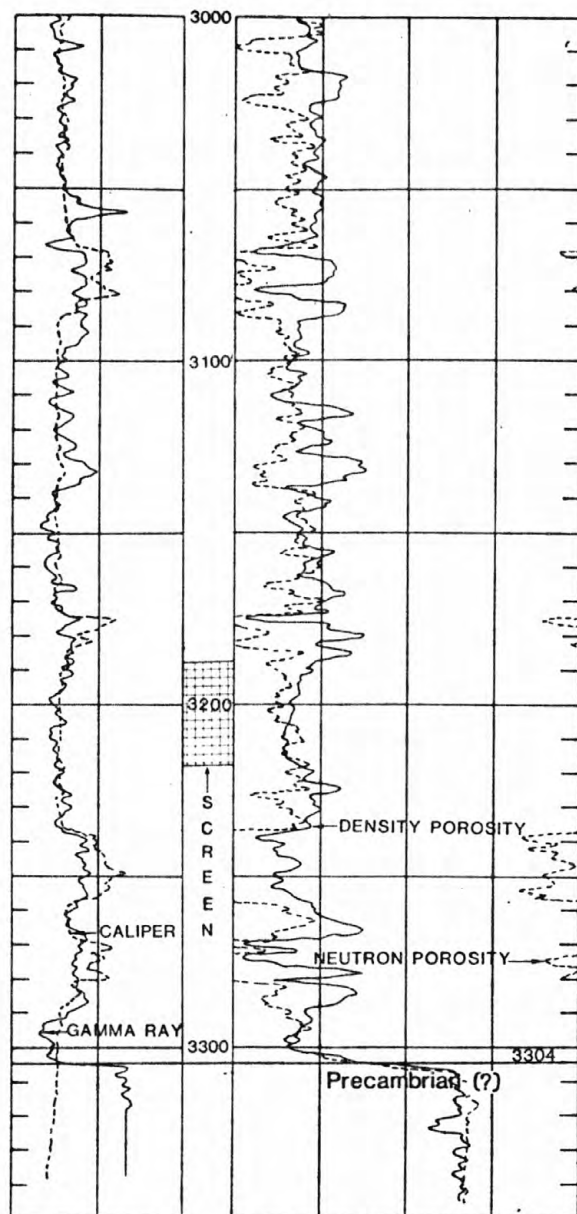


Figure 3.--Continued

Altitude: Kelly bushing: 9.42 feet
Ground: 4.42 feet

Depth - Logger: 3337 feet

Casing - Logger: 12 inches at 108 feet

Bit Size: 8 3/4 inches

Mud resistivity: 3.80 ohm-meter at
20.6 C

Mud filtrate resistivity: 2.85
ohm-meter at 20.6 C

Mud cake resistivity: 5.70 ohm-
meter at 20.6 C

Mud resistivity at bottom temperature:
2.55 ohm-meter at 41.1 C

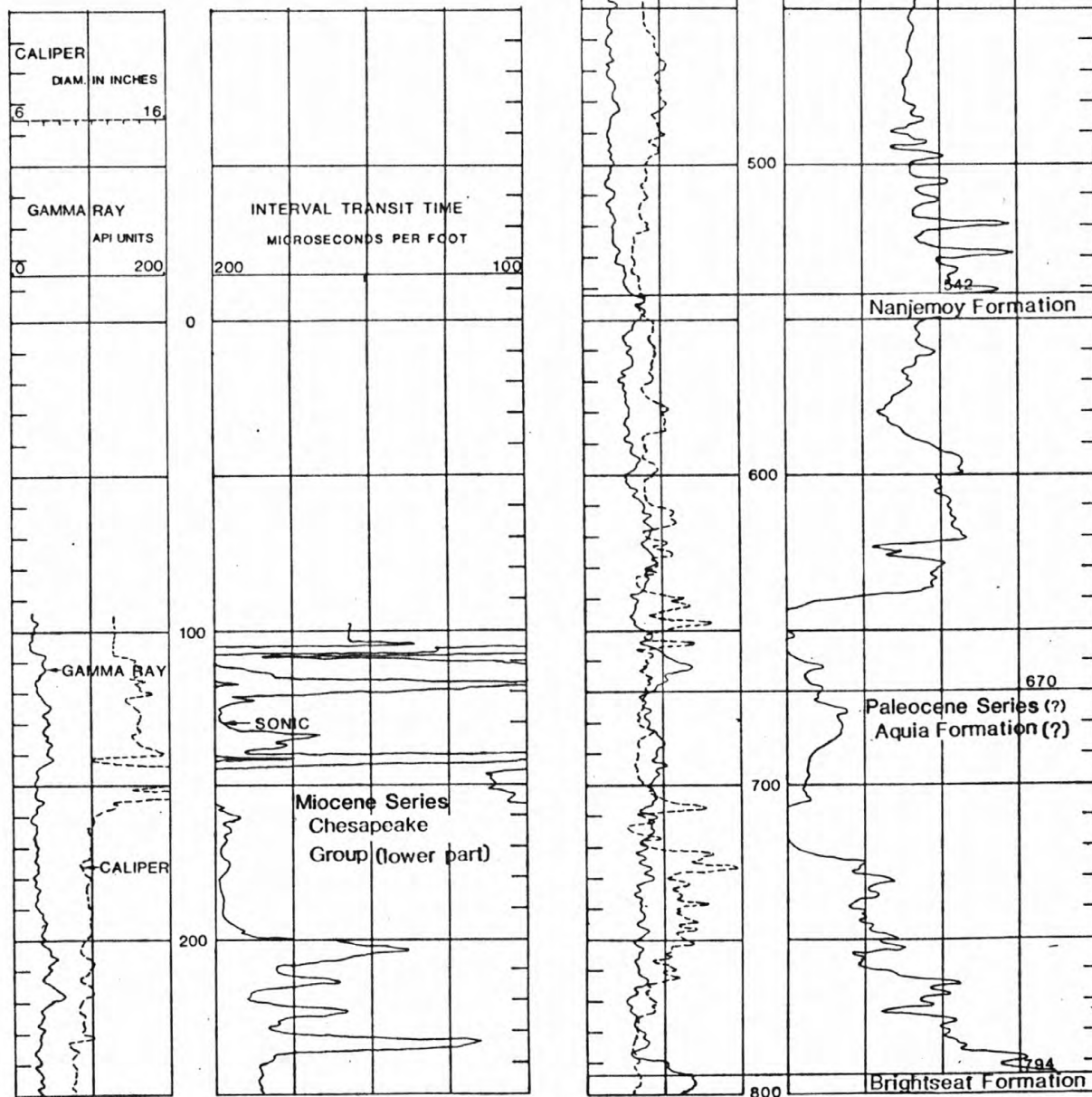


Figure 4.--Borehole-compensated sonic log, with gamma-ray and caliper logs, screened and perforated zones, and formation tops.

