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SELECTED LOGGING DATA AND EXAMPLES OF GEOPHYSICAL LOGS FOR THE COASTAL PLAIN OF DELAWARE

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SELECTED LOGGING DATA AND EXAMPLES OF GEOPHYSICAL LOGS FOR THE COASTAL PLAIN OF DELAWARE

ABSTRACT

Geophysical logging techniques have been used in Delaware for many years as a means of identification and correlation of Coastal Plain formations. Criteria for the recognition of those formations having distinctive types of logs are presented. Formation factors have been calculated using multiple-point resistivity logs, temperature logs, and ground-water quality data and range from 1.2 to 6.8 for various formations underlying the State. Formation factors in turn are used to estimate water quality in later test holes.

Temperature log data indicate that the average temperature gradient south of the Fall Line is about 1.2 degrees F (0.6 degrees C) per 100 feet (30 meters) of depth.

Two persistent gamma-log peaks can be recognized in Delaware; one peak seems to occur near the Cretaceous-Tertiary boundary while the second peak apparently marks a horizon within sediments of Late Cretaceous age.

INTRODUCTION

Purpose

Subsurface geologic information is in great demand in Delaware and is widely used in ground-water studies, water well design, facility siting investigations, mineral exploration, and local and regional geologic correlation of buried rock units. This demand is being reinforced by the exploration of the subsurface in nearby offshore areas for possible sources of petroleum. Most subsurface information comes from drill holes which, in Delaware, are bored primarily for ground-water. The record of a boring, that is, its log, is a description of the rock materials encountered below the surface. A geophysical log is a record produced by lowering measuring devices into the well and recording the electrical or other properties of the units penetrated. Geophysical logs thereby yield objective records of the subsurface that may be analysed to provide more information than can be obtained from descriptive logs alone. In this report, certain types of geophysical log characteristics have been identified that will enable the user to locate and identify specific rock units in the subsurface. Also provided are certain factors derived from geophysical logs that are often used in calculating various rock properties. It is assumed that the reader has some general knowledge of logging methods. The Appendix, at the end of this report, deals briefly with the mechanics of some of the more common types of logs and is presented for those with little or no background in logging.

Existing Data

Geophysical logs have been used for many years in Delaware as a routine tool in geologic and hydrologic studies. The most commonly available logs are the single-point resistance electric log and the gamma-ray log. These logs are widely applied in selecting well screen depths and for stratigraphic correlations. In the last few years, multipoint electric logs have also been frequently used in Delaware for determining water quality in selected aquifers. Several hundred single-point resistance and gamma-ray logs and several temperature, caliper neutron, flow meter, and conventional multi-point resistivity logs are available in Delaware Geological Survey files.

Acknowledgments

Robert R. Jordan and Nenad Spoljaric of the Delaware Geological Survey reviewed the manuscript and offered suggestions for improvement. Appreciation is extended to the many water well contractors who cooperated with the Survey on numerous occasions. The writer also benefited from field data compiled by the U.S. Geological Survey during their recently completed water resources study of the Delmarva Peninsula (Cushing and others, 1973). Thomas E. Pickett of the Delaware Geological Survey provided valuable suggestions and comments concerning Delaware stratigraphy.

GEOLOGIC FRAMEWORK

The geology of Delaware has been discussed in such publications, as those by Marine and Rasmussen (1955), Jordan (1962, and Sundstrom and Pickett (1967, 1968, 1969, 1970). The basic stratigraphy of the State is outlined in Table 1. South of the Fall Line, the boundary between the Coastal Plain and Piedmont physiographic provinces, unconsolidated sediments of Cretaceous, Tertiary, and Quaternary ages rest upon an older crystalline basement complex. The basement rocks are generally exposed north of the Fall Line. The mass of unconsolidated sediments thickens from a feather edge at the Fall Line in northern Delaware to a maximum of about eight thousand feet in the southern part of the State. The influence of more detailed

TABLE 1: Correlation chart of the Coastal Plain units in New Jersey, Delaware, and Maryland (after Pickett, 1972).

Period	Epoch	New Jersey Group	New Jersey	Delaware Group	Delaware	Delaware (other)	Maryland Group	Maryland	Maryland (other)
Quaternary	Pleistocene		Cape May Fm. Pensauken Fm. Bridgeton Fm.		Columbia Fm.	Omar Fm. Beaver-dam Fm. Columbia Grp.	Columbia Grp.	Walston Fm. Salisbury Fm.	Lowland Deposits
Tertiary	Pliocene (?)		Beacon Hill Gravel		Bryn Mawr Fm.			Upland Gravels	
	Miocene		Cohansey Fm. Kirkwood Fm.		Chesapeake Group		Chesapeake Grp.	Yorktown Fm. St. Marys Fm. Choptank Fm. Calvert Fm.	
	Oligocene								
	Eocene		Piney Point Fm. Shark River Fm. Manasquan Fm.		Piney Point Fm. Nanjemoy Fm.			Piney Point	Chickahominy Fm.
	?	Rancocas Grp.	Vincentown Fm.	Rancocas Grp.	Vincentown Fm.	Pamunkey Fm. (downdip)	Pamunkey Grp.	Nanjemoy Fm. Marlboro Clay	
	Paleocene	Rancocas Grp.	Hornerstown Fm.	Rancocas Grp.	Hornerstown Fm.	Pamunkey Fm. (downdip)	Pamunkey Grp.	Aquia Fm. Brightseat Fm.	
Cretaceous	Upper Cretaceous	Monmouth Grp.	Tinton Fm. Redbank Fm. Navesink Fm. Mt. Laurel Fm.		Mt. Laurel Fm.	Monmouth Fm. (downdip)		Monmouth Fm.	
		Matawan Grp.	Wenonah Fm. Marshalltown Fm. Englishtown Fm. Woodbury Clay Merchantville Fm. Magothy Fm.	Matawan Grp.	Marshalltown Fm. Englishtown Fm. Merchantville Fm. Magothy Fm.	Matawan Fm. (downdip)		Matawan Fm. Magothy Fm.	
			Raritan Fm.						
	Lower Cretaceous		Potomac Fm. ?		Potomac Fm.		Potomac Grp.	Patapsco Fm. Arundel Fm. Patuxent Fm.	

stratigraphy on geophysical logs is discussed in later sections of this report.

IDENTIFICATION OF COASTAL PLAIN STRATIGRAPHIC UNITS BY GEOPHYSICAL LOGS

In Delaware, outcrops or surface exposures of the various rock units are limited and at least one formation (the basic rock-stratigraphic unit), the Piney Point, has no outcrop. Many rock-stratigraphic units, including formations, aquifers, and groups (units composed of two or more formations) are recognizable on geophysical logs and thus heavy reliance is often placed on logging techniques in the collection of subsurface data. Indeed, the Code of Stratigraphic Nomenclature indicates that "electrical or other mechanically recorded logs" are desireable to support a proposal for establishing any new rock-stratigraphic unit. The establishment of a new formation name, for instance, requires that the unit is mappable in the surface or subsurface and this mappability can often be demonstrated by means of geophysical logs. Those rock units that generally show persistent characteristics on geophysical logs, particularly on the electric and gamma logs, are discussed below. Reference should be made to Table 1 to determine where each unit fits within the geologic framework of the State. Those units that are not readily identifiable by means of geophysical logs are not discussed.

Cretaceous Series

The bulk of the Coastal Plain sediments in Delaware is made up of the Potomac Formation, a deltaic deposit of Early to Late Cretaceous age. Clays predominate but are often interbedded with silts and fine to coarse, generally well sorted, fluvial sands. Individual sands are difficult, if not impossible, to correlate for any distance, but there appears to be two general zones within the Potomac where sands tend to predominate (Jordan, 1968). Sundstrom (1967) informally referred to these as the "upper" and "lower" hydrologic zones respectively.

Spoljaric (1967) discusses the depositional history of the Potomac sediments and mentions the presence of channel sequences. Figure 2 shows a single-point resistance curve in a thick channel sand of the Potomac Formation, (see Figure 1 for location of holes discussed in text.) Test drilling showed that the sand could be traced for several hundred feet both to the east and west before, typically, it began to thin quite rapidly.

A detailed example of sand and clay interbedding within the Potomac Formation is shown by the electric log of well Eb22-10 in Figure 3. The sandy interval from about 300 feet

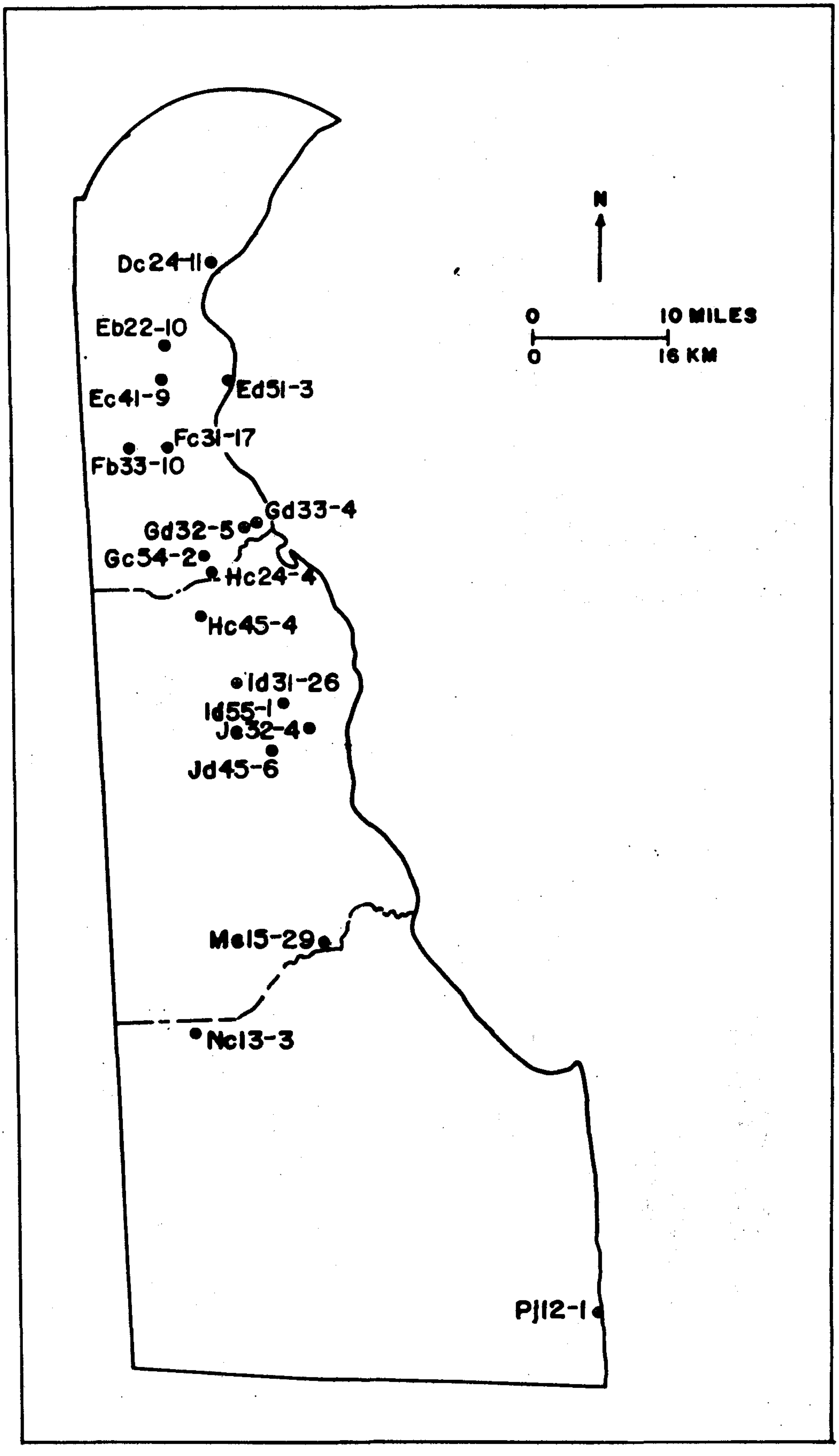


Figure 1. Location of wells and test holes discussed in text.

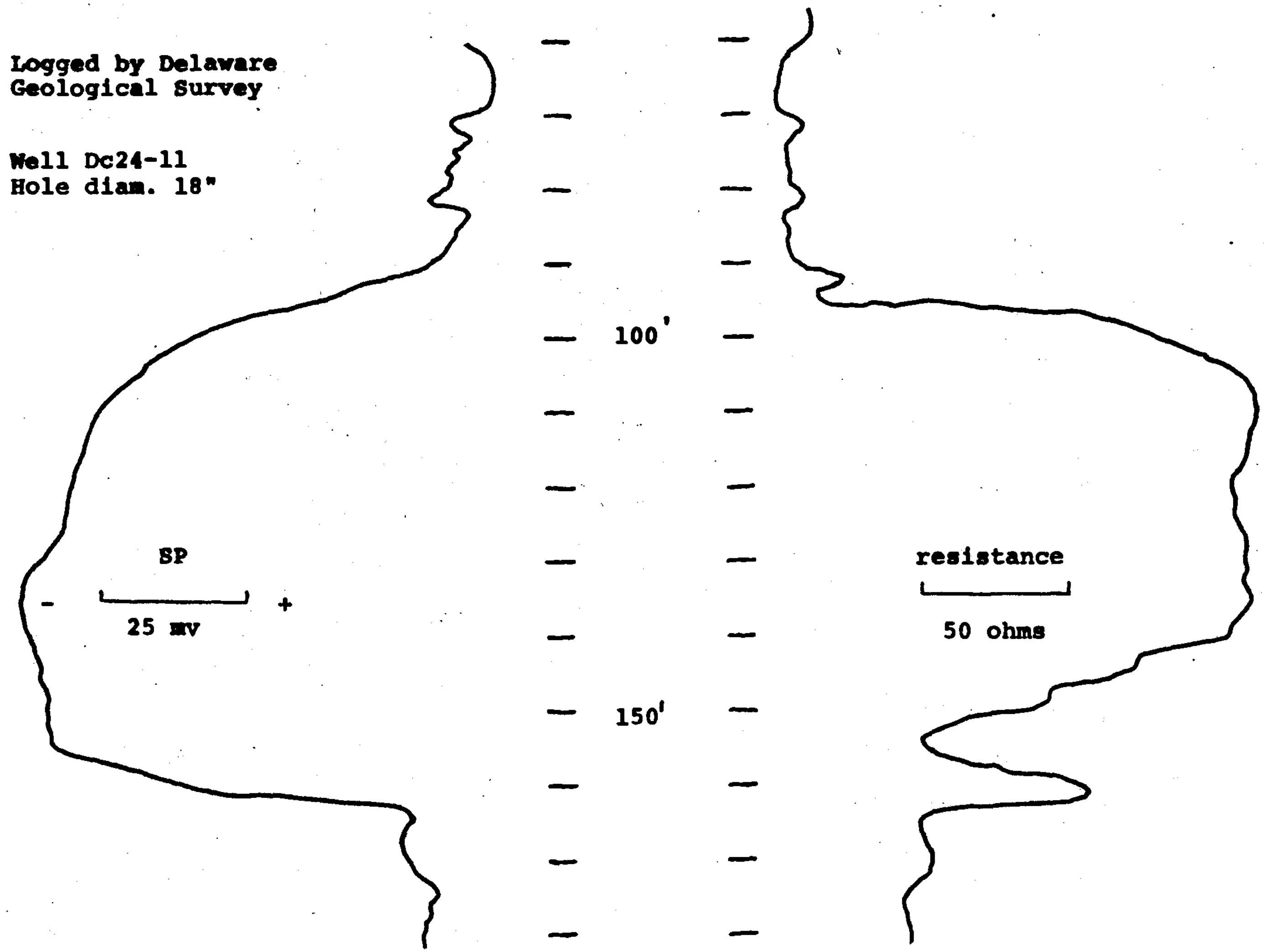


Figure 2. Single-point resistance log of Potomac Formation channel sand.