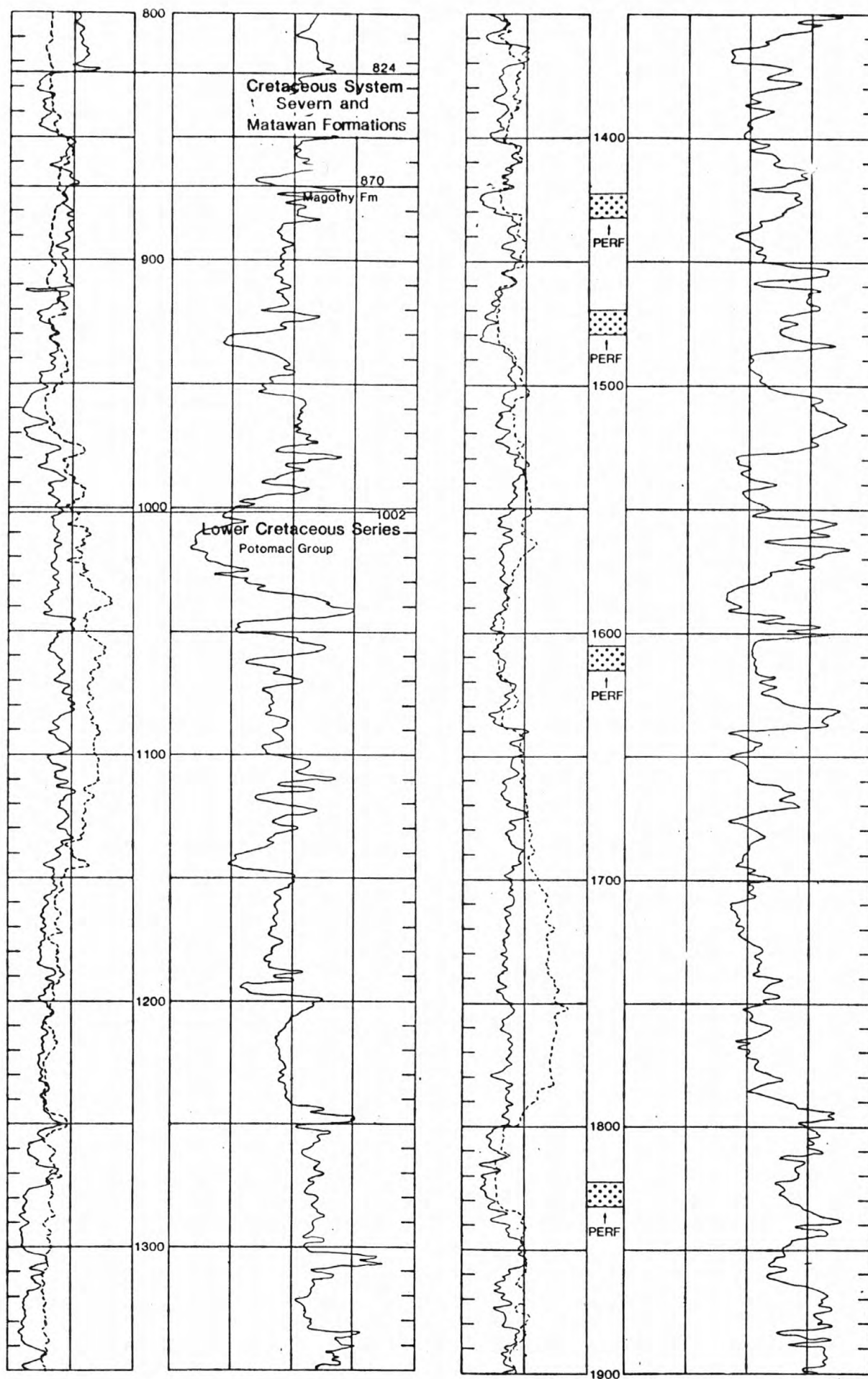


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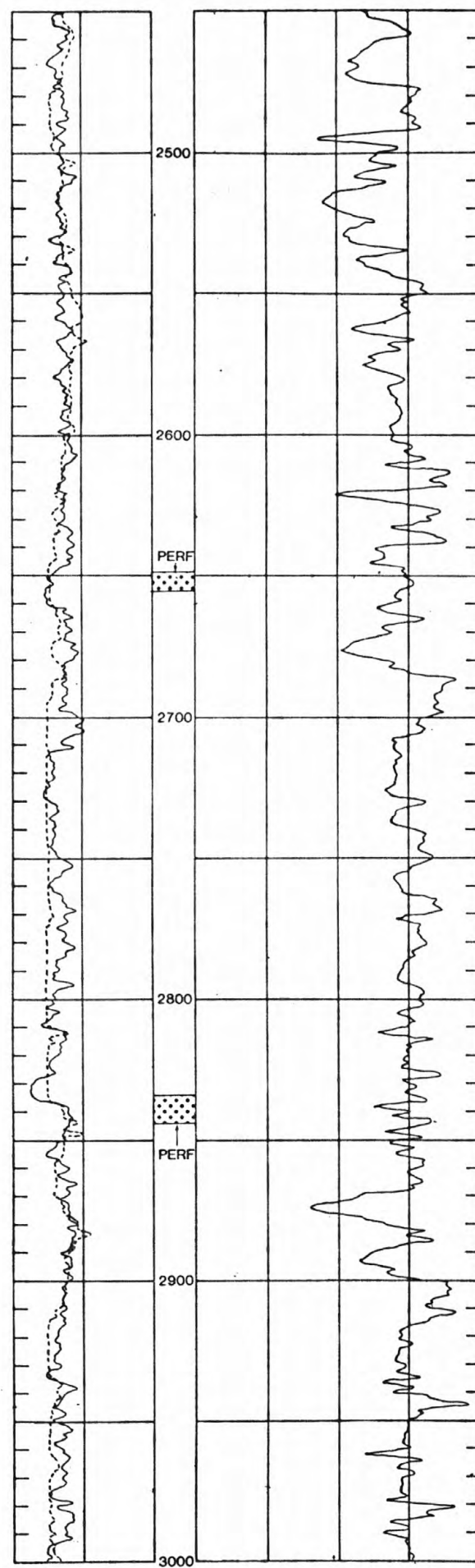
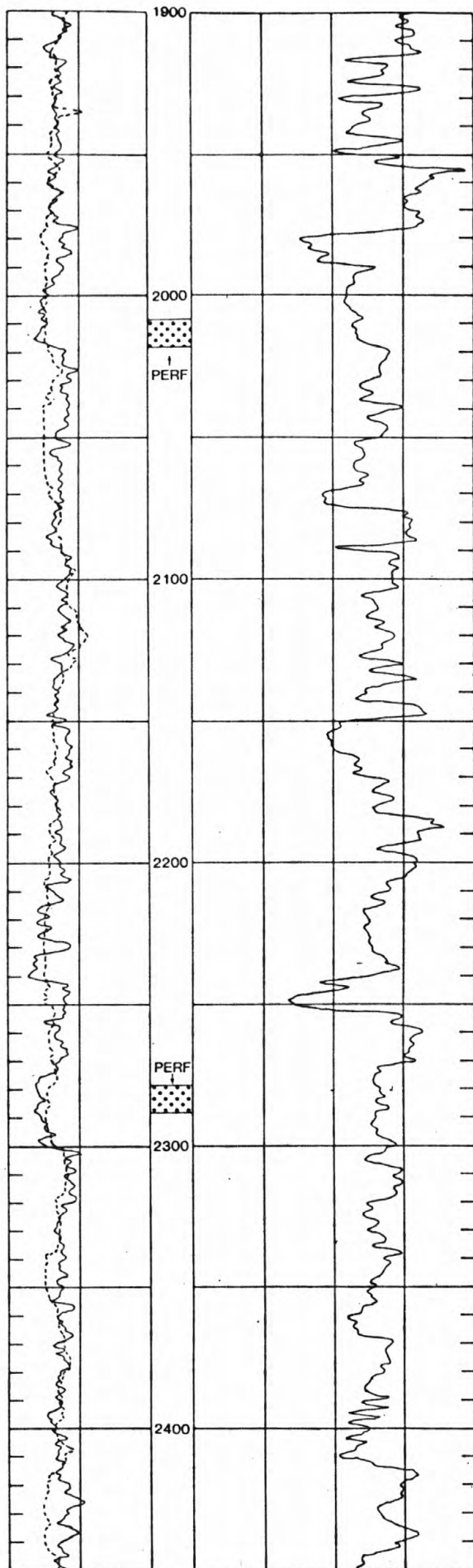


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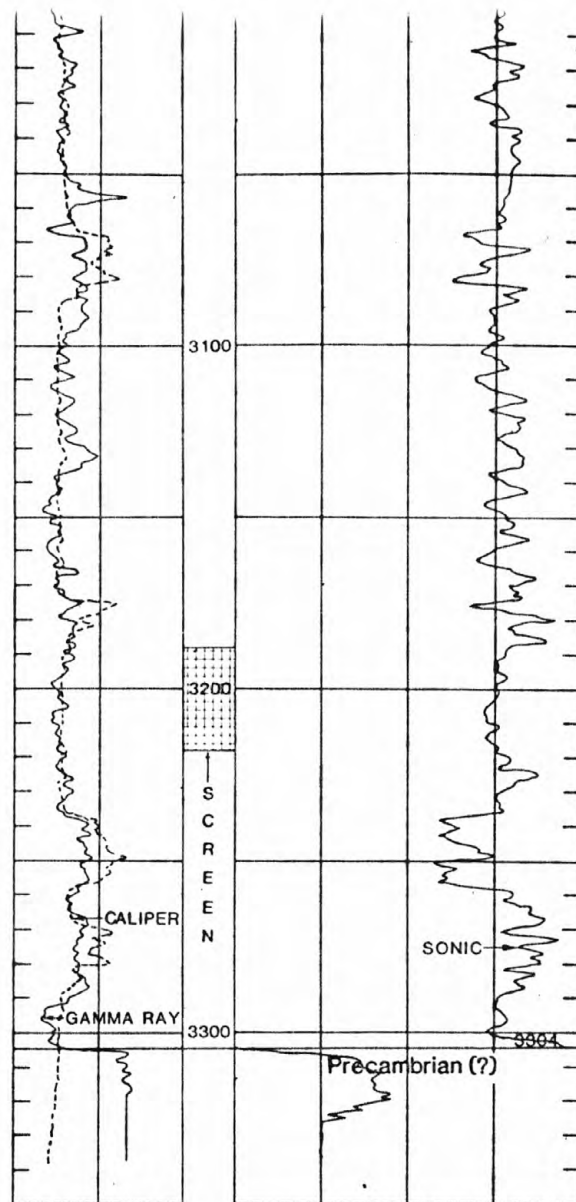


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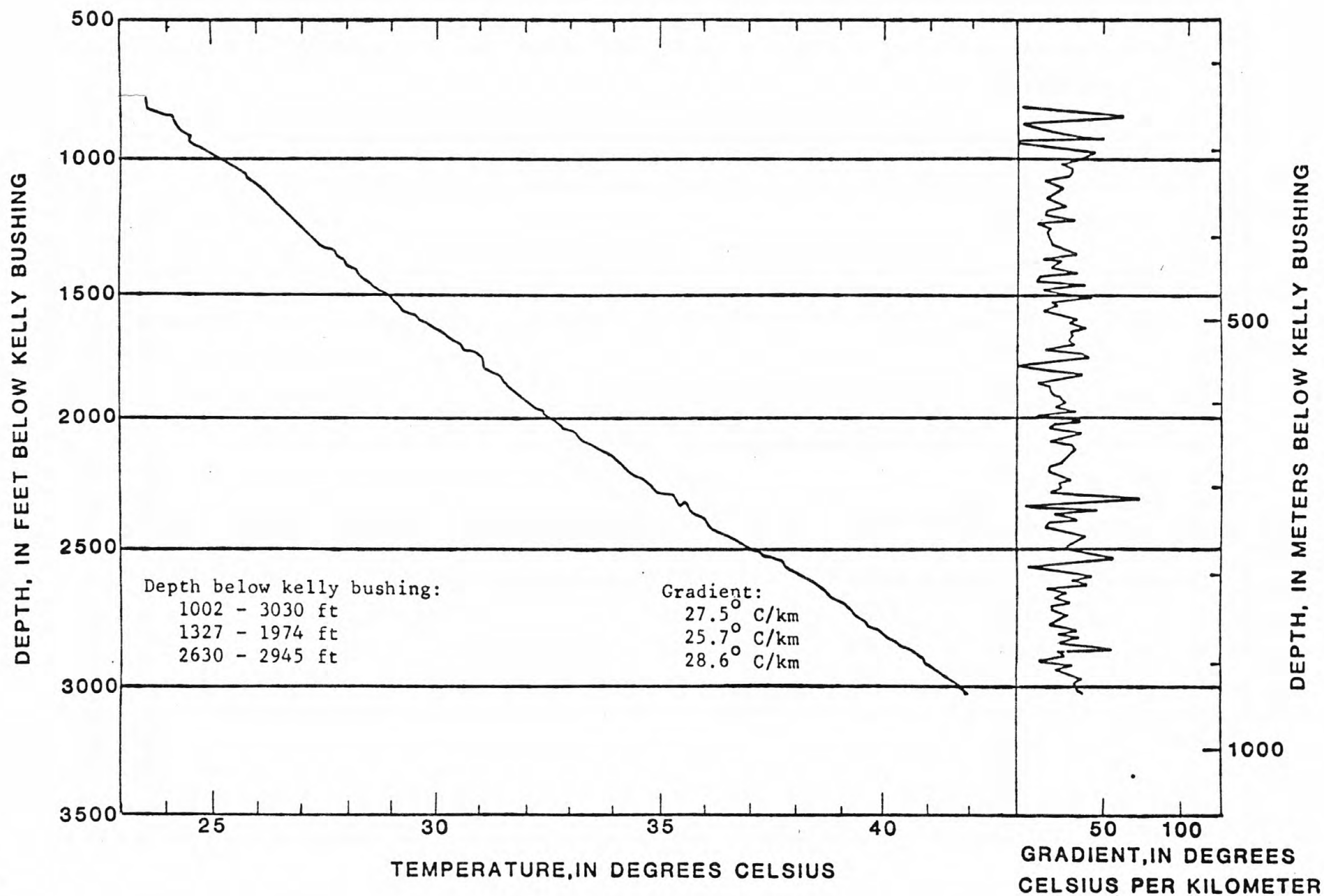


Figure 5.--Temperature log.

Cores

Coring Methods

Cores were taken with a 10-ft wireline core barrel. From 730 ft to total depth, an inner lining of 1.9-in inside-diameter steel tubing with 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, from hand-lens and microscopic examination and grain-size analysis are given in table 3.

Paleontology

Age determinations of cores based on identification of microfossils are given in table 3. Tables 4-12 list the species identified.

Hydraulic Analysis

Core Laboratories, Inc., Houston, Texas, hydraulically analyzed fourteen core samples (table 3). Porosity and vertical hydraulic conductivity ranged from 22.4 percent (at 1,111 ft) to 41 percent (at 730-732 ft), and 1.5×10^{-6} ft/d (at 1,650-1,652 ft) to 1.3 ft/d (at 3,212 ft), respectively. The horizontal hydraulic conductivity 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 communication, 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.

Table 3.--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	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 (5Y 5/2), silt-vfg, increasingly clayey with depth.	Abbott Zone IV, Shattuck Zones 12-13. ⁶ (Middle Miocene, Calvert Fm, Chesapeake Group).							Yel-gr 5Y 7/2	Dominant	Major	Minor	160
2. 150-160	2	150-152	Sand, lt olive-gr (5Y 5/2), silt-vfg, clayey at 152 ft, sparingly glauc.	Abbott Zones III-IV, ⁶ Shattuck Zones 10-11. (Middle Miocene, Calvert Fm, Chesapeake Group).											
3. 340-350	3	340-343	Silt, olive-gr (5Y 4/1), clayey.	Abbott Zone II, Shattuck Zones 3-8. ⁶ (Middle Miocene, Calvert Fm, Chesapeake Group).							Yel-gr 5Y 7/2	Dominant	Major	Minor	99
4. 590-594	2	590-592	Clay, lt olive-gr (5Y 5/2), silty, v glauc, w vfg grn-gr glauc grains.	Upper half of Middle Eocene. ⁷ Middle Eocene. ⁸ Upper lower to Middle Eocene, outer shelf. ⁹							Yel-gr 5Y 7/2	Dominant	Major	Trace	90
5. 730-740	2	730-732	Sand, dusky-brn (5YR 2/2), vfg, clayey, glauc, micaceous.	Middle Paleocene, inner to mid-shelf environment. ⁹	41	2.4×10^{-6}					Yel-gr 5Y 7/2	Dominant	Trace	Trace	54
6. 805-815	0														
7. 815-825	0														
8. 863-870	2	863-863.3	Sand, grn-blk (5GY 2/1), vfg, silty, glauc, finely micac, clayey.								Pale yel-brn 10YR 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 (5Y 2/1), vfg, glauc, clayey, micac. Trace shell fragments.	Santonian Stage, Magothy Fm, non-marine. Christopher's (1979) <u>Pseudoplicapollis cuneata-semiculopollis verrucosa</u> zone ¹⁰ .	34.4	2.9×10^{-4}					Pale yel-brn 10YR 6/2	Major	Minor	Major	
10. 970-972	0.6	970-970.6	Clay, pale brn (5YR 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. 1111-1114	2	1111-1113	Clay, moderate to olive brn (5Y 4/4), w dk gr silty strks, v plastic.	Barren ¹⁰ .							Lt brn 5YR 6/4	Trace	Major	Dominant	100
		1111			22.4	4.9×10^{-6}									
12. 1370-1372	0														
13. 1436-1439	2	1436-1438	Clay, varicolored gray-pk (5R 8/2), lt brn (5YR 6/4), moderate brn (5Y 4/4), and yel-gr (5Y 7/2), silty, glauc.	Barren ¹⁰ .							Moderate or-pk 10R 7/4	Trace	Major	Dominant	79
		1438			26.8	2.4×10^{-6}									
14. 1650-1653	2	1650-1652	Clay, gr-or-pk (5YR 7/2) and moderate yel-brn (10YR 5/4), somewhat silty, plastic.		29.9	1.5×10^{-6}					Moderate red-or 10R 6/6	Major	Minor	Dominant	50
15. 1753-1757	2	1753-1755	Clay, moderate brn (5YR 4/4), silty, waxy.								Gr-red 10R 4/2	Minor	Trace	Dominant	
		1754			33	2.4×10^{-6}									

Table 3.--Core data--Continued

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	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 18A	Kaolinite 7.2A	
16. 1950-1954	2	1950-1950.3	Sand, gr-olive (10Y 4/2), fg, clayey, abundant muscovite.	Barren ¹⁰ .	24.6	1.2 X 10 ⁻⁵					Pale yel-brn 10YR 6/2	Dominant	Trace	Major	30
		1950.3-1950.7	Clay, olive gr (5Y 3/2), silty, v finely micaceous, lignite fragments.												
		1950.7-1952	Clay, yel-gr (5Y 7/2) w or mottling, silty, non-calc, waxy, interbedded w sand, med bl-gr (5B 5/1) to gr-red-purple (5RP 4/2), vfg, clayey.												
		1951													
17. 2004-2006	0														
18. 2094-2096	1.5	2094-2095.6	Clay, gr-red-purple (5RP 6/2), plastic. "Poor core."								Pale red-or 10R 5/4	Major	Major	Major	57
19. 2200-2204	3	2200-2203	Sand, gr-grn (5G 5/2) vfg, and clay, w carb spks.	Barren ¹⁰ .							Pale olive 10Y 6/2	Dominant	Trace	Trace	230
		2202.5-2203			29-33	1.5 X 10 ⁻⁵	1.8 X 10 ⁻³	2.54	0.1321	1.6285					
20. 2300-2302	0.1	2300-2300.1	Clay, mottled greenish-gr and dusky red, dns.												
21. 2310-2314	0.1	2310-2310.1	Clay, dominantly mottled dusky red and lt gr, dns.												
22. 2319-2322	3	2319-2322	Clay, dusky red (5R 3/4), dns, crumbly.								Moderate yel-brn 10YR 5/4	Dominant	Trace	Minor	280
23. 2422-2426	3	2422-2425	Sand, gr-grn (5G 5/2), vfg-fg, subang, vf dk grns, sli clayey.	Barren ¹⁰ .							Yel-gr 5Y 7/2	Dominant	Trace	Minor	
		2422-2425			35-37	1.6 X 10 ⁻⁴	2.2 X 10 ⁻⁴	2.69	0.1058	1.3309					28 24,28
24. 2484-2488	3	2484-2487	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. 2585-2589	3	2585-2588	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. 2692-2696	3	2692-2695	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	
		2694-2695													440 360
27. 2794-2798	0.5	2794-2794.5	Sand, med lt gr, vfg-fg, silty.	Barren ¹⁰ .											
28. 2823-2827	0.1	2823-2823.1	Clay, med gr, silty, and sand, lt gr, vfg, finely laminated w dk gr clay, silty, micac.	Barren ¹⁰ .											1,200
29. 2900-2910	9	2900-2909	Silt, v clayey, w blk carb laminae and blebs, muscovitic.	Berriasian to Barremian ? Pre-Zone I to Zone I, non-marine ¹⁰ .											10,000- 11,000

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	K_v^2 (ft/d)	K_h^3 (ft/d)	Grain density	Median grain size (mm)	Fraser's sorting coefficient	Color ⁴	X-ray analysis	Smectite 17A	Illite 10A		Kaolinite 7.2A
30. 3008-3015	2.5	3008-3010.5	Sand, grn-gr (5G 6/1), fg-med, w gr clay matrix, interbedded w clay, clay increasing downward.	Neocomian to Aptian? Zone I ¹⁰ .												12,000-17,000
		3009.5			29-30	6.3×10^{-3}	5.0×10^{-2}	2.52	0.2288	1.8027						18,000
31. 3110-3116	2	3110-3112	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, non-marine ¹⁰ .												
		3111			28-30	1.2×10^{-5}	2.2×10^{-5}		0.128	1.7854						
32. 3210-3216	3	3210-3213	Sand, med gr (N3), fg, subang, qtz, some muscovite and lignite, clean.													
		3212			32-34.8	1.3	1.3		0.3065	1.36						
33. 3310-3315	0															
34. 3315-3320	0.1	3315-3315.12	Gneiss													
35. 3320-3324	4	3320-3324	Gneiss													
36. 3324-3326	2	3324-3326	Gneiss													
37. 3331-3336	5	3334	Gneiss, qtz monzonite. Holo-crystalline, hypidomorphic-granular, non-porphyrific, medium-grained. Slight gneissic fabric. Qtz 39 percent, plagioclase (oligoclase) 34 percent, microcline 18 percent, biotite 10 percent, trace apatite, zircon, leucocoxene ¹² .													
		3336				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=glaucous, 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), Shattuck (1904).

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

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

⁹ Determination based on foraminifera 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), Doyle and Robbins (1977).

¹¹ X-ray analysis of clay also showed unidentified peak at 6.35Å.

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

¹³ Porosity calculated from water content of .0059.

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 communication, June, 1981):

Series Determination: Miocene (not above middle Miocene)

Paleoecology: Marine

	<u>Range</u>	<u>Frequency</u>
1. <u>Fagus</u> sp.	Long range	Rare
2. <u>Quercus</u> (oak)	Paleocene to Holocene	Abundant
3. <u>Periporopollenites</u> cf. p. sp. z Bebout, 1980	Eocene to middle Miocene	Sparse
4. <u>Carya</u> (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 communication, Sept. 22, 1981):

139.5 ft:

Hystriosphæeropsis 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
Hystriocholpoma rigaudiae
Hystriosphæeropsis 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 communication, September 22, 1981):

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

Middle Miocene flora.

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 communication, 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 communication, September 22, 1981):

Cyclopsiella cf. C. elliptica
Heteraulacacysta sp.
Lejeunecysta sp.
Lingulodinium machaerophorum

Palaeocystodinium golzowense
Spiniferites sp.
Tuberculodinium vancampoae

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

	<u>Number of specimens:</u>
<u>Hanzawaia</u> cf. <u>concentrica</u>	1-10
<u>Buliminella</u> cf. <u>elongata</u>	1-10
<u>Uvigerina</u> 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.

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

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

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

Age is upper half of middle Eocene.

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

	<u>Number of specimens</u>
<u>Gaudryina cf. pseudocollinsi</u>	1-10
<u>Textularia sp.</u>	1-10
<u>Brazilina atlantisae</u>	+1000
<u>Turritilina sp.</u>	+1000
<u>Bulimina cf. subrotundata</u>	+1000
<u>Bulimina trigonalis</u>	11-100
<u>Anomalinoidea alazanensis</u>	11-100
<u>Pullenia compressiuscula</u>	1-10
<u>Cibicides westi</u>	11-100
<u>Alabamina midwayensis</u>	11-100
<u>Cibicidoides pippeni</u>	11-100
<u>Gyroidinoides peramplus</u>	100-1000
<u>Bulimina pupoides</u>	11-100
<u>Lenticulina sp.</u>	1-10
<u>Lagena striata</u>	1-10
<u>Lagena fenestrissima</u>	11-100
<u>Subbotina eocaena</u>	100-1000
<u>Acarinina pentacamerata</u>	+1000
<u>Morozorella spinulosa</u>	1-10
<u>Stilostomella sp.</u>	1-10
<u>Globulina gibba</u>	1-10
<u>Morozorella spinuloinflata</u>	11-100
<u>Pseudohastigerina wilcoxensis</u>	11-100
<u>Truncorotaloides cf. ruhri</u>	1-10

Very rich in foraminifers. Outer shelf environment of deposition.

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

Planktic foraminifers (Richard Z. Poore, U.S. Geological Survey,
written communication, April 20, 1931):

Truncorotaloides collactea (Finlay)

T. bullbrooki (Bolli)

Pseudohastigerina micra (Cole)

Age: middle Eocene. Planktic foraminifers are sparse and
poorly preserved.

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

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

	<u>Number of specimens</u>
<u>Stilostomella paleocenica</u>	1-10
<u>Epistominella minata</u>	11-100
<u>Bulimina cacumenata</u>	100-1000
<u>Cibicides succeedens</u>	1-10
<u>Bulimina quadrata</u>	1-10
<u>Anomalinoides welleri</u>	1-10
<u>Alabamina midwayensis</u>	1-10
<u>Pseudouvigerina seligi</u>	100-1000
<u>Acarinina sp.</u>	1-10
<u>Morozorella angulata</u>	1-10
<u>Subbotina triloculinoides</u>	1-10
<u>Dentalina sp.</u>	1-10
<u>Tappanina selmensis</u>	1-10
<u>Fursenkoina sp.</u>	1-10

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

Table 9.--Fossil species identified from core sample 912-915 feet

Diagnostic Plant Microfossils (G. J. Brenner, State University of New York at New Paltz, written communication, June, 1981):

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

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

Table 10.--Fossil species identified from core sample 2900-2909 feet

Diagnostic Plant Microfossils (G. J. Brenner, State University of New York at New Paltz, written communication, June, 1981):

Stage Determination: Berriasian to Barremian ?