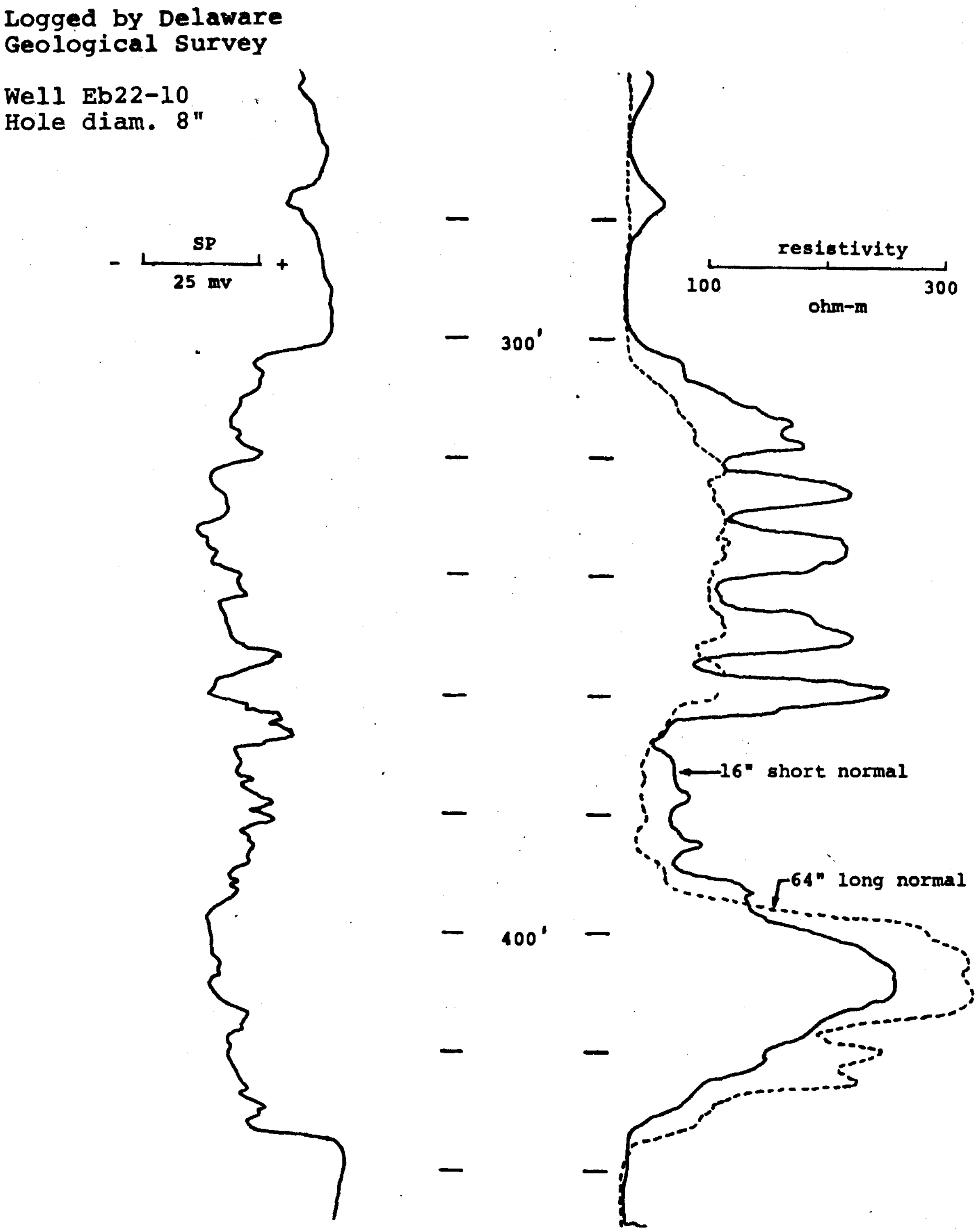


Figure 3. Partial electric log of well Eb22-10 showing sand and clay interbedding within the Potomac Formation.

to about 430 feet is the "lower hydrologic zone" mentioned above. The log in Figure 3 is more indicative of Potomac stratigraphy in general and also illustrates the difficulties involved in trying to correlate individual sands.

In general, the variable lithology of the Potomac Formation as observed on the electric log usually distinguishes the Potomac from overlying formations in those areas downdip from the Potomac subcrop. In central Delaware, for example, where considerable marine section is present, the contact between the Potomac and overlying marine sediments is suggested by a decrease in both log variability and amplitude.

Magothy Formation

The overlying Magothy Formation is generally thought to be a transitional unit between the nonmarine Potomac Formation and younger marine sediments. The Magothy is distinctive stratigraphically, but because of its gross lithologic similarities to the Potomac may often be hard to define on the basis of geophysical logs alone. Good formation samples are usually necessary for a more exact correlation. In salt or brackish water sections, the self-potential curve usually has a relative high amplitude and can often be used to define the approximate top of the Potomac-Magothy sequence even though the resistivity curves may be lacking in detail (see Figure 4).

Rancocas Group

Pickett and Spoljaric (1971) showed that the Rancocas Formation (Paleocene-Eocene age) in Delaware is equivalent to the Vincentown Formation (upper unit) and Hornerstown Formation (lower unit) of New Jersey and thus elevated the Rancocas to group status. In Delaware, the Vincentown Formation is predominantly composed of a glauconitic, poorly sorted, fine to medium sand while the Hornerstown Formation is generally a silty clay.

In most places, the top of the Vincentown Formation appears on resistivity logs as a gradual increase in resistivity over several feet rather than as an abrupt change (see Figure 5). South of the outcrop area and especially just north of Smyrna, the Vincentown Formation as a whole stands out rather markedly on the electric log in contrast to a log obtained in the finer-grained sediments of the Hornerstown Formation below.

Rima and others (1964) called attention to the presence of thin interbeds of indurated calcareous sandstone in the lower half of the Vincentown Formation and the response of the resistivity log to these beds. Figures 5 and 6 are examples of logs which show in some detail the indurated beds in the lower part

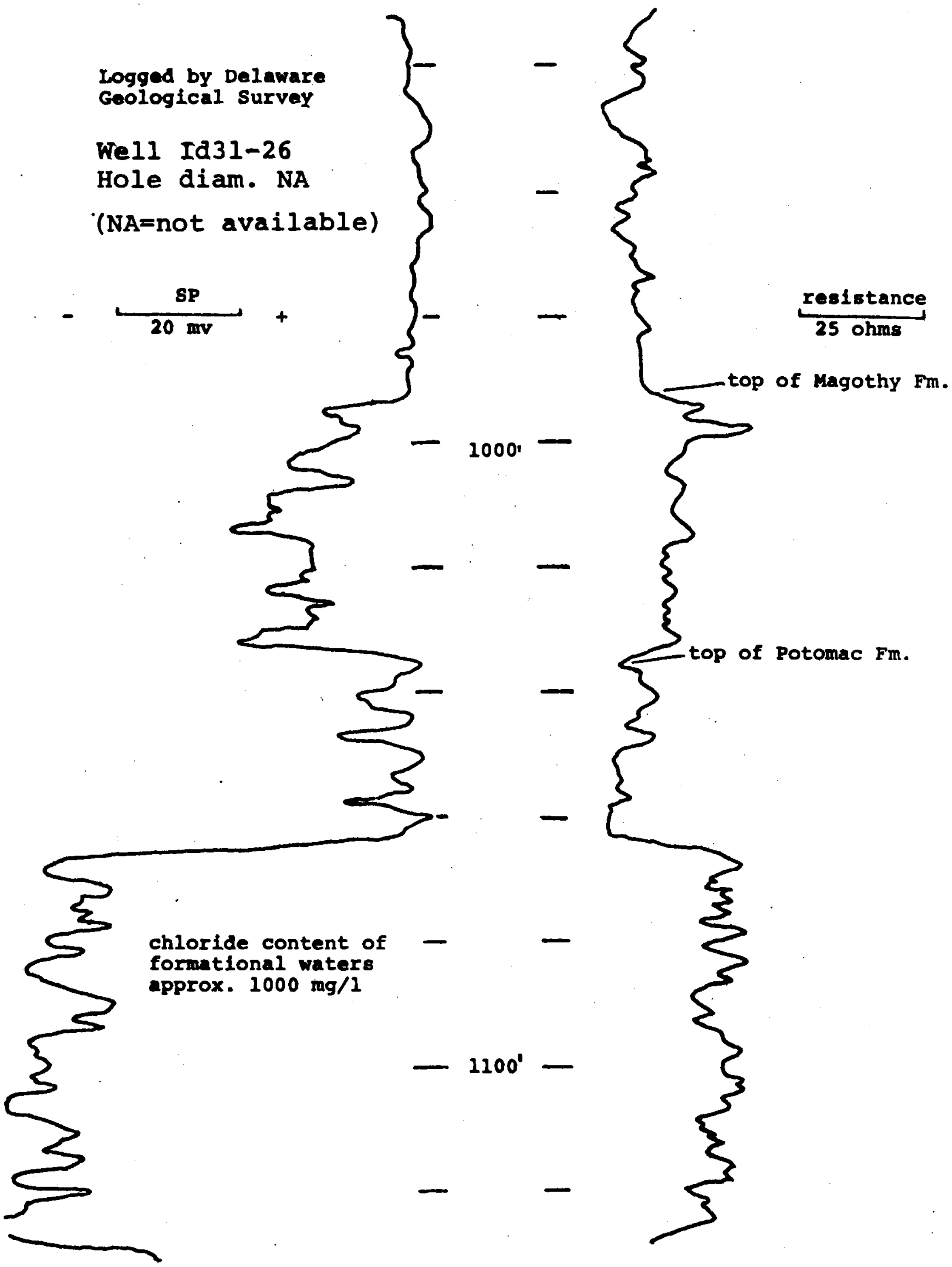


Figure 4. Partial electric log of well Id31-26.

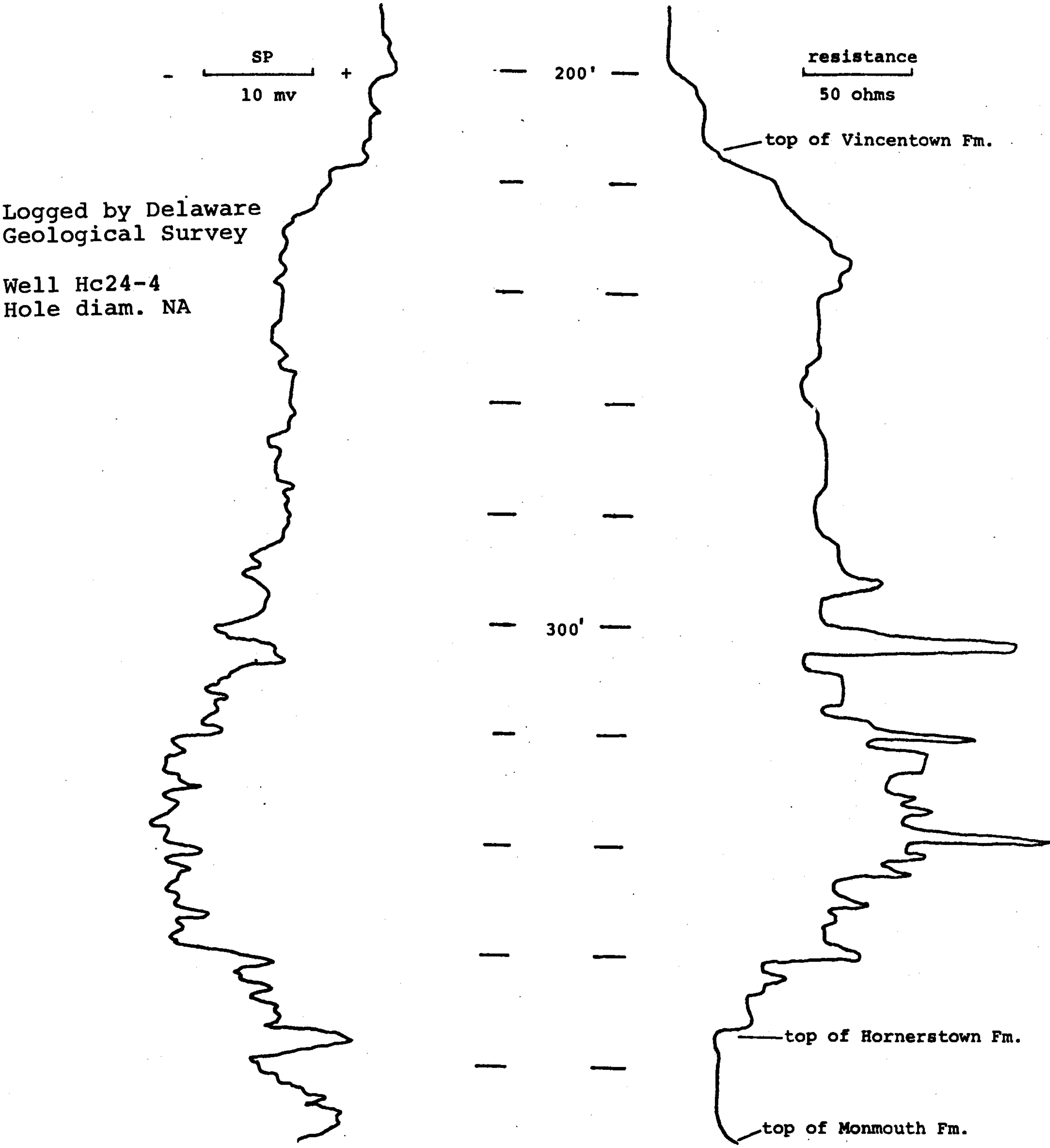


Figure 5. Partial electric log of well Hc24-4 showing Vincentown and Hornerstown Formations.