Stratigraphic Correlation: Pre-Zone I ? to Zone I

Paleoecology: Nonmarine

	<u>Range</u>	<u>Frequency</u>
1. <u>Alisporites</u>	Long range	Sparse
2. <u>Concavissimisporites verrucatus</u>	Valanginian +	Rare
3. <u>Klukisporites pseudoreticulatus</u>	Berriasian to Turonian	Rare
4. <u>Leptolepidites verrucatus</u>	Berriasian to Albian	Rare
5. <u>Lycopodiumsporites</u> sp.	Long range	Rare
6. <u>Lycopodiacidites ambifoveolatus</u>	Zone I and II	Rare
7. <u>Parvisaccites radiatus</u>	Upper Jurassic and Berriasian to Albian	Rare
8. <u>Podocarpidites</u> 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
3008-3010.5 feet

Diagnostic Plant Microfossils (G. J. Brenner, State University of
New York at New Paltz, written communication, 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. Tauocusporites reduncus

Table 12.--Fossil species identified from core sample 3110-3112 feet

Diagnostic Plant Microfossils (G. J. Brenner, State University of New York at New Paltz, written communication, June, 1981):

Stage Determination: Barremian ? to Aptian

Stratigraphic Correlation: ? Zone I

Paleocology: Nonmarine

	<u>Range</u>	<u>Frequency</u>
1. <u>Klukisporites pseudoreticulatus</u>	Berriasian to Turonian	Rare
2. <u>Perotriletes striatus</u>	Barremian to Albian	Rare
3. <u>Pilosporites</u> sp.	--	
4. <u>Trilobosporites apiverrucatus</u>	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."

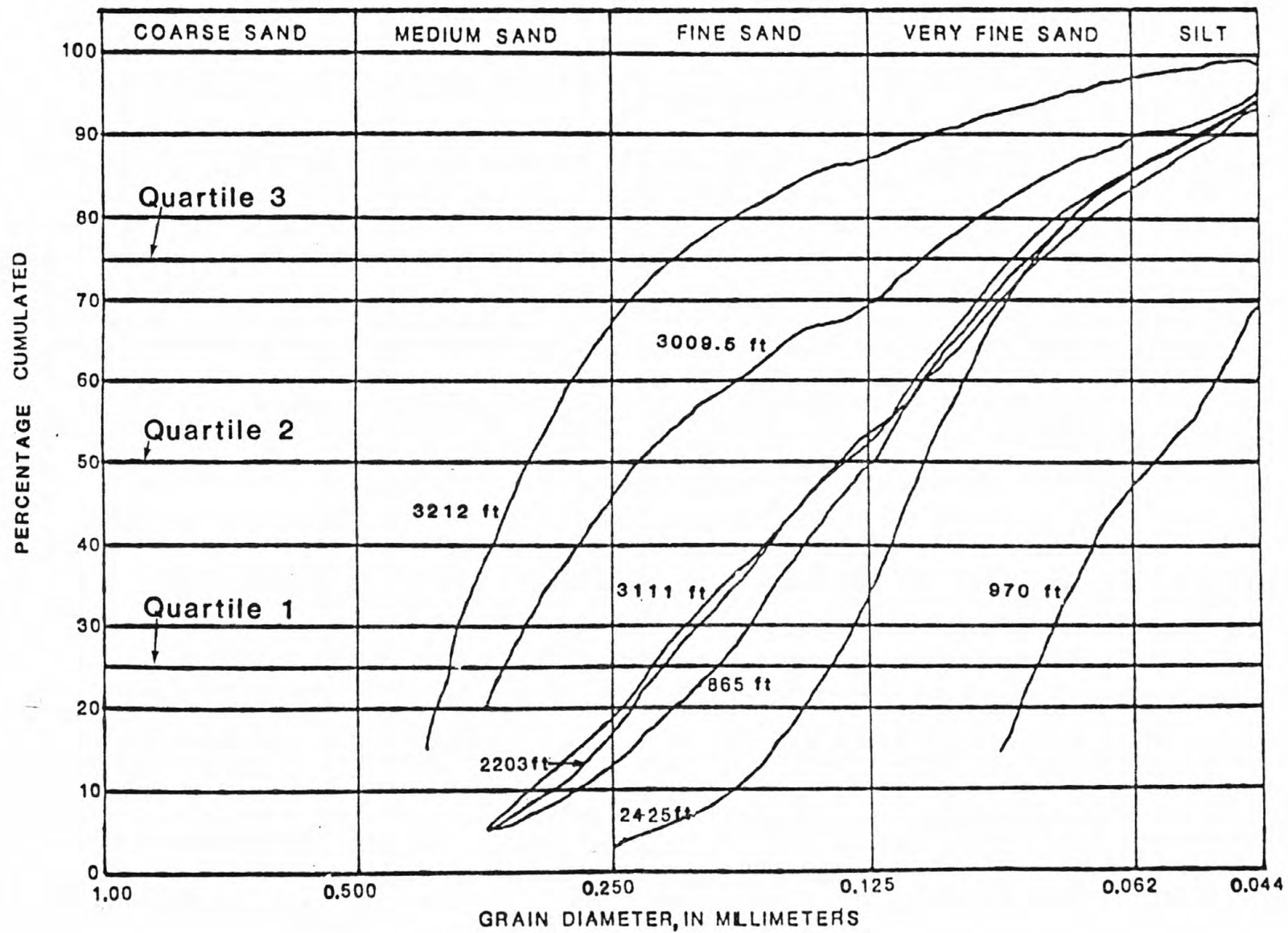


Figure 6.--Grain-size distribution of core samples.

X-ray Analysis of Clay Fractions

The qualitative mineralogical composition of the clay fractions of twenty core samples was determined by X-ray diffractometer. The relative abundance of smectite, (17Å clays), illite (10Å clays) and kaolinite (7.2Å 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 (912-1,770 ft) is dominated by the presence of 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 Determinations

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 communication, 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, Virginia (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 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, 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.

Table 13.--Heavy minerals and feldspars in selected core samples¹

Depth (ft below Kelly bush- ing)	Rock frag- ments	Percentages of light fraction				Percentage of opaque heavy- mineral fraction					Percentages of non-opaque heavy- mineral fraction									
		Common quartz	Polycry- stalline quartz	Potas- sium feld- spar	Plagio- clase feld- spar	Ilmenite	Brown ilme- nite	Leucoxene	Horn- blende	Epi- dote	Gar- net	Chlori- toid	Glauc- con- ite	Staur- olite	Kya- nite	Silli- manite	Tour- maline	Rutile	Zircon	Ap- ti-
130.5	14	81	3	3	tr ²	-	-	-	0	8	6	4	1	0	3	15	12	3	47	
135	10	86	1	4	tr ²	-	-	-	0	23	5	9	0	0	3	5	5	18	32	
139.5	2	92	0	6	tr ²	-	-	-	0	32	12	8	0	0	0	24	4	12	8	
150	5	92	0	3	tr ²	-	-	-	0	2	10	4	0	0	0	17	21	2	42	
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	
913	3	80	0	13	0	87	3	10	0	26	10	15	0	8	2	0	3	11	25	
1951	35	63	0	2	0	49	very abundant	51	5	13	1	0	0	11	4	0	13	18	35	
2203	5	80	0	12	3	87	1	12	0	51	4	0	0	0	0	0	1	0	33	
2484	0	45	0	32	23	63	15	12	0	14	9	0	0	3	1	0	5	0	68	
2903	20	73	0	7	0	66	25	9	tr ²	38	5	4	0	8	3	0	2	3	36	
3112	5	61	0	30	4	90	4	6	0	7	3	1	0	0	0	0	1	1	80	
3212	8	40	2	44	6	30	15	55	0	78	8	0	0	6	1	0	1	0	6	

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 P = Present. Heavy minerals consist mostly of opaque, green-black glauconite aggregates.

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

(USGS No. 3834010760320.01)

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, 9.46 ft above msl = 5.0 ft
 above land surface.

Lithology	Thickness (ft)	Depth (ft)
<u>Quaternary (?) System</u>		
<u>Pleistocene (?) Series</u>		
Clay, brown, sandy.	5	10
Sand, brown, medium.	11	21
Clay, blue, sandy.	2	23
Sand, brown.	13	36
Clay, blue, sandy.	17	53
<u>Tertiary (?) System</u>		
<u>Miocene (?) Series</u>		
<u>Chesapeake (?) Group (lower part)</u>		
Sand and shells, interbedded. ¹	62	115
Sandstone, light brown (5YR 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

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 14.--Interpretative lithologic description,
Well D0-CE 88--Continued

Lithology	Thickness (ft)	Depth (ft)
Silt, light olive-gray (5Y 5/2), very fine sandy, clayey; with shell fragments and very fine black phosphatic (?) specks.	14	132
Sand, light olive-gray (5Y 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 (5Y 5/2), very fine sandy, calcareous in part.	14	150
Sand, light olive-gray (5Y 5/2), silt to very fine, clayey, sparsely glauconitic; grading to:	2	152
Clay, light olive-gray (5Y 5/2), silty and sandy.	3	155
Sand, pale brown (5YR 5/2), very fine to fine, very clayey; trace yellow-stained quartz pebbles.	25	180
Sand, pale brown (5YR 5/2), very fine to medium, predominantly very fine, sub-angular, very clayey; trace 1/2 -in sub-round quartz pebbles, trace fine white shell fragments.	10	190
Silt, pale brown (5YR 5/2), scattered very fine black specks.	9	199
Sand, pale brown (5YR 5/2), silt to medium, predominantly very fine, subangular, with very fine black specks.	11	210
Sand, pale brown (5YR 5/2), very fine to medium, predominantly medium, subangular, with black grains.	10	220
Sand, pale brown (5YR 5/2), very fine to coarse, predominantly medium, subangular.	6	226

Table 14.--Interpretative lithologic description,
Well D0-CE 88--Continued

Lithology	Thickness (ft)	Depth (ft)
Sand, pale brown (5YR 5/2), very fine to coarse, predominantly medium, becoming finer and clayey downward.	4	230
Sandstone, pale brown (5YR 5/2), very fine, weakly cemented, noncalcareous.	4	234
Sand, pale brown (5YR 5/2), very fine, subangular, silty, with scattered black grains.	44	278
Clay, pale brown (5YR 5/2), silty; interbedded with sand as above, trace white shell fragments.	60	338
Silt, olive-gray (5Y 4/1), clayey.	12	350
<u>Eocene Series</u>		
<u>Piney Point Formation</u>		
Sand, moderate brown (5YR 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 (5YR 5/2), very fine to medium, predominantly fine; interbedded with very fine clayey sand.	15	381
Ironstone, moderate brown (5YR 5/2).	3	384
Sand, moderate yellow-brown (10YR 5/4) with black specks, fine to coarse, predominantly medium, angular to sub-round, mostly quartz, with limonite and glauconite grains; trace of shell fragments.	76	460
Sand as above; interbedded with gray-green (5G 5/2) silt.	82	542

Table 14.--Interpretative lithologic description,
Well D0-CE 88--Continued

Lithology	Thickness (ft)	Depth (ft)
<u>Nanjemoy Formation</u>		
Sand, moderate yellow-brown (10YR 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 (5Y 5/2), silty, very glauconitic.	19	592
Sand, dark yellow-brown (10YR 4/2), silt to very fine, quartz, subangular, clayey, glauconitic; interbedded with light olive-gray (5Y 5/2), very glauconitic, silty clay with occasional shell fragments.	20	612
Silt, gray-green (5G 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 (5G 5/2) silty clay; trace shell fragments.	10	650
Clay, gray-green, silty.	10	660
Sand as in 640-650.	10	670
<u>Paleocene (?) Series</u>		
<u>Aquia (?) Formation</u>		
Sand, glauconite, as in 629-640 ft, with occasional thin layers of gray-green (5G 5/2) silt.	28	698
Silt, gray-green (5G 5/2), glauconitic; interbedded with greenish-gray (5G 6/1) clay.	11	709

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

Lithology	Thickness (ft)	Depth (ft)
Clay, greenish-gray (5GY 6/1) and light gray (5GY 8/1), silty, glauconitic, calcareous; with traces of very coarse angular quartz grains and shell fragments.	18	727
Sand, dusky brown (5YR 2/2), very fine, clayey, glauconitic, micaceous.	10	737
Clay as in 709-727 ft.	3	740
Silt, greenish-gray (5GY 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
<u>Brightseat Formation</u>		
Clay, greenish-gray (5GY 6/1) and light green (5GY 8/1), silty, calcareous, trace shell fragments.	16	810
Sand, greenish-black (5GY 2/1), very fine to medium, predominantly fine, composed of polylobate glauconite.	14	824
<u>Cretaceous System</u>		
<u>Upper Cretaceous Series</u>		
<u>Severn and Matawan Formations, undifferentiated</u>		
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 (5GY 2/1), fine, glauconite, clayey; interbedded with clay and quartz sand.	20	870

Table 14.--Interpretative lithologic description,
Well D0-CE 88--Continued

Lithology	Thickness (ft)	Depth (ft)
<u>Magothy Formation</u>		
Sand, greenish-black (5GY 2/1), silt to medium, predominantly fine, about 60 percent glauconite, 40 percent quartz.	23	893
Sandstone, dark yellowish-orange (10YR 6/6), fine to medium, mostly quartz grains, some glauconite, calcareous.	2	895
Sand, greenish-black (5GY 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 (5G 6/1), silty, with trace shell fragments and foraminifera.	3	921
Sand as above, with trace of shell fragments.	7	928
Silt, grayish-green (5GY 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 (5Y 7/2), light brownish-gray (5Y 6/1), and greenish-gray (5Y 6/1) slightly calcareous clay; trace of shell fragments, foraminifera, and quartz pebbles.	37	973
Sand, very fine to very coarse, predominantly fine, with trace shell fragments.	20	993
Silt, greenish-gray (5G 6/1), clayey.	9	1,002
<u>Lower Cretaceous Series</u>		
<u>Potomac Group, undifferentiated</u>		
Silt, greenish-gray (5G 6/1), clayey; interbedded with very fine to very coarse, predominantly very fine sand.	32	1,034

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

Lithology	Thickness (ft)	Depth (ft)
Sand, very fine to coarse, predominantly very fine to fine, subangular, mostly clear quartz.	10	1,044
Silt, greenish-gray (5G 6/1), clayey.	6	1,050
Sand, as above, with a few very coarse grains.	11	1,061
Clay, yellowish-gray, (5Y 8/1).	6	1,067
Sand, as in 1034-1044 ft.	5	1,072
Clay, light brown (5YR 5/6); inter-bedded 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 (5YR 5/6), sandy.	6	1,100
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 (5Y 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 (10Y 8/2) and grayish-orange (10YR 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

Table 14.--Interpretative lithologic description,
Well D0-CE 88--Continued

Lithology	Thickness (ft)	Depth (ft)
Clay, mottled light gray (N7) and moderate red-brown (10R 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

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

Lithology	Thickness (ft)	Depth (ft)
Sand as above; interbedded with moderate yellow-brown (10YR 10/4) silt and moderate brown (5YR 4/4), light brown (5Y 6/4), pale greenish-yellow (10Y 8/2), and greenish-gray (5GY 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 1431-1459 and moderate yellow-brown (5YR 5/4) to moderate brown (5YR 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 (10Y 8/2) and greenish-gray (5GY 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 (5YR 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 (5YR 4/4) iron-cemented siltstone.	28	1,620
Sand, very fine to fine, clayey and silty.	8	1,628

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

Lithology	Thickness (ft)	Depth (ft)
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 (5YR 7/2) and moderate yellowish-brown (10YR 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 (5YR 5/6).	20	1,708
Silt, moderate brown (5Y 4/4); inter-bedded with moderate brown and pale greenish-yellow (10Y 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 (5GY 8/1) clay and light brown (5YR 5/5), yellowish-gray (5Y 7/2), and grayish-green (10GY 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 (10Y 6/2) silt to very fine, clayey sand; interbedded with light greenish-gray (5GY 8/1) clay.	18	1,858
Sand, very fine to very coarse, predominantly fine to medium; with 1-ft layer of siltstone, as in 1810-1820, at 1,871 ft; trace lignite.	24	1,882

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

Lithology	Thickness (ft)	Depth (ft)
Clay, moderate red (5R 4/6) and light greenish-gray (5G 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 (5Y 3/2), yellowish-gray (5Y 7/2), partly with orange mottling, silty, partly micaceous, partly waxy; interbedded with grayish-olive (10Y 4/2), fine, clayey, micaceous sand and light brown (5YR 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 1916-1955 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 (5YR 5/6), moderate brown (5YR 4/4) and grayish-brown (5YR 3/2); interbedded with moderate brown, grayish-red-purple (5RP 6/2) and pale greenish-yellow (10Y 8/2) clay. Clay increasing downward.	14	2,102

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

Lithology	Thickness (ft)	Depth (ft)
Clay as above; interbedded with silt.	18	2,120
Sand, very fine to very coarse, predominantly very fine, clayey; interbedded with light brown (5YR 5/6) silt and clay.	30	2,150
Clay, light brown (5YR 5/6), silty; interbedded with light brown silt and fine to medium clayey sand, with trace of sub-angular quartz pebbles.	21	2,171
Sand, moderate brown (5YR 4/4), silt to medium, predominantly very fine, clayey, slightly calcareous.	22	2,193
Clay, pale yellow-brown (10YR 6/2), very silty and very fine sandy, slightly calcareous.	4	2,197
Sand, grayish-green (5G 5/2), with dark specks, very fine, clayey.	9	2,206
Sand, very fine to very coarse, predominantly medium to coarse, angular to sub-angular quartz.	6	2,212
Clay, pale yellow-brown (10YR 6/2), silty and sandy.	2	2,214
Sand as above.	27	2,241
Clay, moderate reddish-brown (10R 4/6), moderate yellowish-brown (10YR 5/4), grayish yellow-green (5GY 7/2), and dark greenish-gray (5G 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 sub-angular, quartz, clean.	30	2,300

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

Lithology	Thickness (ft)	Depth (ft)
Clay, light brown (5YR 5/6), grayish-green (10G 4/2), mottled greenish-gray (5GY 6/1), and dusky red (5R 3/4), silty, mostly non-calcareous, non-swelling.	10	2,310
Silt, light brown (5YR 5/6).	8	2,318
Clay, dusky red (5R 3/4), dense, crumbly, and light brown (5YR 5/6), moderate brown (5YR 4/4), and light greenish-gray (5G 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 2,318-2339 ft; interbedded with very fine clayey sand and silt.	60	2,416
Sand, grayish-green (5G 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 (10GY 5/2), fine, subangular with fine dark specks, slightly clayey, with clay laminae.	16	2,494

Table 14.--Interpretative lithologic description,
Well D0-CE 88--Continued

Lithology	Thickness (ft)	Depth (ft)
Clay, moderate brown (5YR 4/4), moderate orange-pink (10R 7/4), pale greenish-yellow (10Y 8/2), dark greenish-gray (5GY 4/1), and medium brown (5YR 3/4), locally mottled red, gray, and purple; with thin layers of fine to poorly sorted sand and yellow-gray (5Y 7/2), light brown (5YR 5/6), pale brown (5YR 5/2), and dusky yellow (5Y 6/4), slightly calcareous silt.	154	2,648
Sand, very fine to very coarse, predominantly medium to coarse, sub-angular, clean.	12	2,660
Clay, varicolored as in 2,494-2,648 ft; interbedded with moderate reddish-brown (10R 4/6) silt.	25	2,685
Sand, dark greenish-gray (5G 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 (5B 7/1), grayish-purple (5RB 4/2), and very pale orange (10YR 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

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

Lithology	Thickness (ft)	Depth (ft)
Clay, interbedded with silt and clayey sand.	64	2,900
Silt, moderate brown (5YR 4/4) and dark greenish-gray, clayey, muscovitic, with black carbonaceous laminae.	15	2,915
Sand, moderate yellow-brown (10YR 6/4), very fine, silty, clayey, with carbonaceous specks.	5	2,920
Silt, greenish-gray (5GY 6/1), slightly calcareous.	4	2,924
Sand, very fine to coarse, predominantly fine to medium, slightly clayey.	21	2,945
Clay, pale green (5G 7/2) and moderate red-orange (10R 6/6), swelling; interbedded with medium reddish-brown (10R 4/6) and pale yellowish-brown (10YR 6/2) silt and medium yellowish-brown (10YR 5/4), very fine silty, clayey sand; trace of lignite.	28	2,973
Sand, moderate yellow-brown (10YR 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 (5G 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
Silt, moderate yellow-brown (10YR 5/4) and gray-green (5G 5/2), with trace of lignite.	8	3,025

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

Lithology	Thickness (ft)	Depth (ft)
Sand, very fine to very coarse, predominantly fine, slightly clayey, with trace of lignite.	27	3,052
Sand as above; interbedded with greenish-gray (5G 6/1), grayish-green (10GY 5/2), very pale green (10G 8/2), and light olive-brown (5Y 5/6), silty, slightly calcareous clay, and dark yellowish-green (10GY 4/4), sandy, slightly calcareous silt, with traces of lignite.	40	3,092
Silt, light olive-gray (5Y 5/2), very fine sandy, clayey, calcareous.	16	3,108
Sand, dark greenish-gray (5GY 4/1) to olive-gray (5Y 4/1), very fine, subangular, somewhat clayey, becoming increasingly clayey downward.	20	3,128
Silt, light olive-gray (5Y 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 (10GY 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 (10GY 3/2), clayey, slightly calcareous, swells.	22	3,258
Sand as in 3,218-36 ft.	5	3,263

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

Lithology	Thickness (ft)	Depth (ft)
Silt as in 3,236-58 ft.	27	3,290
Sand, very fine to very coarse, predominantly fine to medium, angular to subangular quartz, clean.	14	3,304
<u>Precambrian (?) basement</u>		
Gneiss, quartz monzonite, biotitic.	33	3,337

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	3188-3218 ⁵	380	12.5	4	Temperature corrected for brackish water; Cooper and Jacob (1946), straight-line analyses; T = 29.9°C.
3/31/81	2834-2844	275-300	27-30	9	Temperature corrected. Specific capacity at t = 452 min; T = 38.3°C.
4/16/81	2649-2655.6	525	75	18	Temperature corrected. Specific capacity at t = 240 min; T = 38.0°C.
5/28/81	2278.4-2288.4	850	85	23	Temperature corrected. Specific capacity at t = 217 min; T = 34.0°C.
7/31/81	1422.4-1432.4	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.