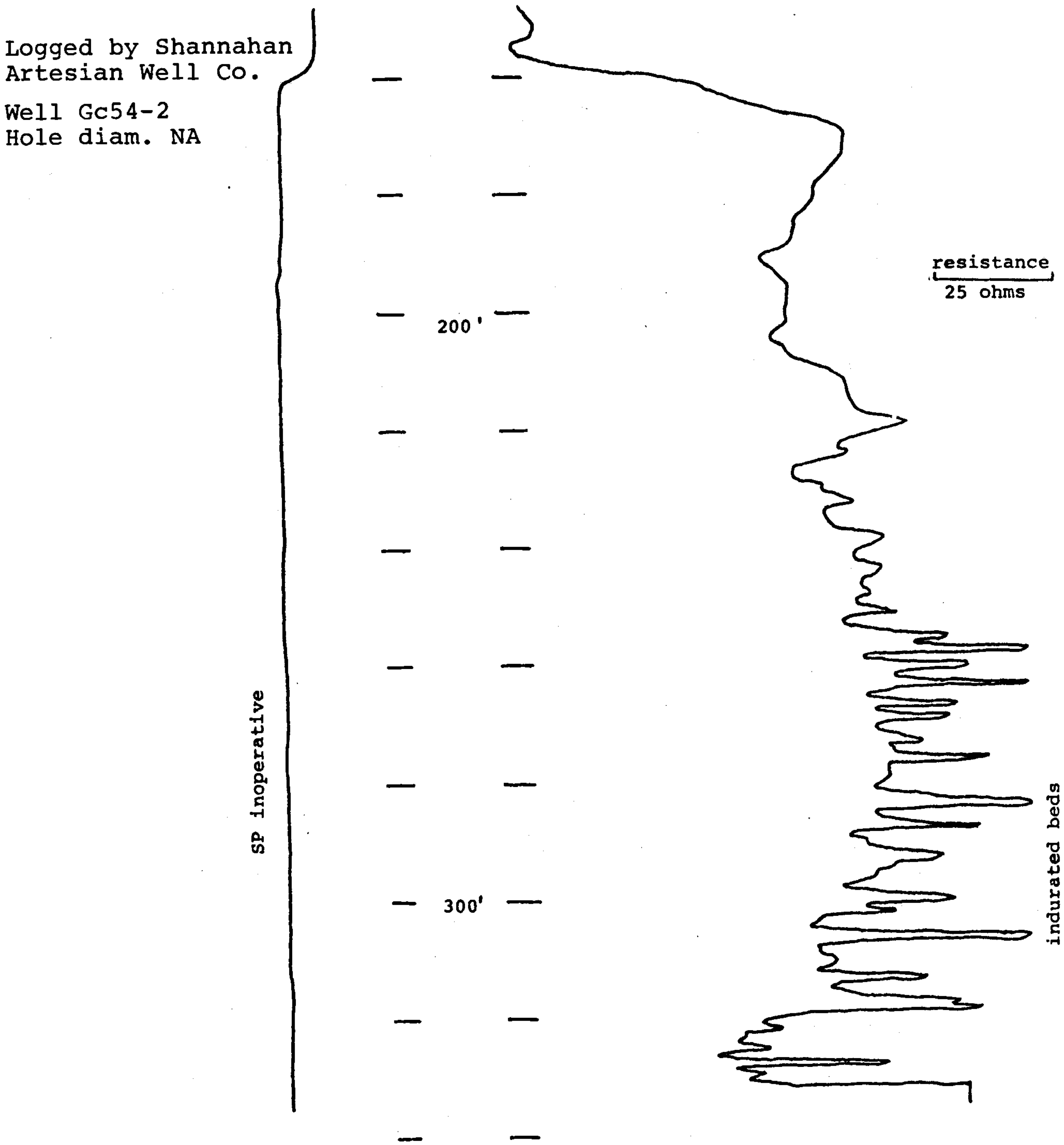


Figure 6. Partial electric log of well Gc54-2 showing indurated beds within the Vincentown Formation.

of the Vincentown. In these latter examples the apparent resistance on the single-point curve is much lower than true resistivity. However, because individual beds are thin (two feet or less) they are not usually defined by the long normal (64") resistivity log and only poorly defined by the short normal (16") log. The lack of detail on the self-potential curve in Figure 6 is due primarily to faulty instrument adjustment but also partly to the similarity of formation water quality and the water used to make up the drilling fluid. In Delaware it is sometimes difficult to determine precisely the contact between the Hornerstown Formation (Late Cretaceous to Tertiary age) and the underlying Monmouth Formation (Cretaceous age) by electric logs alone because of the similarity of sediment type. However, in New Jersey, Minard and others (1968) pointed out that the Hornerstown Formation can be identified by a distinctive pattern on the gamma-ray log. A similar gamma peak seems to occur in Delaware and is discussed in a later section of this report.

Piney Point Formation

The Piney Point was first described in Maryland and named by Otton (1955) after its type locality along the Potomac River. The Piney Point was later described in Delaware by Rasmussen and others (1958) from the Dover Air Force Base deep test hole (Je32-4). Subsequent drilling has shown that a thicker sandy facies of the formation is especially well developed around the Dover area and for several miles to the south. In informal usage the term "Piney Point" has thus often implied only the sandy portion of the unit that has served as an aquifer. However, Jordan (1962) pointed out that the unit as a formation becomes finer-grained to the north of Dover where it grades into the Nanjemoy Formation (Pickett, 1972) and probably extends as far south as Milford and Bridgeville. Additional drilling at Cheswold, Milford, and Greenwood has indeed confirmed the presence of the Piney Point as a formation at these locations and shown that it becomes much finer-grained several miles to the north and south of Dover.

The response of the electric log in the Piney Point Formation is perhaps one of the most distinctive and persistent in the central Delaware area. The top of the unit typically appears on resistivity curves as a moderate but readily identifiable rounded "shoulder" as seen in Figure 7. The Piney Point also becomes finer-grained with depth as it grades into the underlying Pamunkey Formation (Pickett, 1972) as shown by a gradual decrease in amplitude of both the resistivity and self-potential curves. The bottom of the Piney Point is thus often difficult to determine on the basis of electric logs alone.

The single point resistance curve can be particularly misleading in the Piney Point when the water producing capabilities

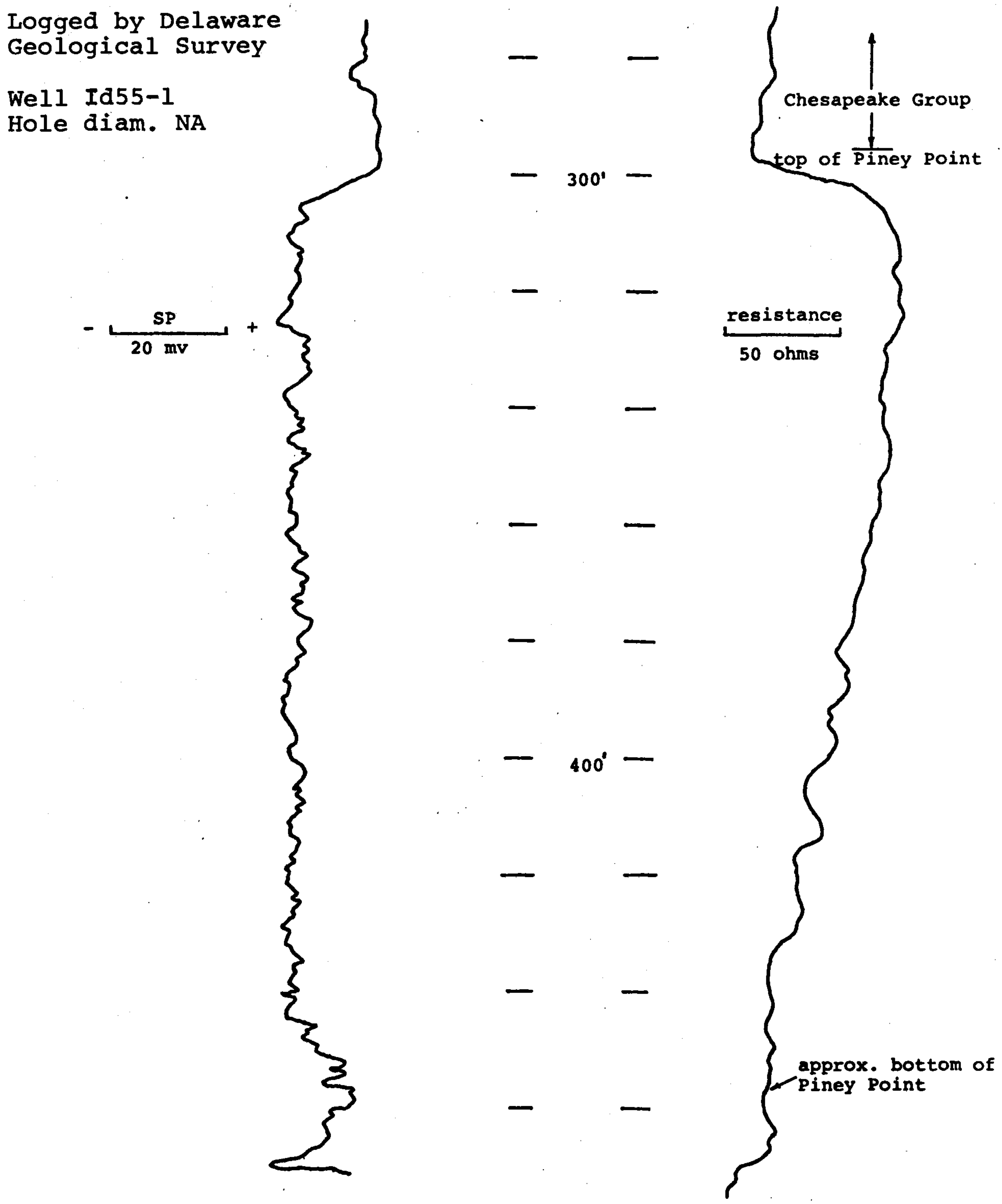


Figure 7. Partial electric log from well Id55-1.

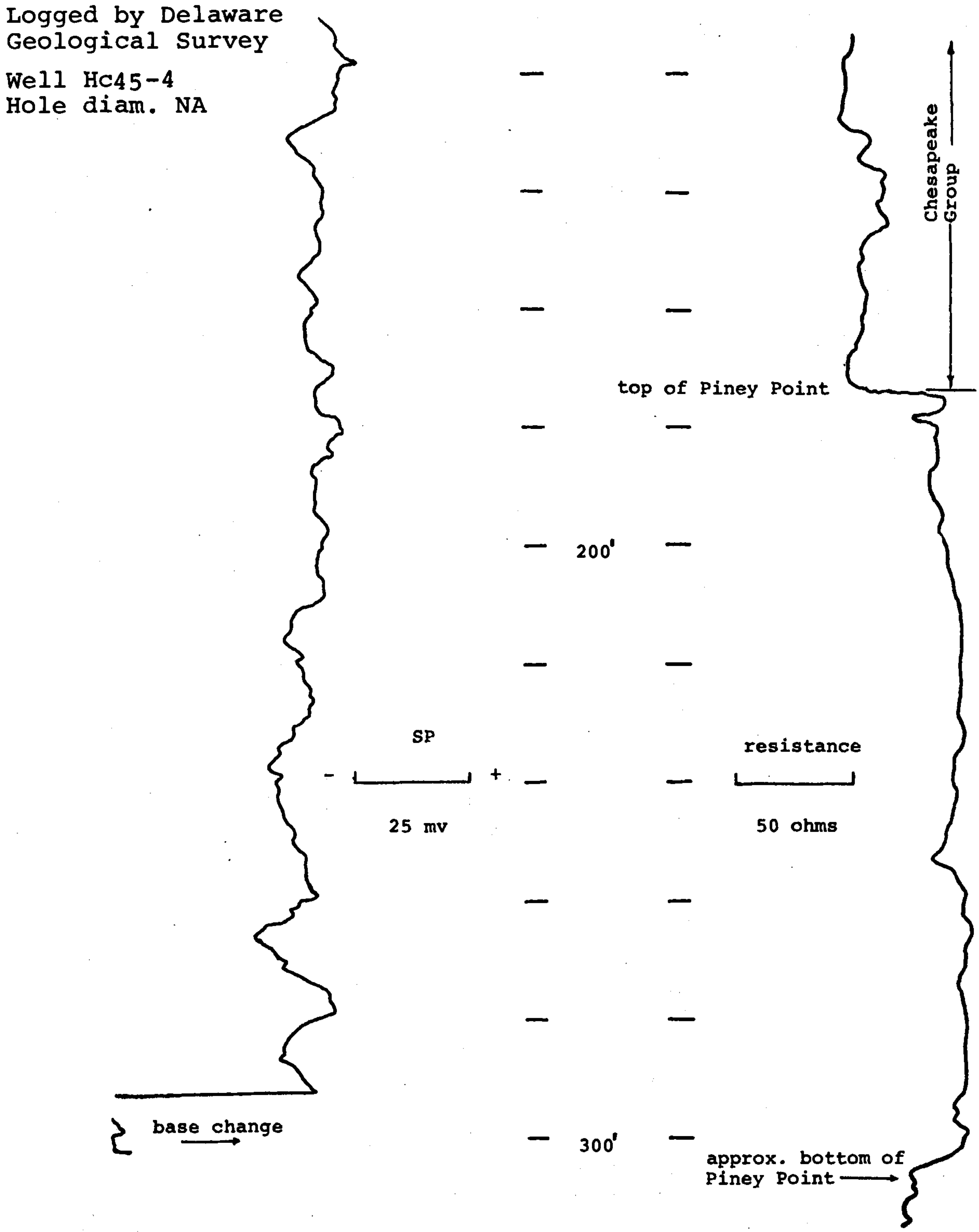


Figure 8. Partial single-point electric log from well Hc45-4.

of the formation must be determined. If Figures 7 and 8 are compared it can be seen that the general curve shapes and relative amplitudes on both of the logs are nearly the same. The log in Figure 7 was made in the sandier portion of the formation beneath the Dover area where groundwater yields from the Piney Point may average several hundred gallons per minute. The log shown in Figure 8 was made in an area where the Piney Point was shown by drill cuttings to be a sandy silt and thus a relatively poor water producer. Also, subsequent lateral and long normal resistivity logs at the latter location gave apparent resistivity values of only about 25-30 ohm-meters, considerably lower than for most good aquifers in Delaware. A later test well at location Hc45-4 produced only about 5 gallons per minute despite lengthy development attempts.