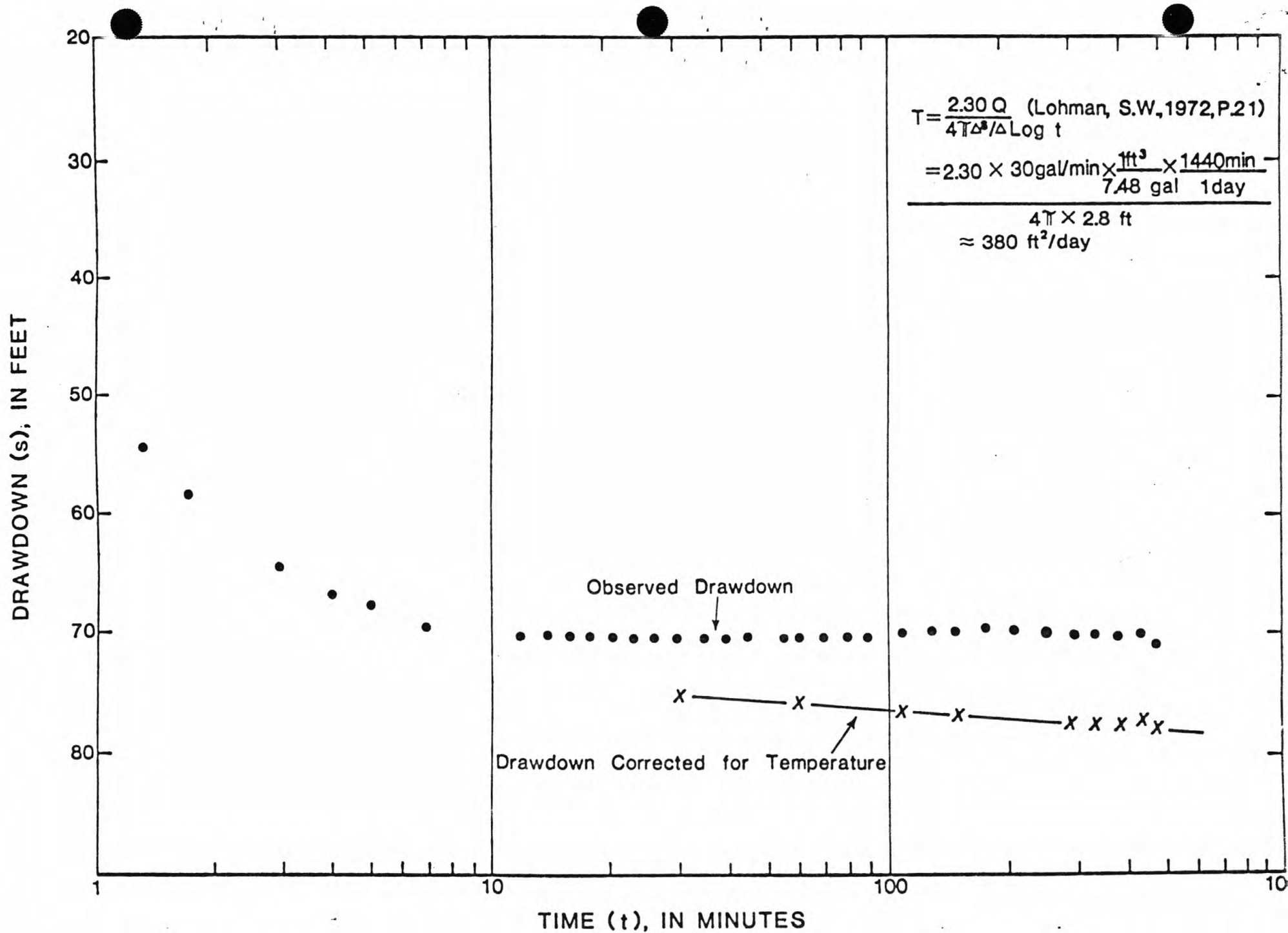


Figure 7.--Computation of transmissivity of screened zone 31883218 ft below kelly-bushing datum

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 minutes. For the remaining 27 minutes 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 equals 30 min to 35°C at time equals 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; and 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 the temperature profile in the well was linear at all times. Temperature profiles were constructed from measured well-head 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 $P = \rho g(h+z)$; cw refers to cold water, hw is hot water, z is the

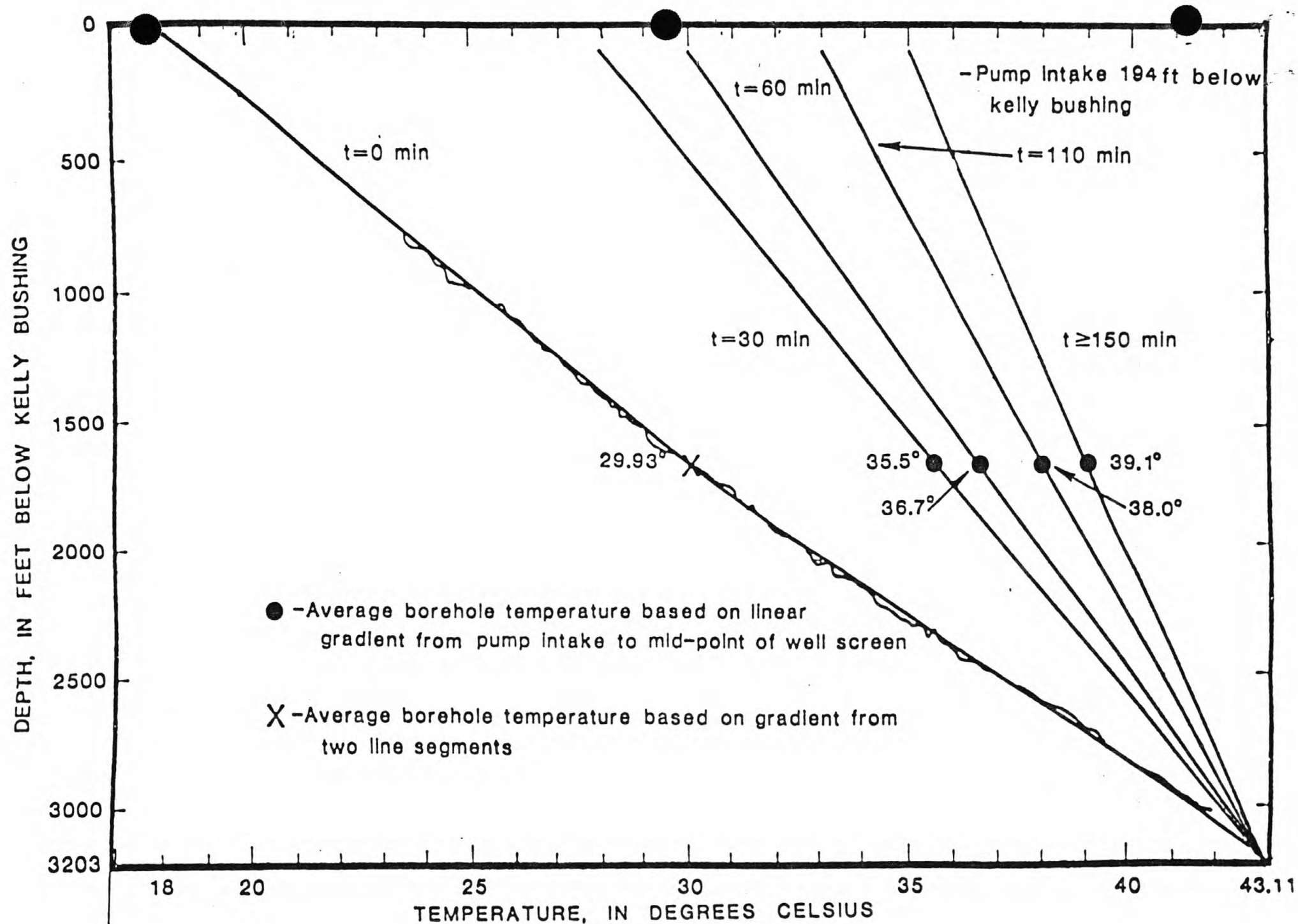


Figure 8.--Temperature profiles during test of screened zone 3188-3218 ft below kelly-bushing datum.

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:

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

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 (T) can be used:

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

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). The calculated average densities of the brine in the well at various times during the drawdown phase of the pumping test are:

<u>time (min)</u>	<u>(gm/mL)</u>
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 fig. 7. The uncorrected drawdowns rapidly increased during the first ten minutes 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 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 on table 15.

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. A 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 defined as 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. The 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 ground-water 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 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

Table 16.--Summary of fluid-head measurements

Date	Time	Perforation interval (ft) below KB	Measuring point (ft) sl	Point-water heads (ft) relative to KB	Point-water heads (ft) relative to sl	Environment-water heads (ft) relative to sl ¹	Freshwater heads (ft) relative to sl ²
2/27/81	1215	3188-3218	9.52	-63.17	-53.75	+44.16	+53.22
3/25/81	0857	2834-2844	6.35	+18.64	+28.06	+40.11	+42.38
4/16/81	-	2649-2655.6	7.05	+25.52	+34.94	Approximately equal to point-water head	Approximately equal to point-water head.
5/27/81	About 1800	2278.4-2288.4	do	+11.53	+20.95	do	do.
6/23/81	-	1822.4-1832.4	do	+5.13	+14.55	do	do.
7/27/81	-	1469.4-1479.4	do	-25.50	-16.08	do	do.
7/31/81	0915	1422.4-1432.4	do	-27.75	-18.33	do	do.

Kelly-bushing datum (KB) is 9.42 ft above sea level (sl), or 5 ft above land surface.

¹ Environmental-water heads are not compensated for an increasing temperature with depth. Heads would further increase with depth if the temperature compensation were incorporated.

² Freshwater heads computed using density of 0.998 g/mL at 20°C. This density was measured for water from the 1422.4-1432.4 ft perforation interval.