Chesapeake Group

The Miocene age sediments in Delaware are known as the Chesapeake Group and generally consist of bluish-gray silts with interbedded sands. The Chesapeake Group rests unconformably upon older Paleocene and Eocene age sediments (Pickett, 1968). The thicker sands within the Chesapeake Group are important sources of ground water in Kent and Sussex Counties and have been given informal aquifer names. In Kent County the name Frederica aquifer has been given to the upper sand of Miocene age and the name Cheswold to the lower sand. In addition, Cushing (1973) showed that a third, relatively thin sand, which often occurs between the Cheswold and Frederica south of Dover, could be identified as the Federalsburg aquifer. The name is derived from the type section near Federalsburg, Maryland. The electric log in Figure 9 indicates the presence of all three aquifers. Further to the south in Sussex County, two younger, relatively thick sands, occur above the Frederica aquifer and are known as the Pocomoke (upper) and Manokin (lower) aquifers (Miller, 1971). However, their correlation from place to place is difficult and a well defined intervening layer is often lacking.

Columbia Formation

The Columbia Formation comprises probable Pleistocene age surficial sands and gravels with some silts and clays. In southern Delaware at least two units, the Beaverdam and Omar Formations, can be recognized and the term Columbia is elevated to group status (Jordan, 1962). The Pleistocene sands and gravels are among the most permeable sediments in the Delaware Coastal Plain and usually show the highest resistivity readings of the entire geologic section in any single hole. Because the Columbia Formation is usually the uppermost geologic unit and often quite thin, it may not be recorded because of the electrode configuration used in running the conventional long and short normal resistivity logs. However, surface resistivity measure-

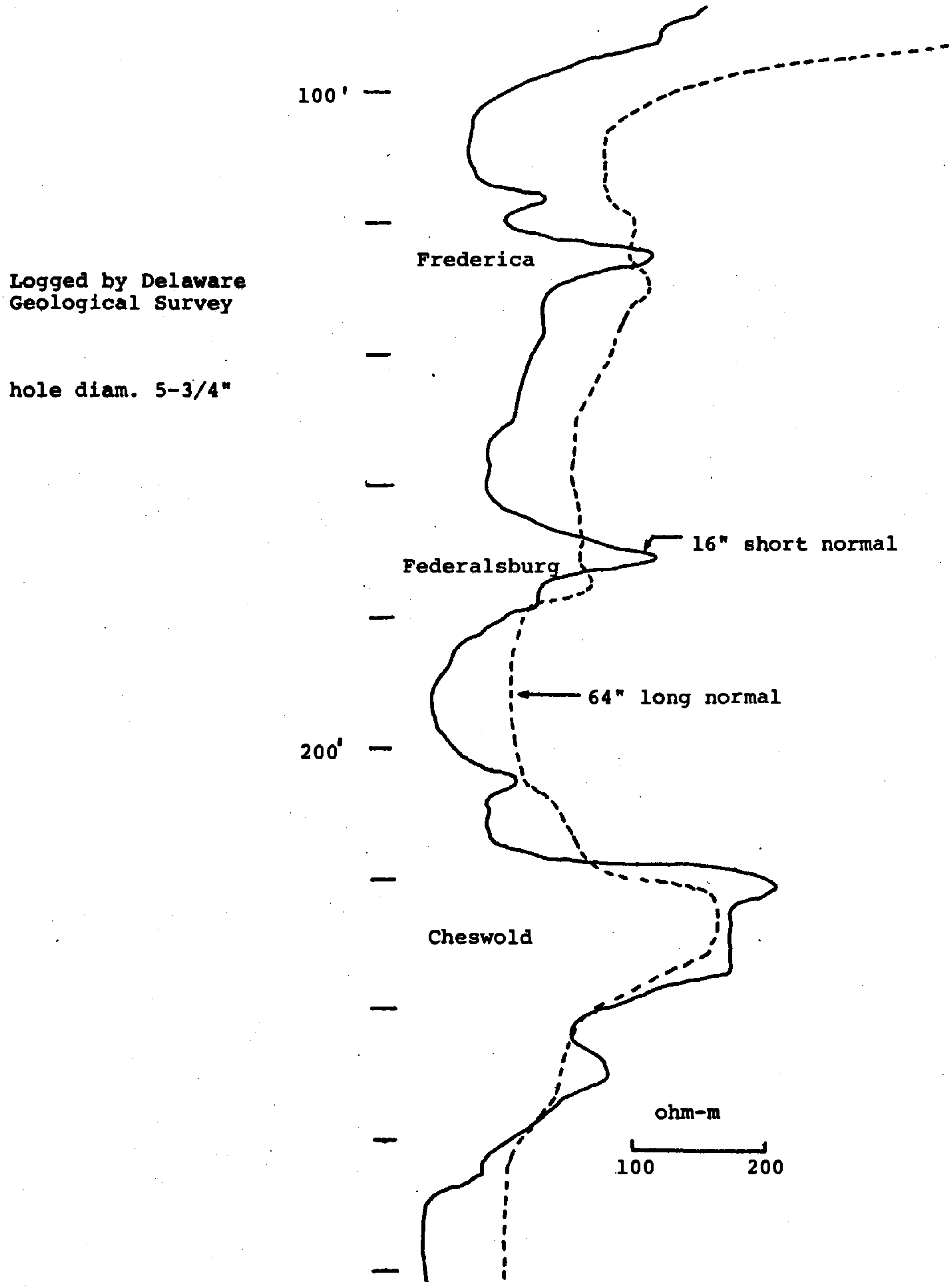


Figure 9. Partial electric log of well Jd45-6 showing log response to Frederica, Federalsburg, and Cheswold aquifers.

ments show that apparent resistivities of several hundred ohm-meters are not uncommon both in the saturated (fresh-water) and unsaturated portions of the Columbia sediments.

A common characteristic of electric logs made in Columbia sands is reversal of the self-potential curve in sandy formations, i. e. deflection in the positive (usually to the right) rather than the negative direction. This is due to the fact that the drilling fluid often has a higher total dissolved solids content than does the formation water. Such reversals are not entirely confined to the Columbia Formation but may occur in other aquifers as well, depending on water quality conditions. A related, and even more common problem in Delaware is the lack of expression of the SP curve on an entire log. The chemical composition of the formational water and drilling fluid are often so similar that a scale as sensitive as 5 or 10 millivolts per inch may sometimes be necessary to obtain a definitive SP log.

TEMPERATURE GRADIENTS

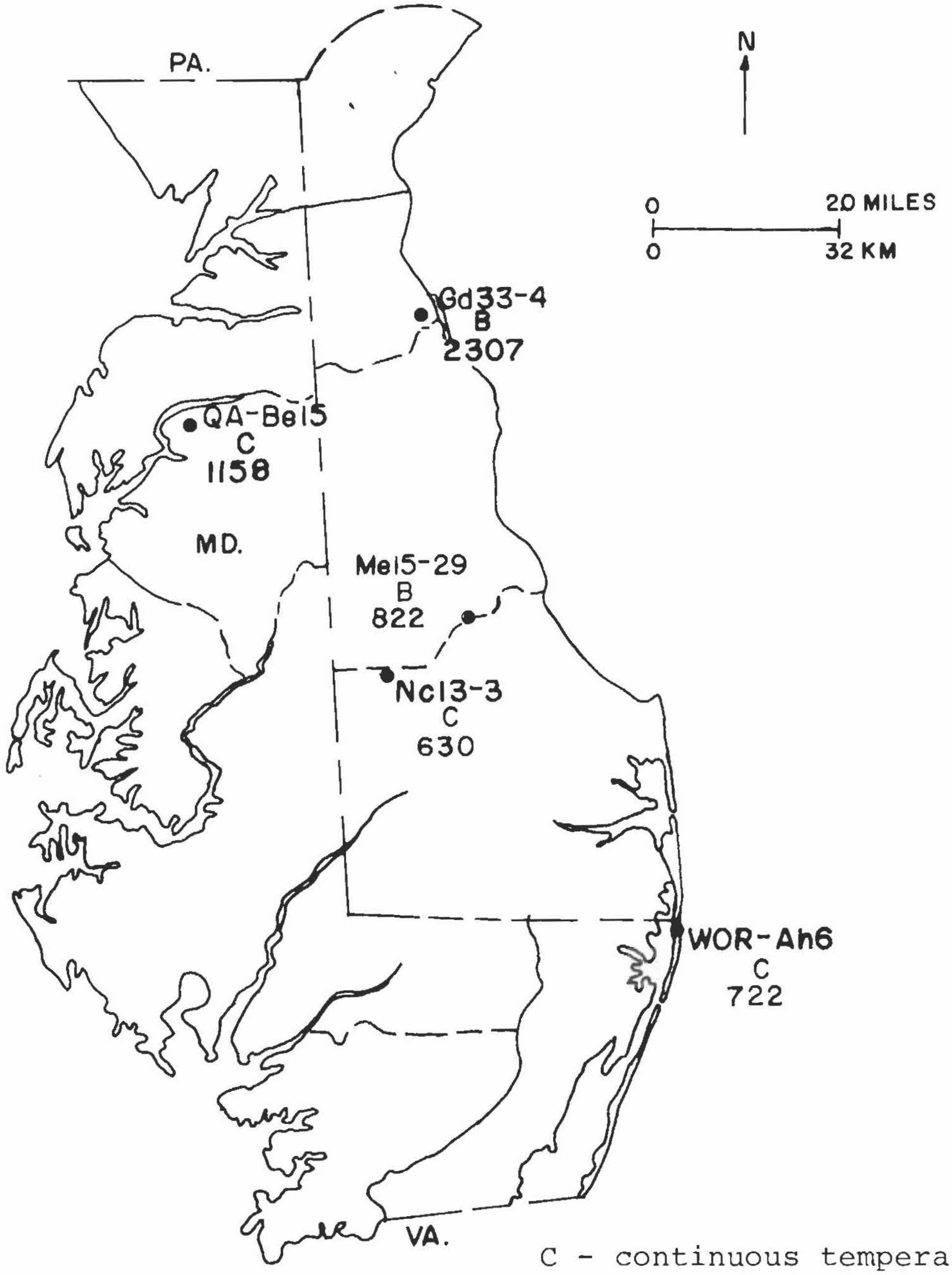
A few temperature logs and bottom-hole temperature measurements are available in Delaware or nearby at other locations on the Delmarva Peninsula. Locally, temperature logs are used mainly for applying correction factors to multipoint resistivity data. Figure 10 shows the location of the three deepest continuous temperature logs available at this time in or near Delaware and the locations where other bottom-hole temperature measurements have been made. The average temperature gradient as determined from the three continuous temperature logs in Figure 10 is about 1.2°F/100'. Monthly mean surface temperatures in Delaware are shown in Table 2. In the absence of temperature logs, the mean annual temperature and temperature gradient can be used to calculate an approximate temperature at any given depth.

TABLE 2

Monthly Temperature means for Delaware

Month	°F	Month	°F
Jan.	32.4	July	75.8
Feb.	33.6	Aug.	74.1
March	41.6	Sept.	67.9
April	52.3	Oct.	57.2
May	62.4	Nov.	45.7
June	71.4	Dec.	34.7
Annual Mean: 54.1°F			

Source: National Weather Service, NOAA (1974).



C - continuous temperature log
B - bottom hole temperature only
722 - total depth measured (feet)

Figure 10 Location of down-hole temperature measurements in and near Delaware.

FORMATION FACTORS

The formation factor (F) is defined as the ratio R_o/R_w where R_o is the measured resistivity of the water saturated rocks in question and R_w is the resistivity of the interstitial water. R_o is usually obtained from a 64" normal or induction log and R_w is measured from ground-water samples taken at the corresponding depth. Once reliable background data are obtained on formation water quality the formation factor can be calculated from the electric log. The formation factor (or field formation factor) is then used in turn to estimate water quality (total dissolved solids) from electric logs in any future test holes. The method is empirical but seems to yield reliable results in most cases. A detailed discussion of the method is given by Alger (1966) and Keys and McCary (1971). Temperature corrected formation factors that have been calculated for Delaware in this study are listed in Table 3 (see Figure 1 for location of wells). Cushing (personal communication) also calculated formation factors (unpublished) during his study of the water resources of the Delmarva Peninsula (Cushing and others, 1973).

The more direct method of using the self-potential curve to calculate total dissolved solids generally is not applicable in Delaware for the depths investigated to date (about 3000 feet below sea level). This is due to the relatively low total dissolved solids content of ground waters in the State as compared to waters found in other parts of the country or those waters generally considered in petroleum exploration. Also, it should be noted that the dominant ground-water type in Delaware at these shallow depths is sodium and calcium bicarbonate as opposed to a sodium chloride type of water. Thus it is usually necessary to apply a correction factor even when predicting chloride content of waters indirectly by use of the formation factor.

GAMMA-LOG MARKERS

Many workers in Delaware and adjacent states have noticed on natural gamma-ray logs a persistent gamma "high" apparently occurring at, or very close to, the Cretaceous-Tertiary boundary. Cushing (personal communication) emphasized its possible value as a stratigraphic marker in Maryland and Delaware. Minard and others (1969) mention the existence of a "three-pronged" gamma peak that seems to mark the base of the Hornerstown Formation (lower Paleocene age according to authors) in New Jersey. Rosenau and others (1969) also noted the presence of what is apparently the same marker in New Jersey and placed the bottom portion of the peak within the Navesink Formation (Late Cretaceous age). The present study indicates that a two or three pronged peak is well developed at about the Cretaceous-

TABLE 3: Formation Factors Calculated from Selected Well Data

Formation or unit	Depth Feet Below l.S.	Well #	Apparent Resistivity (Ra) from 64" or Induction Log ohm-m	Formation Temp. °F	Corrected Ra for Std Temp., (Ro) ohm-m	Conductivity of Formation Water micromhos	Resistivity of Formation Water, (Rw) ohm-m	Formation Factor F (Ro/Rw)
Cheswold Aquifer	399-409	Nc13-3	75	64	70	372	28	2.5
Cheswold Aquifer	480-540	Me15-29	30	63*	24	930	12	2.0
Manokin Aquifer	184-188 192-196	Pj12-1	15	61.6*	13	820	11	1.2
Piney Point Fm.	764-774	Nc13-3	28	69*	26	2550	3,8	6.8
Piney Point Fm.	620-630	Nc13-3	48	66.5	43	1340	8.0	5.4
Piney Point Fm.	640-700	Me15-29	14	65*	12	3150	3.2	3.8
Monmouth Fm.	304-427	Gd33-4	90	60*	69	300	33	2.0
Magothy Fm.	625-657		45	62.1*	38	577**	17.5	2.2

*Extrapolated

**Calculated from total dissolved solids content

Tertiary boundary in northern Delaware but seems to grade into one distinct peak in central and southern Delaware. Microfossil work in Delaware, while not entirely conclusive as to the exact position of the peak in relation to the Cretaceous-Tertiary boundary, indicates that the peak seems to bracket the boundary in every case examined. Figure 11 shows an example of the peak on a log from a test hole northeast of Smyrna.

The mineralogy responsible for the peak is not completely understood at this time. Workers in New Jersey have attributed it to high concentrations of glauconite or to shell layers (Rosenau and others, 1969). In Delaware, Jordan and Adams (1962) reported on a bentonite from near the Cretaceous-Tertiary boundary in a deep test hole (Je32-4) near Dover. Since the bentonite is less than a foot thick it would not easily be detected in most drilling operations even though it was fairly widespread. Talley (1975) showed that in well Nc13-3 near Greenwood, Delaware, the high gamma peak corresponded to unusually high concentrations of glauconite.

A second gamma marker occurs in Delaware beneath the marker discussed above. In northern Delaware this second marker seems to fall consistently at the top of the Marshalltown Formation of the Matawan Group. The peak is extremely prominent on logs of test holes drilled about two miles south of the Chesapeake and Delaware Canal and west of U. S. Route 13. For example, Figure 12 shows the peak as it appears in hole Ec41-9. The peak can be traced further south into the subsurface to about Cheswold where it appears higher in the section, near the bottom of the Pamunkey Formation. Correlations south of this point become quite tenuous due to a decrease in amplitude and the introduction of other peaks. In well Je32-4 at Dover Air Force Base the peak appears to be in the Pamunkey Formation again but still slightly higher in section than at Cheswold. It is possible that the peak marks a discreet event in time.

Figure 13 shows both markers, informally designated as (a) - upper and (b) - lower, as they are correlated in selected wells. The stratigraphic and time boundaries were determined by independent means, i.e. microfossils and/or lithology. Portions of the actual logs, from which the correlations in Figure 13 were made, are given in Figures 14-21. It is possible, of course, that these peaks occur only by chance and bear no real relationship to time. For the present, however, a useful indicator does seem to exist, particularly when used in conjunction with formation samples and a general knowledge of the stratigraphy.

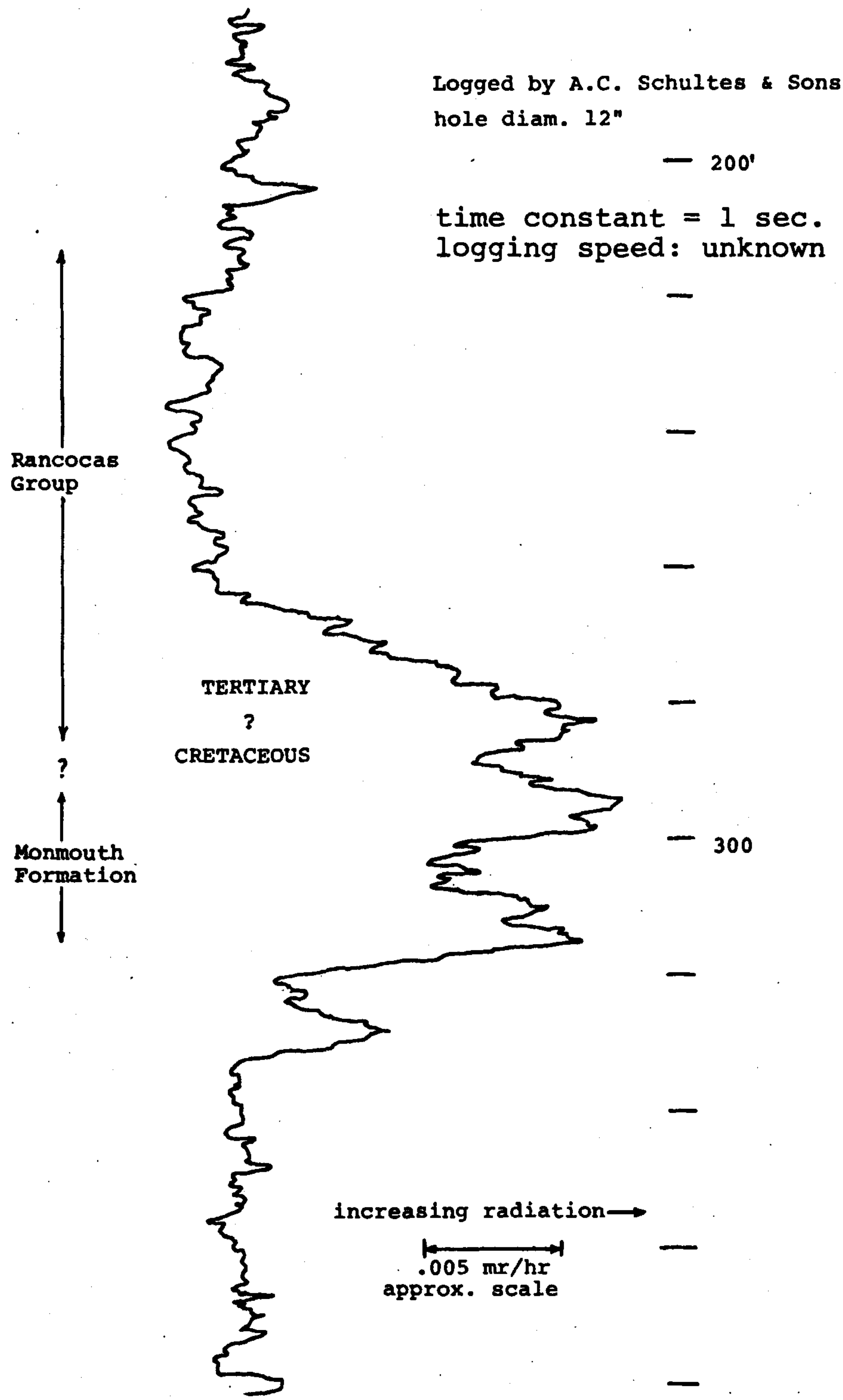


Figure 11. Partial gamma log of well Gd32-5 showing peak bracketing Cretaceous-Tertiary boundary.

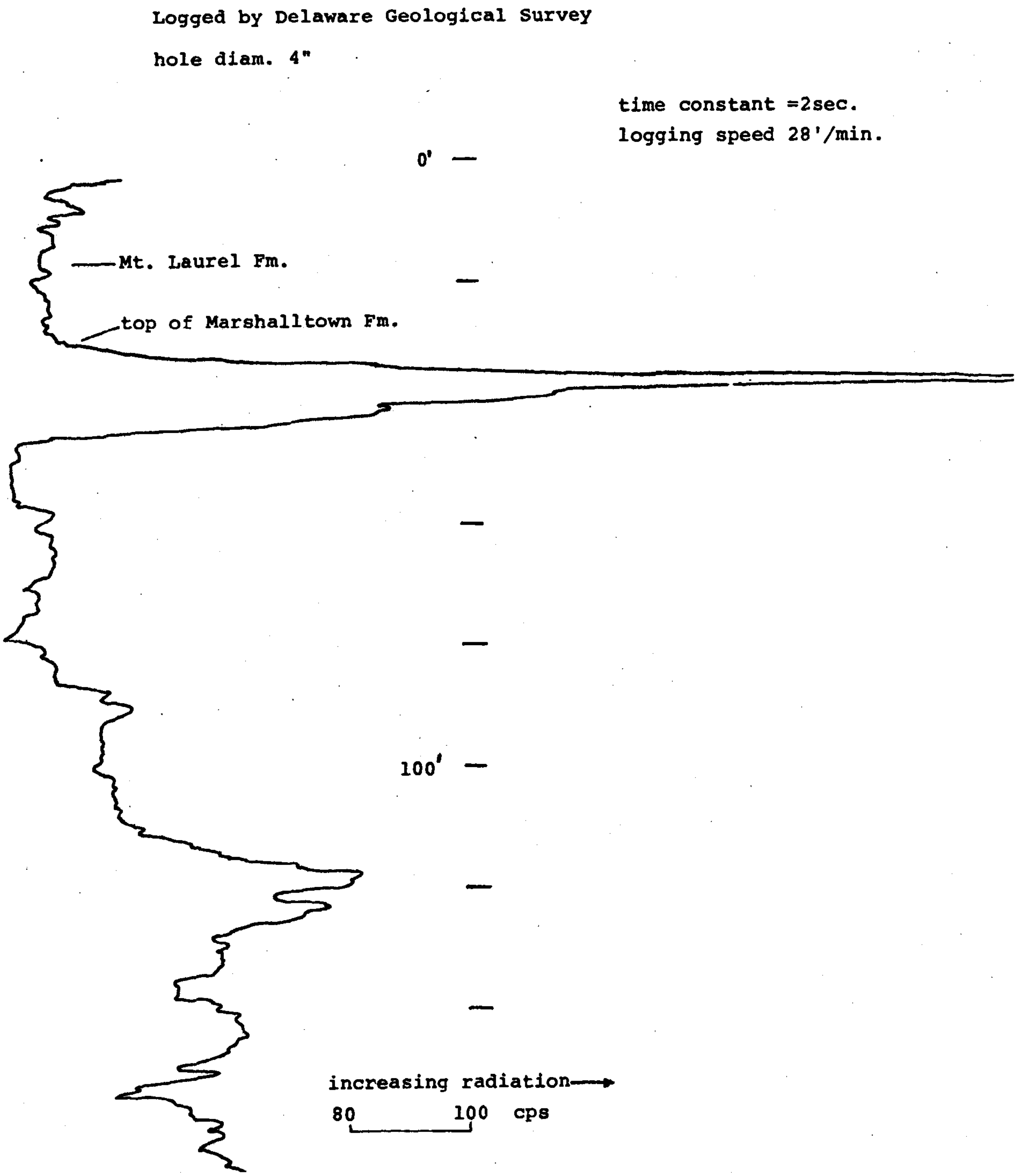


Figure 12. Partial gamma log of well Ec41-9 showing peak at approximate contact of Mt. Laurel and Marshalltown Formations.

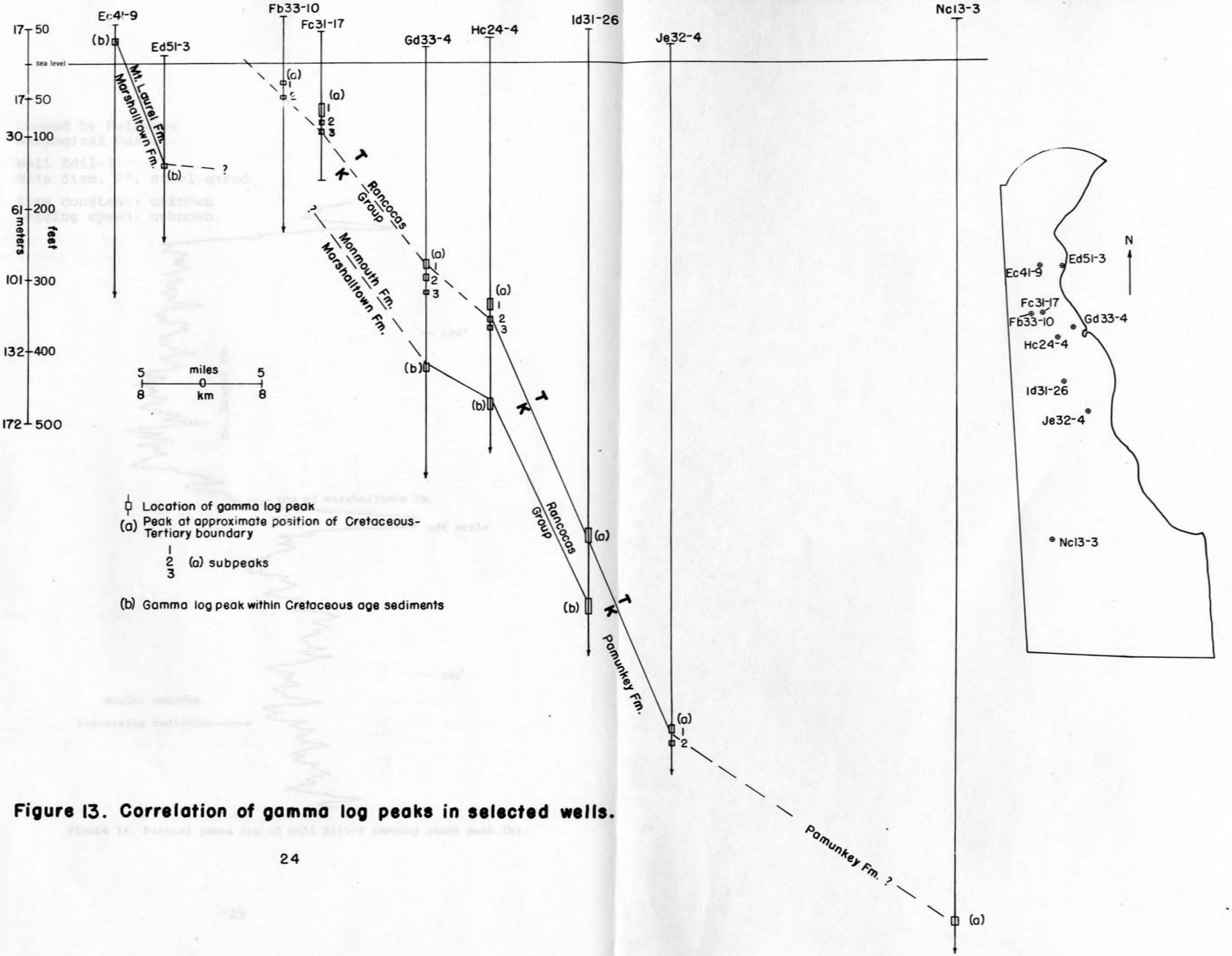


Figure 13. Correlation of gamma log peaks in selected wells.