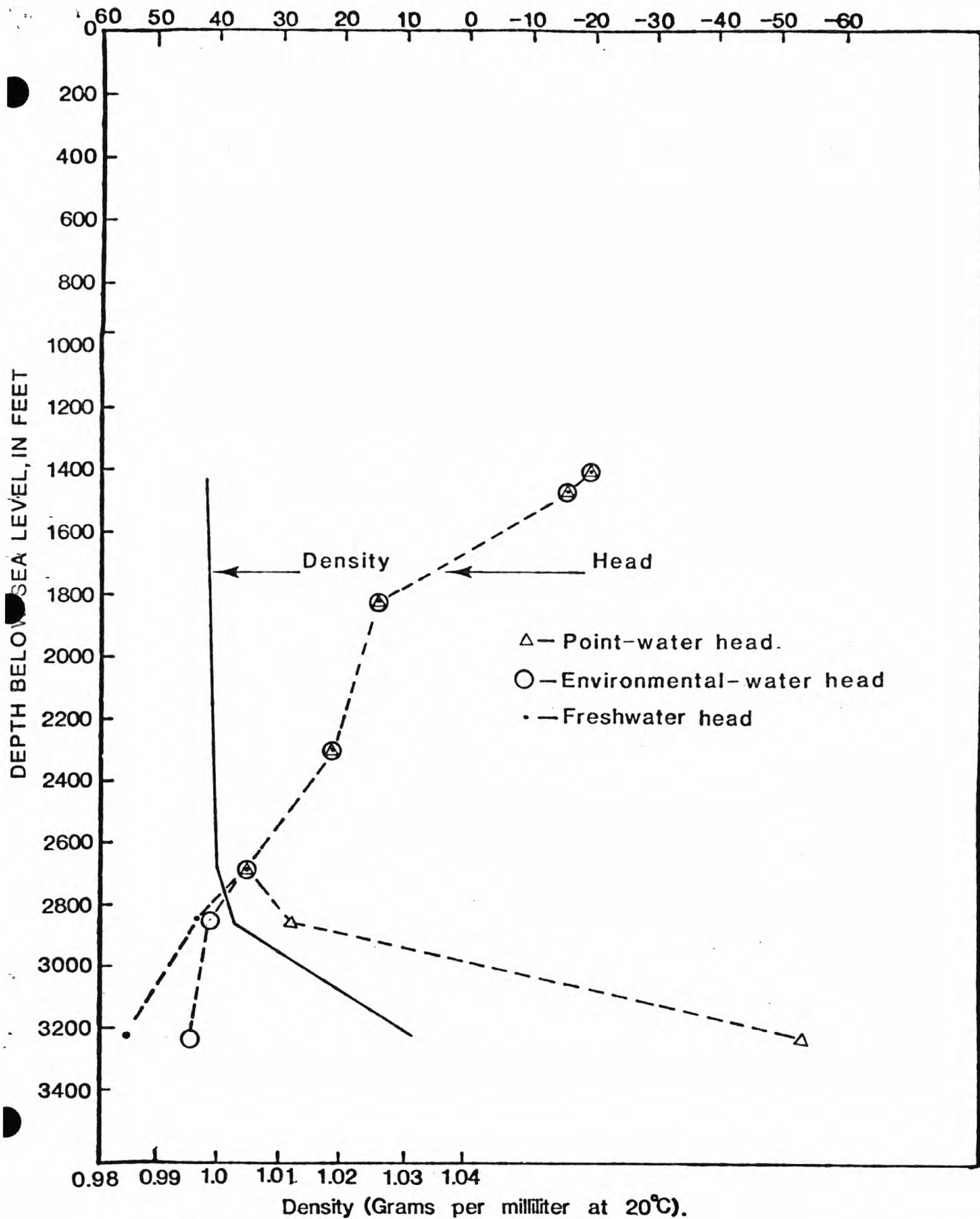


Fig. 9.-- Head and Density Profile

in the well, with peaks every twelve and a half hours. In addition, the observed water level responded to longer-term atmospheric-pressure changes.

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/in². 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, non-sandy 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, Georgia 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 communication). 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, Massachusetts, using a Coulometric Buchler chloridometer.

The zone of transition from freshwater downward to salt-water 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 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.

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, (μ g/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	.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
						720	11,000
3,010	1,300	200	200	7,600	1.1	660	12,000
						310	17,000
3,110	2,000	350	500	11,000	7.7	390	18,000
						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
							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.

Water Produced from Well

Wellhead samples from six zones were analyzed by the U.S. Geological Survey National Water Quality Laboratory in Atlanta, Georgia. 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 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 with 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 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 are depth relative to kelly bushing and the saturation index (SI) of the water with respect to calcite.

while Figure 12 indicates that the cation facies is of the sodium type where the anion facies is either of the bicarbonate type or the chloride type. Combination of the cation and anion facies

Table 10.--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, gpm	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	6500	58500
Specific conductance, lab ³	394	828	1060	1010	7250	64300
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	2900
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	1400	14000
Alkalinity (as CaCO ₃), dissolved ⁵	172	425	341	276	150	48
Sulfate, dissolved ³	16	35	35	28	38	665
Chloride, dissolved	2.3	2.8	120	140	2200	27800
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	3910	45500
Solids, sum-of constituents, dissolved	250	560	637	596	3820	47200
Hardness (as CaCO ₃) ⁶	4	6	7	4	140	9300
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 ⁶	.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	7200
Iron, suspended ⁶	48000	39000	130	1300	1100	5800
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	8600
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 ⁶	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.
 Symbols: < less than
 -- not determined

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 1000 micrograms.

⁷ Picocuries per liter.

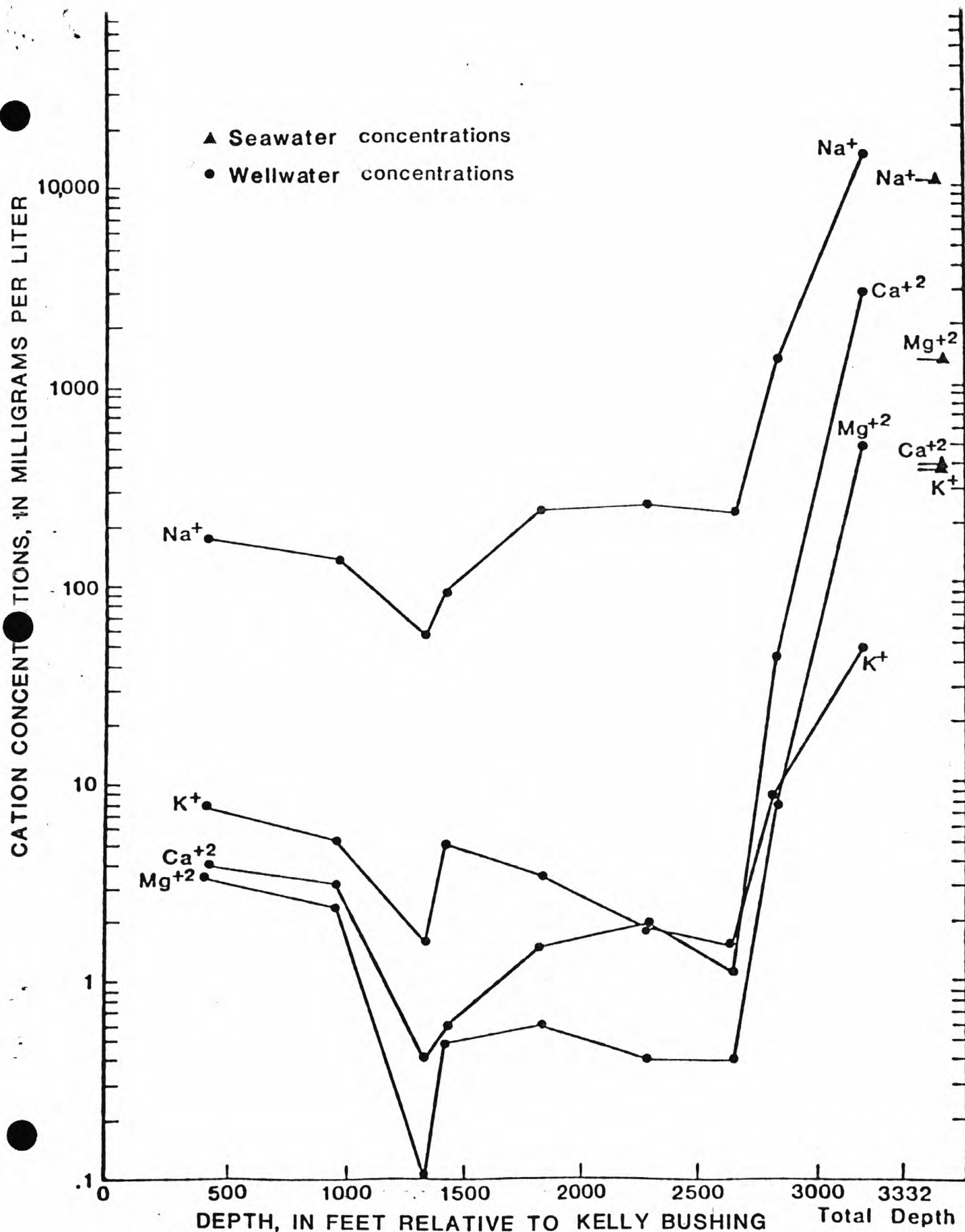


Figure 10 -- Variation in concentration of major cations with depth.

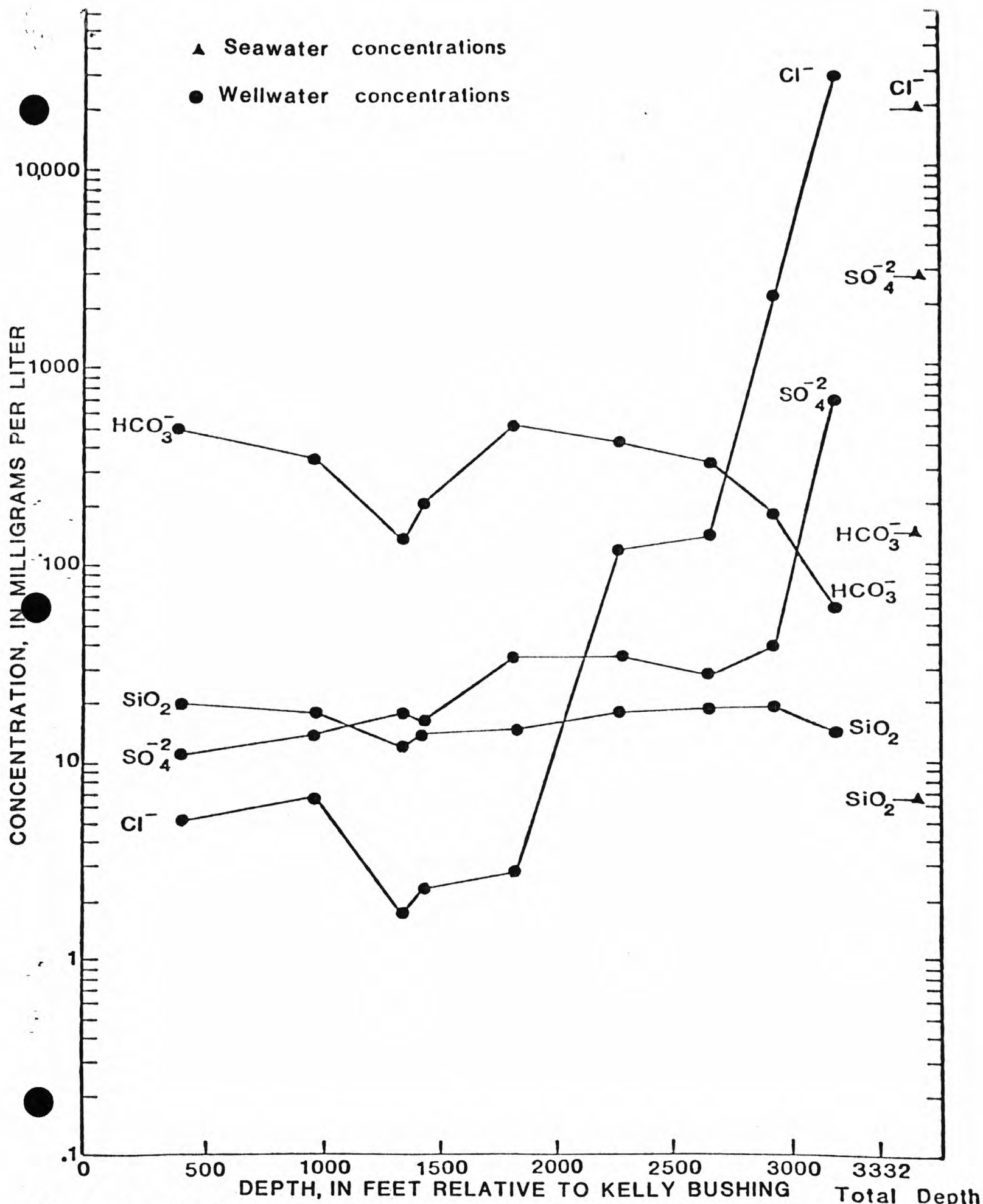


Figure 11.--Variation in concentration of major anions and silica with depth.