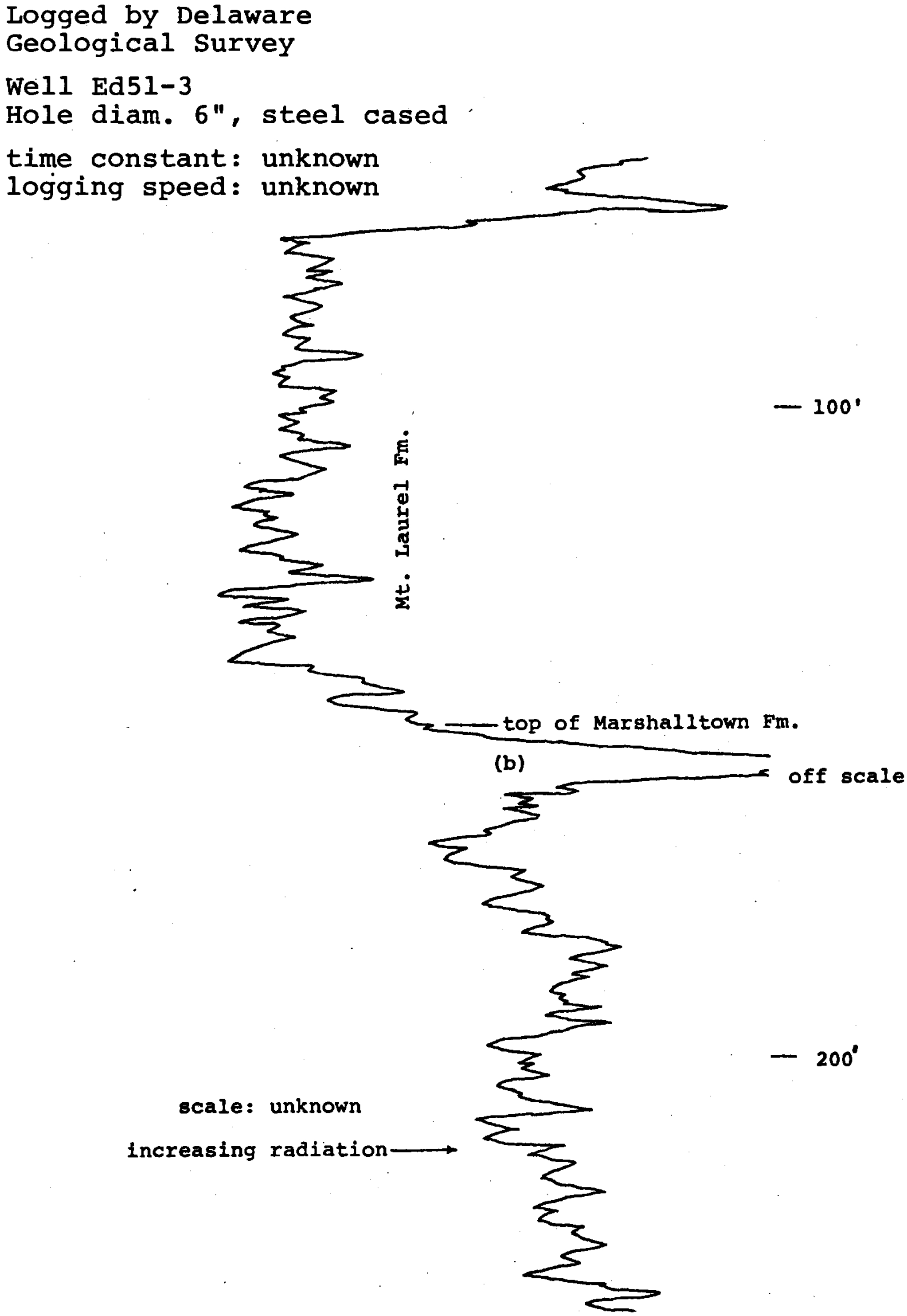


Figure 14. Partial gamma log of well Ed51-3 showing gamma peak (b).

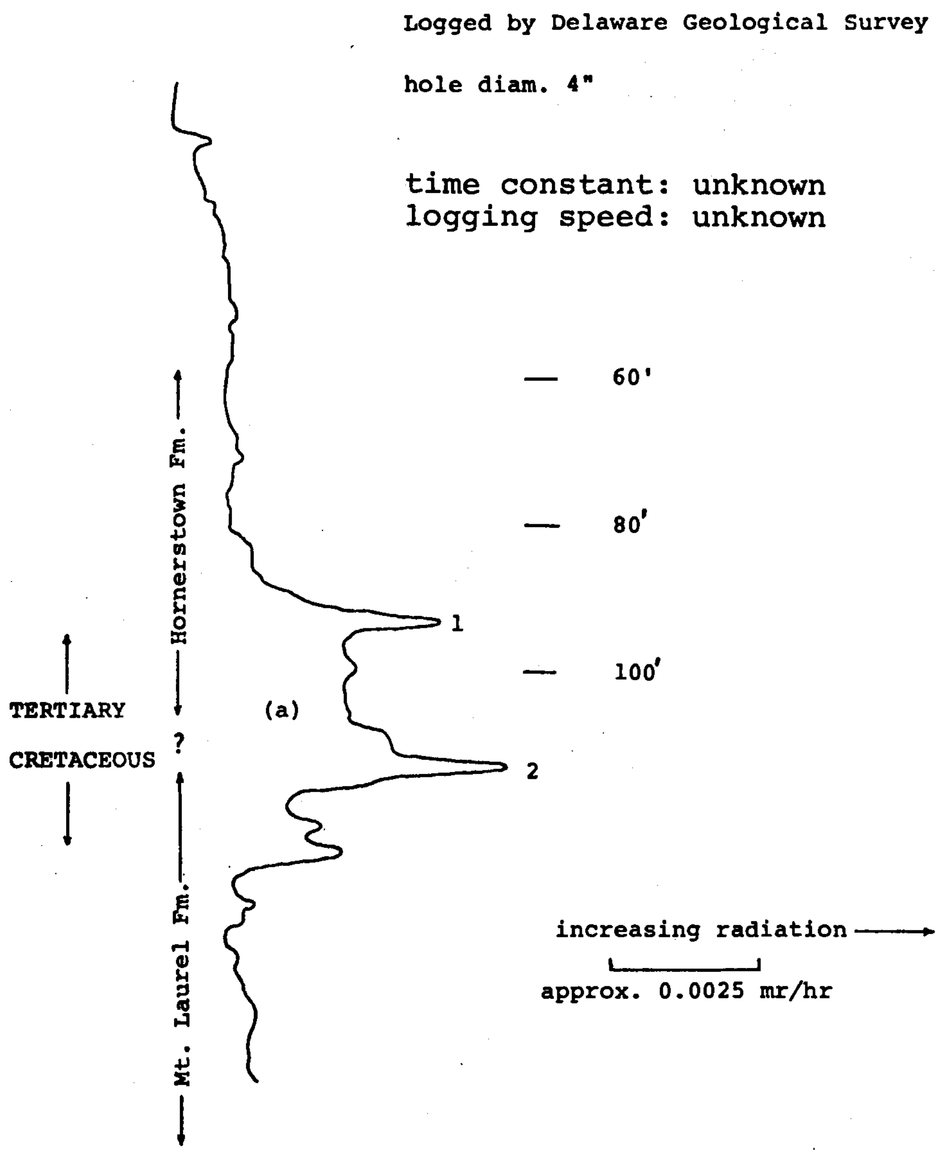


Figure 15. Partial gamma log of well Fb33-10 showing marker (a) at approximate position of Cretaceous-Tertiary boundary.

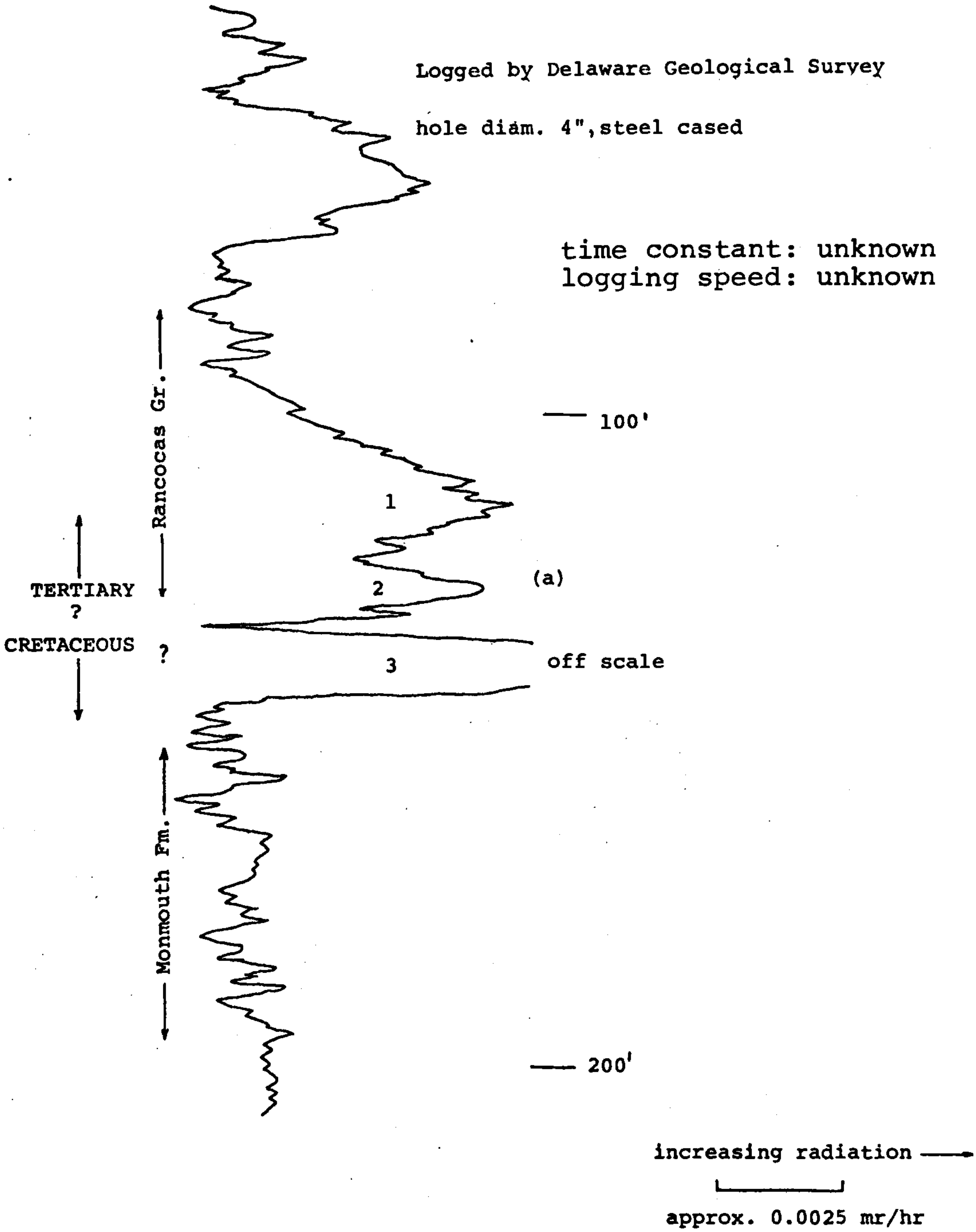


Figure 16. Partial gamma log of well Fc31-17 showing marker (a) at approximate position of Cretaceous-Tertiary boundary.

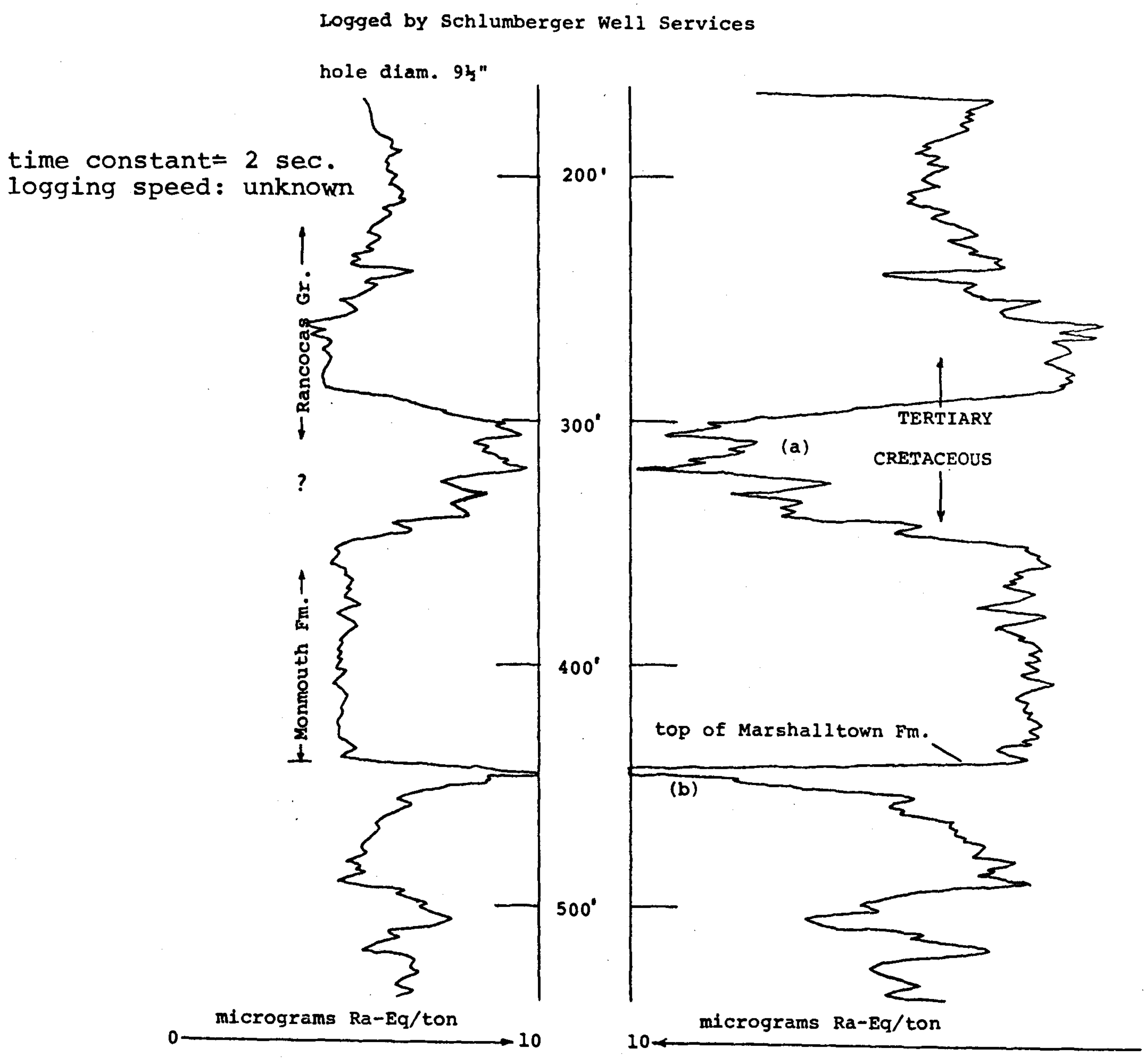


Figure 17. Partial gamma log of well Gd33-4 showing markers (a) and (b).

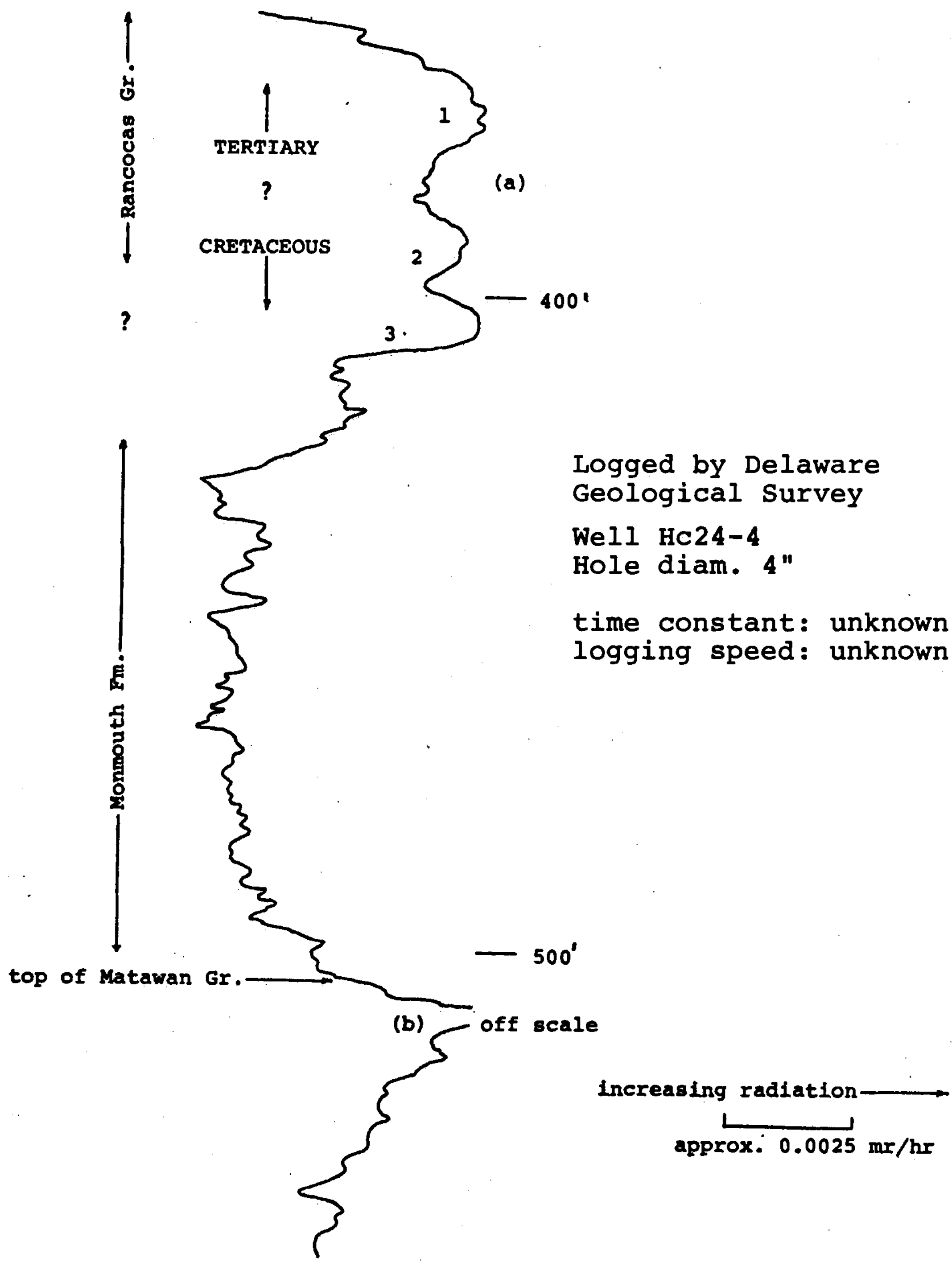


Figure 18. Partial gamma log of well Hc24-4 showing markers (a) and (b).

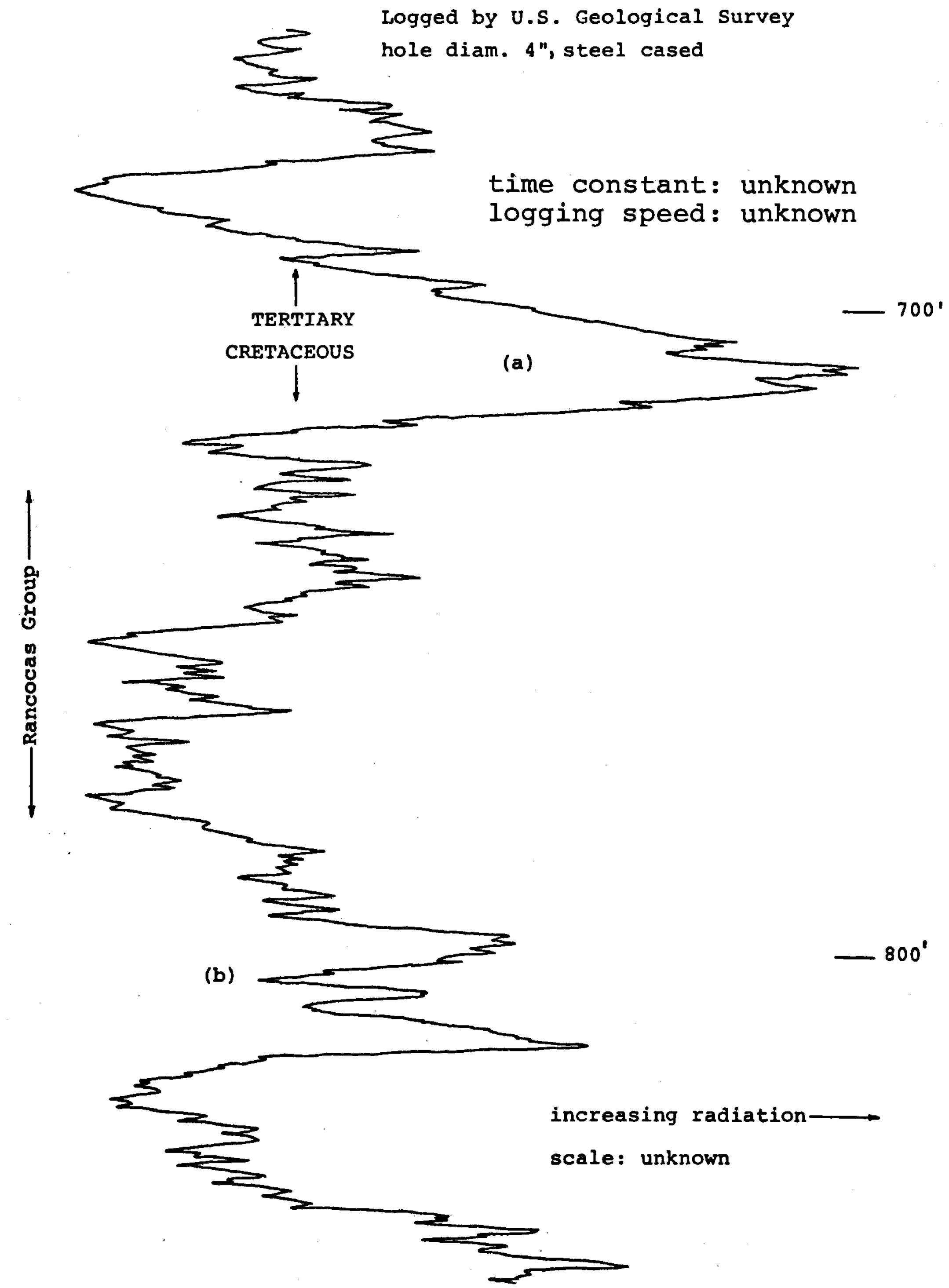


Figure 19. Partial gamma log of well Id31-26 showing markers (a) and (b).

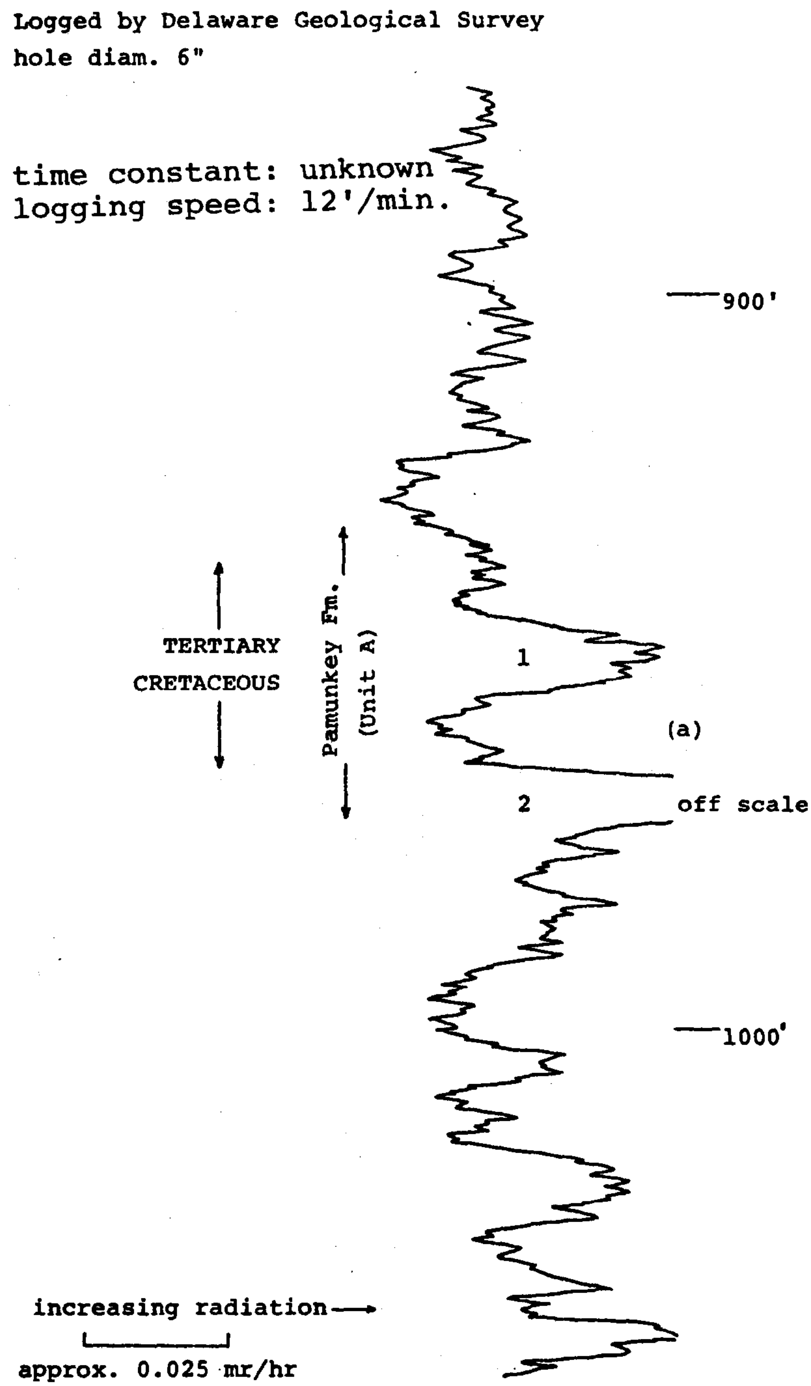


Figure 20. Partial gamma log of well Je32-4 showing marker (a).

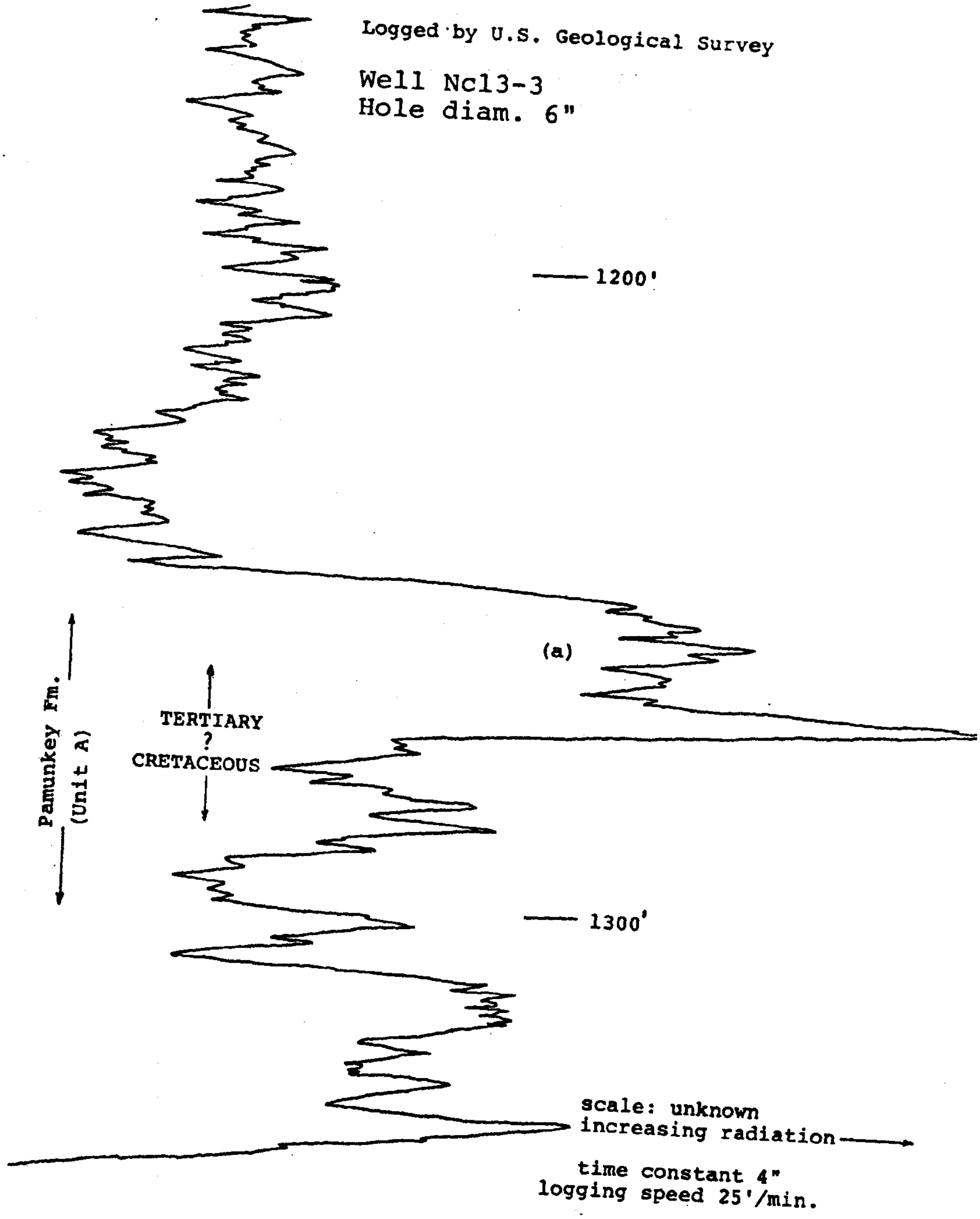


Figure 21. Partial gamma log of well Nc13-3 showing marker (a).