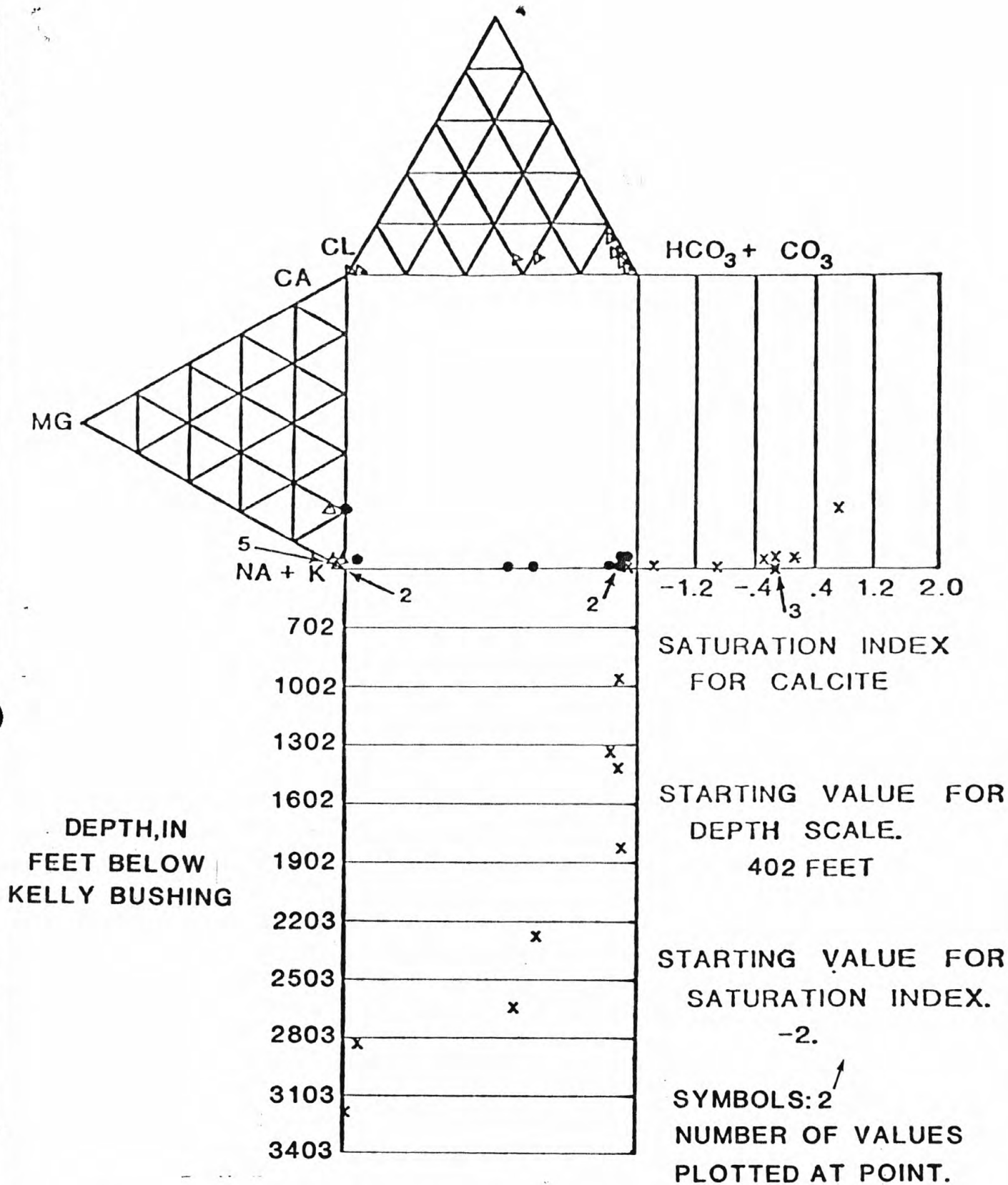


Figure 12.--The hydrochemical facies of ground water from test well DO-CE 88 and other nearby wells.

indicates water of a sodium bicarbonate character or a sodium chloride character. The figure also shows that the ground water changes progressively from a sodium bicarbonate character to a sodium chloride character with depth.

SI was determined for the analyses by the computer program WATEQF (Plummer and others, 1978) and is defined as:

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

where,

IAP = ion activity product

K = the equilibrium constant for the reaction

An SI of zero 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 is, 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 are also given in table 16 for the wellhead samples.

Cation Exchange Capacities and

Concentrations of Exchangeable Cations

Samples of twenty cores were analyzed for cation exchange capacities (CEC) using standard techniques (Hesse, 1972) by 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.

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,

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

<u>Depth¹</u>	<u>Primary</u>	<u>Duplicate</u>	<u>Triplicate</u>	<u>Mean</u>
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
1111	13.6	12.4	16.4	14.1
1436	14.4	11.2	12.0	12.5
1650	21.6	20.0	24.0	21.9
1753	16.4	14.4	10.4	13.7
1950	31.2	28.0	28.4	29.2
2094	22.4	20.0	23.2	21.9
2200	21.6	20.0	20.8	20.8
2319	34.4	32.8	35.2	34.1
2422	16.8	13.6	17.2	15.9
2484	16.0	13.6	18.4	16.0
2585	37.6	37.6	41.6	38.9
2692	20.8	16.4	16.8	18.0
3008	14.4	11.2	13.6	13.1
3210	8.0	7.2	9.6	8.3

¹ Feet below kelly bushing.

magnesium, potassium and sodium (Delora Boyle, U.S. Geological Survey, written communication, 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 per twenty grams and plotted in figure 13 to show the variations with depth for the exchangeable cations. Also plotted on figure 13 are the mean CEC data 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 from a sodium bicarbonate to a sodium chloride character with depth.

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 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 range 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 is 1.5 percent in the quartz monzonite bedrock and ranges 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 $(\mu\text{m})^2$. 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 sl, 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.

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

Depth ¹	Calcium			Magnesium			Potassium			Sodium		
	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
1111	1.74	2.32	2.03	.69	.82	.76	.62	.65	.64	.90	.89	.90
1436	1.05	1.10	1.08	.47	.59	.53	.37	.44	.41	.89	.89	.89
1650	2.31	2.42	2.37	.87	.95	.91	.48	.62	.55	2.59	2.34	2.47
1753	1.27	1.36	1.32	.61	.69	.65	.33	.39	.36	1.66	1.56	1.61
1950	3.05	3.02	3.04	1.22	1.38	1.30	.49	.62	.56	4.27	4.43	4.35
2094	2.74	2.49	2.62	.70	.77	.74	.50	.50	.50	1.79	2.24	2.02
2200	2.50	2.89	2.70	.71	.73	.72	.33	.42	.38	3.14	2.75	2.95
2319	4.65	4.97	4.81	.95	1.12	1.04	.51	.56	.54	4.46	5.65	5.06
2422	1.61	1.54	1.58	.41	.47	.44	.22	.32	.27	1.86	1.78	1.82
2484	1.61	1.73	1.67	.41	.53	.47	.24	.32	.28	1.66	1.52	1.59
2585	4.56	5.18	4.87	.92	1.16	1.04	.48	.53	.51	4.46	5.15	4.81
2692	1.65	1.81	1.73	.53	.65	.59	.20	.32	.26	1.53	1.48	1.51
3008	1.76	1.85	1.81	.19	.24	.22	.25	.35	.30	2.82	2.37	2.60
3210	1.24	1.29	1.27	.17	.21	.19	.09	.20	.15	1.89	1.44	1.67

¹ Feet below kelly bushing.

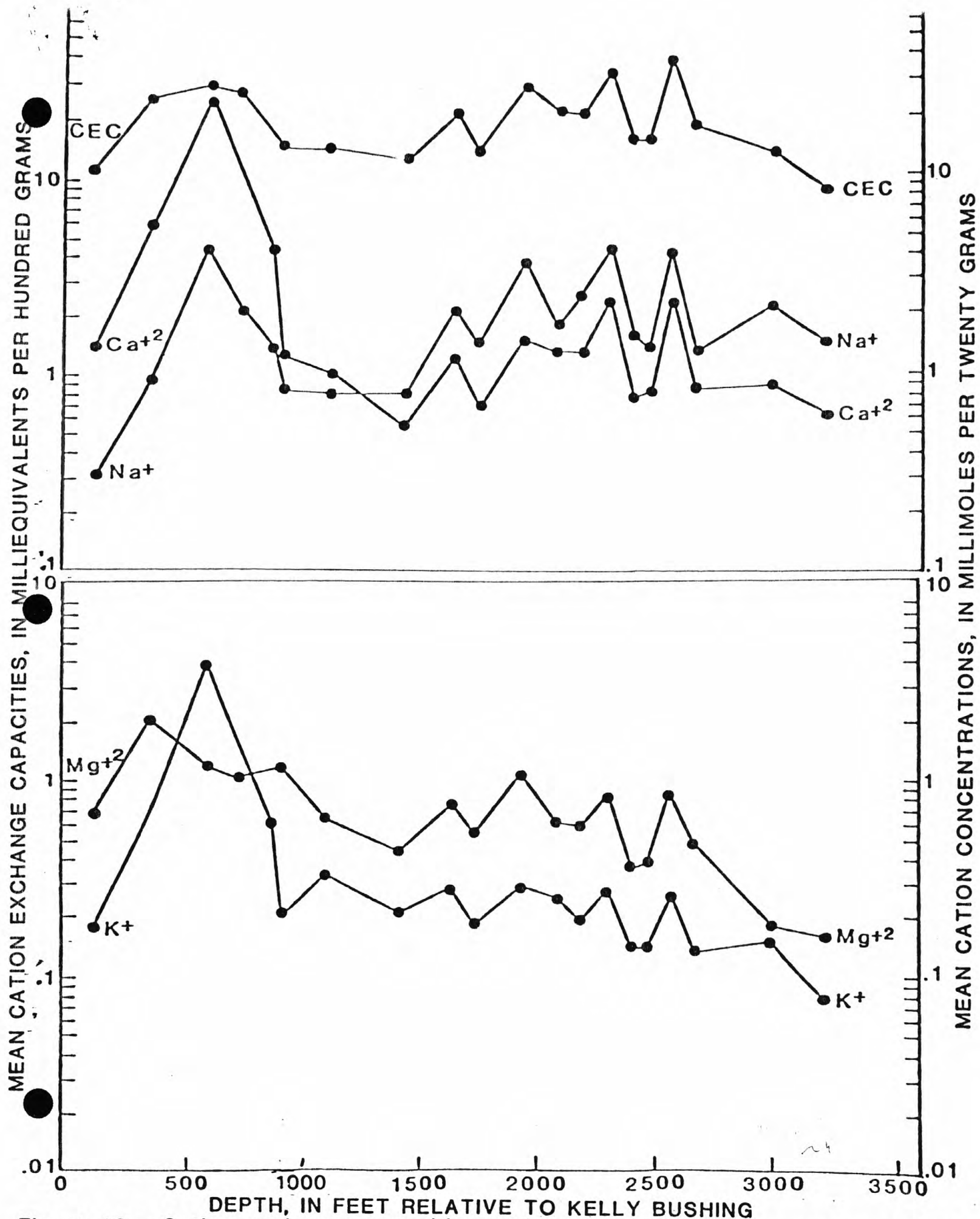


Figure 13.--Cation exchange capacities and exchangeable cation concentrations.

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