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APPENDIX

WELL LOGGING FUNDAMENTALS

The fundamentals of well logging are presented in a number of publications. A particularly good discussion of logging techniques as applied to ground water investigations is given by Keys and MacCary (1971). Other literature, generally oriented towards mineral exploration, is usually available from commercial logging companies. A recent book on techniques of log analysis by Pirson (1970) discusses the application of geophysical logs specifically to petroleum exploration.

Single-Point Resistance Log

The most widespread type of log used in shallow water-well work is probably the single-point resistance log. The single-point device consists of two metal electrodes, one located at the ground surface, generally in the pit used to hold the drilling fluid or "mud", and the other located in the borehole. (See Figures 22 and 23.) The borehole electrode is arranged to continuously traverse the hole by means of a cable and winch assembly. The borehole must contain a fluid to provide electrical continuity with the formations penetrated and with the surface electrode. A known constant current is applied to the electrodes and the resulting voltage drop is measured by the same set of electrodes and recorded at the surface as a resistance measurement. Most loggers record this resistance continuously with depth although some, more compact water well loggers, provide only a meter readout at those depths chosen by the operator. Chart recorders usually show the resistance as increasing to the right. It can be shown that nearly all of the voltage drop measured in the single-point arrangement takes place within a few inches of the probe. Thus the measurement is highly dependent on the resistivity (resistance per unit volume) of the drilling fluid and the degree of invasion of the fluid into the formations penetrated by the drill hole. Usually, at relatively shallow depths, the more permeable the formation, the greater is the degree of fluid invasion. In water well drilling the mud is usually made with a mixture of fresh water and some solid additive such as a bentonite clay and usually has a relatively high resistivity. Thus sandy formations would show a relatively high resistance on the single point log because of the invasion or movement of the high resistivity drilling fluid into the formation. Clay sections generally show relatively lower resistances due to less fluid invasion and to their inherent lower resistivities. Obviously, if the drilling mud is made up with salt or brackish water than there may be little or no contrast on the log between various geologic units. For proper interpretation it then becomes necessary to know the composition of the drilling mud in the hole at the time of logging.

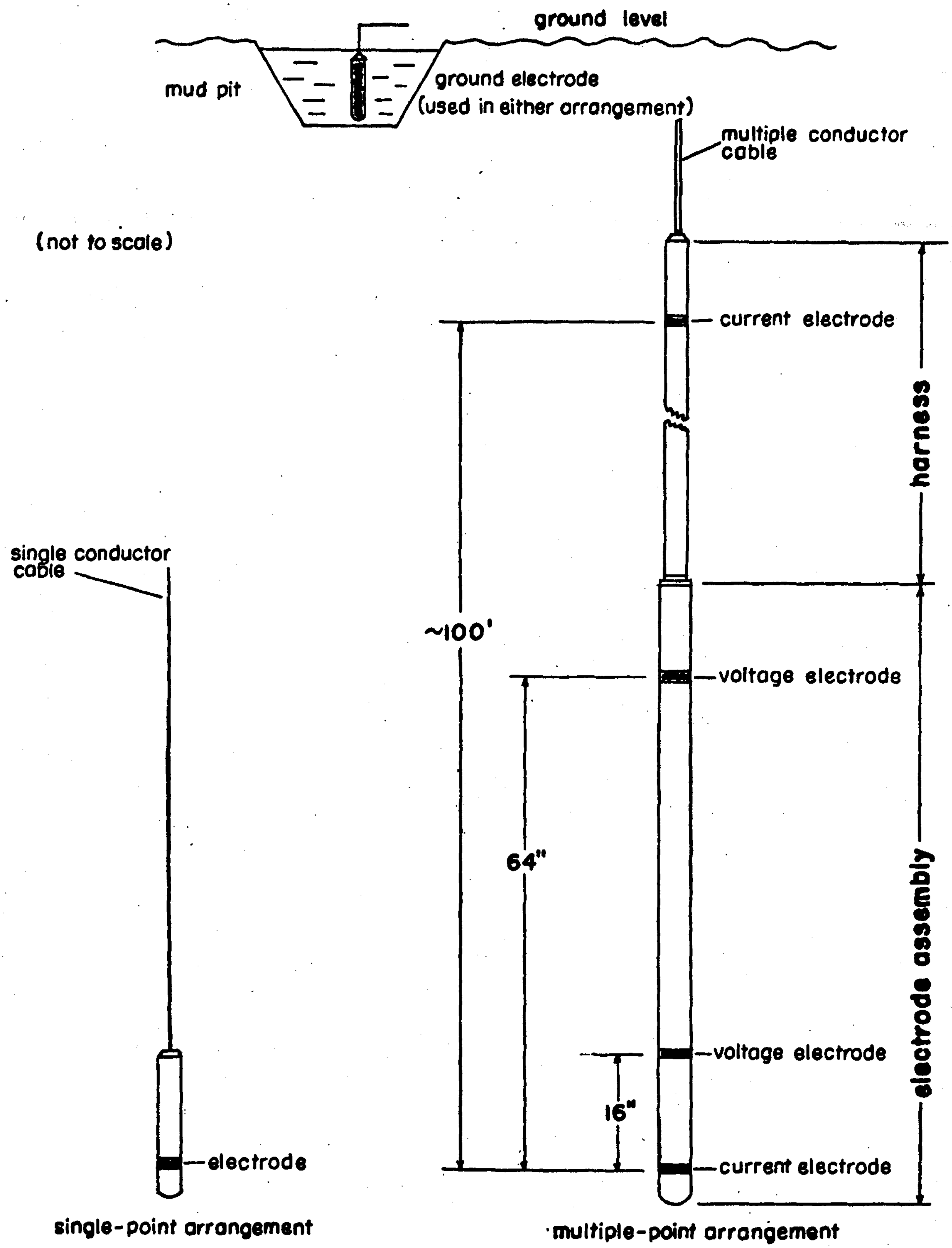

Figure 22: Mechanical details of electric logging tool.

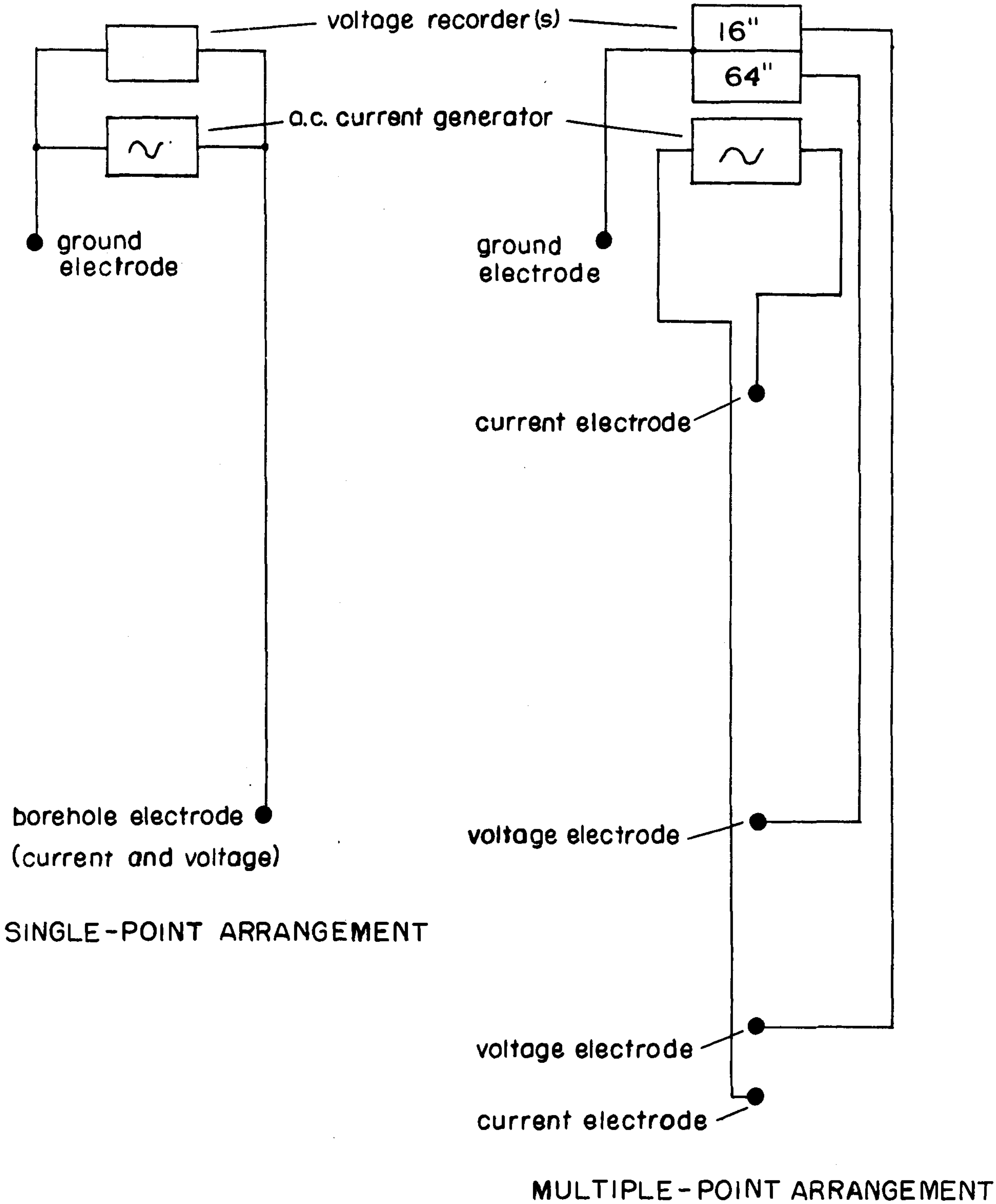

Figure 23. Simplified electrical circuit of electric-logging tool.

Multiple-Point Logs

The addition of other electrodes on the same "tool string" permits other kinds of resistance measurements to be made and generally increases the versatility of the instrument. One of the early, basic logs was the conventional multiple-point resistivity log or "normal" device. The log is still in widespread use today because of its relative simplicity and low cost. However it has been largely superceded in the petroleum industry by induction logs and focused current devices, which overcome some of the inherent difficulties of the conventional log. The "normal" electrode configuration has one of more "active" voltage measuring electrodes at a known distance from a current electrode, generally at distances of 16 inches and 64 inches (see Figure 22). The spacing of these voltage measuring electrodes from the current electrode determines the radial distance from the borehole (or probe center) at which the voltage drop is measured. The longer spacings (64") thus give measurements further from the borehole and are less affected by the drilling mud than are the shorter spacings (16"). Readings from each electrode can be made and recorded simultaneously on separate recorder channels. Two other electrodes are needed to complete the electrical circuit in the multiple-point arrangement - one common voltage electrode generally placed in the drilling mud pit and a second current electrode usually placed on the "tool string" about 60 to 100 feet (18 to 30 meters) above the other electrodes on the tool or probe. It should be noted that the readings from the multiple-point arrangement are in units of resistivity (ohms per meter) while the single-point device reads out in total resistance measured (ohms).

Because the resistivity measured is partly a function of the total dissolved solids in the formation, the longer spacing or long normal curve (64") can be used in estimating general water quality of an aquifer. The shorter spacing or short normal curve (16") may be more affected by the invasion of drilling mud into the formations and may not be quite as useful in predicting water quality; however, it will give a good indication of the lithologies present. In all cases the log performance and resistivity values measured fall off sharply when the thickness of an individual bed approaches the electrode spacing (distance between the active current and voltage measuring electrode). When the bed thickness is less than the electrode spacing a slight deflection may even be noticed in the opposite direction (usually to the left).

Self-Potential Log

A self-potential curve (commonly known as the SP curve) is usually recorded simultaneously with the single point resistance curve or with the "normal" resistivity curves. The SP log is a measure of the natural potential in millivolts that seems to be generated by the reaction of the drilling fluid with other materials in the borehole, primarily the geologic formations penetrated and the fluids contained within the formations. This curve, like a resistivity or resistance log, is also indicative of the lithology and interstitial water quality. The combination of the SP log and one or more resistivity logs (or the single-point log) makes up the standard electric log. The detailed theory of the generation of the self-potential in a borehole is beyond the scope of this report and those interested in further explanation may wish to consult the references given in the beginning of this section.

Under the proper conditions the SP curve is generally a mirror image of the resistivity curve on the electric log. Thus the curve would show deflections to the left or negative direction in sandy formations and would tend to move toward the right or positive in clayey lithologies. However, as indicated earlier in this report, the total dissolved solids content of the water used in making up the drilling fluid will strongly influence the SP curve. If the quality of the drilling fluid water and the formational waters are similar or nearly so, then the SP curve may have little or no expression.

Gamma Logging

The gamma log records the weak natural background radioactivity of the sediments penetrated by the borehole. Most of this radiation comes from natural isotopes of potassium, uranium, and thorium that are present in varying degrees in most rocks. The gamma log is extremely useful as an indicator of lithology and can be used alone with some precautions, or as a supplement to the electric log. As no electrical contact is necessary with the borehole, the log can be run inside cased holes and even in dry holes if a metallic sheathed or multiple conductor cable is used to complete the electrical circuit to the surface electronics. The highest radiation readings are usually obtained opposite clays because of their relative high potassium content, while the lowest readings are obtained in quartz sands containing little or no silts and clay. It is essential, however, to have some prior knowledge of the mineralogy of the sediments or rock type in question to avoid errors in interpretation. Sands, for instance, may contain uranium bearing minerals and thus give an anomalously high gamma reading. In Delaware, the mineral glauconite (a complex iron, potassium silicate) is abundant in certain units (particularly the Piney Point Formation and the Rancocas Group) and tends to cause higher than "normal" readings on the gamma log. It has also been noted that clays derived by weathering in place of crystalline rocks of the Piedmont give much lower readings than are usual for other clays in Delaware. The gamma log is generally not affected by the varying water quality conditions within the range of conditions found in the State. Thus the log may give information on lithology in sediments saturated by salt water that otherwise might not be discernable from electric logs alone.

Other Logs

Other types of logging tools measure such parameters as temperature, hole size, fluid saturation, rate of fluid movement in a well, and porosity. The use of these types of logs is becoming more common in the ground-water field as the need for more quantitative information develops. In many cases data from such logs are used in computing correction factors for certain calculations made with other logs. Many quantitative procedures in log interpretation also require the simultaneous use or cross-plotting of data from two or more types of logs such as those found above.