Hydrogeologic Assessment of Shallow Clastic and Carbonate Rock Aquifers in Hendry and Collier Counties, Southwestern Florida

By Charles E. Brown, Richard K. Krulikas, and Daniel L. Brendle

U.S. GEOLOGICAL SURVEY

Open-File Report 96-556

Prepared in cooperation with the

South Florida Water Management District

Tallahassee, Florida

1996

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information, write to:

District Chief
U.S. Geological Survey
Suite 3015
227 N. Bronough Street
Tallahassee, Florida 32301

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

CONTENTS

FIGURES

TABLES

Hydrogeologic Assessment of Shallow Clastic and Carbonate Rock Aquifers in Hendry and Collier Counties, Southwestern Florida

By Charles E. Brown, Richard K. Krulikas, and Daniel L. Brendle

Abstract

Direct-current electrical resistivity data were collected from 109 vertical electrical sounding sites in Hendry and Collier Counties, southwestern Florida. Selected direct-current electrical resistivity surveys, together with available borehole geologic and geophysical data, were used to determine the approximate areal extent of the shallow clastic aquifers composed of thick sands and carbonate lithologies. Results indicated that a complex pattern of shallow sands, clays, and carbonate lithologies occur throughout the area. Buried channel sands were found as deep as 50 meters below land surface in some places. The channels contain unconsolidated fine- to medium-grained quartz sand interbedded with sandy limestone, shell fragments, and gray-green sandy clay.

Both surface and borehole geophysical techniques with lithologic data were necessary to approximately locate and define layers that might behave as confining layers and to locate and define the extent of any buried sand aquifers. The borehole geophysical data were used to analyze the zones of higher resistivity. Direct-current electrical resistivity data indicated the approximate location of certain layer boundaries. The conjunctive use of natural gamma and short- and long-normal resistivity logs was helpful in determining lithologic effects. Geohydrologic sections were prepared to identify potential locations of buried channels and carbonates containing freshwater. Buried channel sands and carbonate rock sections were identified in the subsurface that potentially may contain freshwater supplies.

INTRODUCTION

The U.S. Geological Survey is one of several agencies participating in a scientific effort to understand the natural environments in southern Florida. An understanding of the extent and location of aquifer systems that may contain rocks with potable ground water is needed to properly manage regional water resources in rapidly growing areas of southwestern Florida. The shallow aquifer systems under study consist of many thick sand layers associated with clay and carbonate-rich zones, which may contain large quantities of usable ground water. These sand layers and carbonates are of variable thickness and lithology, and together form a complex aquifer system. Clays may or may not separate the sand layers.

In order to understand the ground-water flow dynamics and apply them to future management decisions in southwestern Florida, the areal extent, thickness, and hydrology of aquifers that may contain freshwater must be defined. With this objective in mind, the U.S. Geological Survey, in cooperation with the South Florida Water Management District, conducted a study using surface and borehole geophysical techniques and geologic methods to define stratigraphic and hydrogeologic changes in the aquifer systems of southwestern Florida. The study was conducted over a 3-year period from October 1992 through September 1995.

Purpose and Scope

The purpose of this report is to assess the hydrogeologic characteristics and relations of shallow aquifers in southwestern Florida using direct-current (DC) electrical resistivity, borehole geophysics, and lithologic data. Three geohydrologic and four geoelectric sections were constructed using selected direct-current electrical resistivity sounding sites, one test hole, existing lithologic data and geophysical logs from selected wells, and chloride data collected from four wells. All of these data were correlated to determine the approximate areal extent of the shallow channel sands, carbonate aquifers, and associated clays in Hendry and Collier Counties and to identify the areas of highest potential for locating shallow aquifers with freshwater (or slightly saline water) in the study area.

The investigation was limited to the upper 100 m (meters) of the aquifer systems in southwestern Florida. The DC-electrical resistivity soundings were done at about 1.6-km (kilometer) intervals. This report is a compilation of general geologic and hydrogeologic information relating to the subsurface conditions and available water resources in the study area. It is intended that this report serve as a convenient reference for those charged with the responsibility of both developing and protecting water supplies and for those who use or control water in significant quantities.

Previous Investigations

Information concerning the geology and water resources of southwestern Florida is contained in numerous published and unpublished reports including Matson and Sanford (1913), Stringfield (1933), Parker and others (1955), Gleason (1974), Boggess (1981), Boggess and Watkins (1986), Smith and Adams (1988), and La Rose (1990). Other significant studies are referenced throughout the report.

Acknowledgments

The authors thank the various citrus growers, including Duda Inc., Berry Inc., Turner Corporation, and Barfield Farms, for access to their fields to run the DC-electrical resistivity profiles and for the drilling of several test holes for geologic information. The authors also thank Mark Stewart (Department of Geology, University of South Florida in Tampa, Fla.) for supplying the DC-electrical resistivity equipment. Also thanks to Marty Braun, well drilling supervisor of the South Florida Water Management District, who coordinated his field crews to drill the geologic test holes. Special thanks to Richard Kane, Frank Keene, and Gene Krupp at the U.S. Geological Survey field office in Fort Myers, Fla., who assisted in the collection of the DC-electrical resistivity field data.

DESCRIPTION OF STUDY AREA

The study area is located in southwestern Florida, extending south of the Caloosahatchee River in northwestern Hendry County to the northern part of Collier County (fig. 1). Several small residential developments, cities, and towns are located in the study area. The city of La Belle and the town of Immokalee are the primary urban centers in the area, whereas the surrounding area is agricultural. Recently, large-scale citrus farming has become established in the area, resulting in increased water demands.

Physiography

A prominent feature related to the shallow aquifer systems of southwestern Florida is the Ocaloacoochee Slough, a marshy drainageway on the Sandy Flatlands (fig. 2). It is also related to many buried channel sands (that is, sands below clay or limestone) in the area. Ocaloacoochee Slough is about 3.2 km wide and extends southward about 50 km from the vicinity of La Belle into the Big Cypress Swamp (Parker and others, 1955). The northern end of the Ocaloacoochee Slough has a number of branches, most of which discharge into small creeks flowing into the Caloosahatchee River. The southern end branches out in a similar manner into the Big Cypress Swamp. The Fahkahatchee Slough is the southwestern branch of the Ocaloacoochee Slough (fig. 2). Land-surface elevations range from 3 to 20 m above sea level and average 6 to 20 m above sea level.

Ocaloacoochee Slough typically drains northward and southward, but at times of high water it can overflow westward toward the Sandy Flatlands or eastward toward the Everglades (fig. 2). Drainage is retarded by the growth of vegetation and the accumulation of peat and organic muck that clogs the slough. As a result, the general movement of water is sometimes difficult to ascertain.

Ocaloacoochee Slough occupies a poorly drained depression on the ancient Pamlico and Talbot sea bottoms (Parker and others, 1955). The depression is now partly obstructed by former beach bars. When the Pamlico Sea withdrew from its high stand (25 m above present sea level), it left behind many low beach ridges and bars. This physiography has been modified by erosion, but is still discernible by a higher elevation around the city of Immokalee.

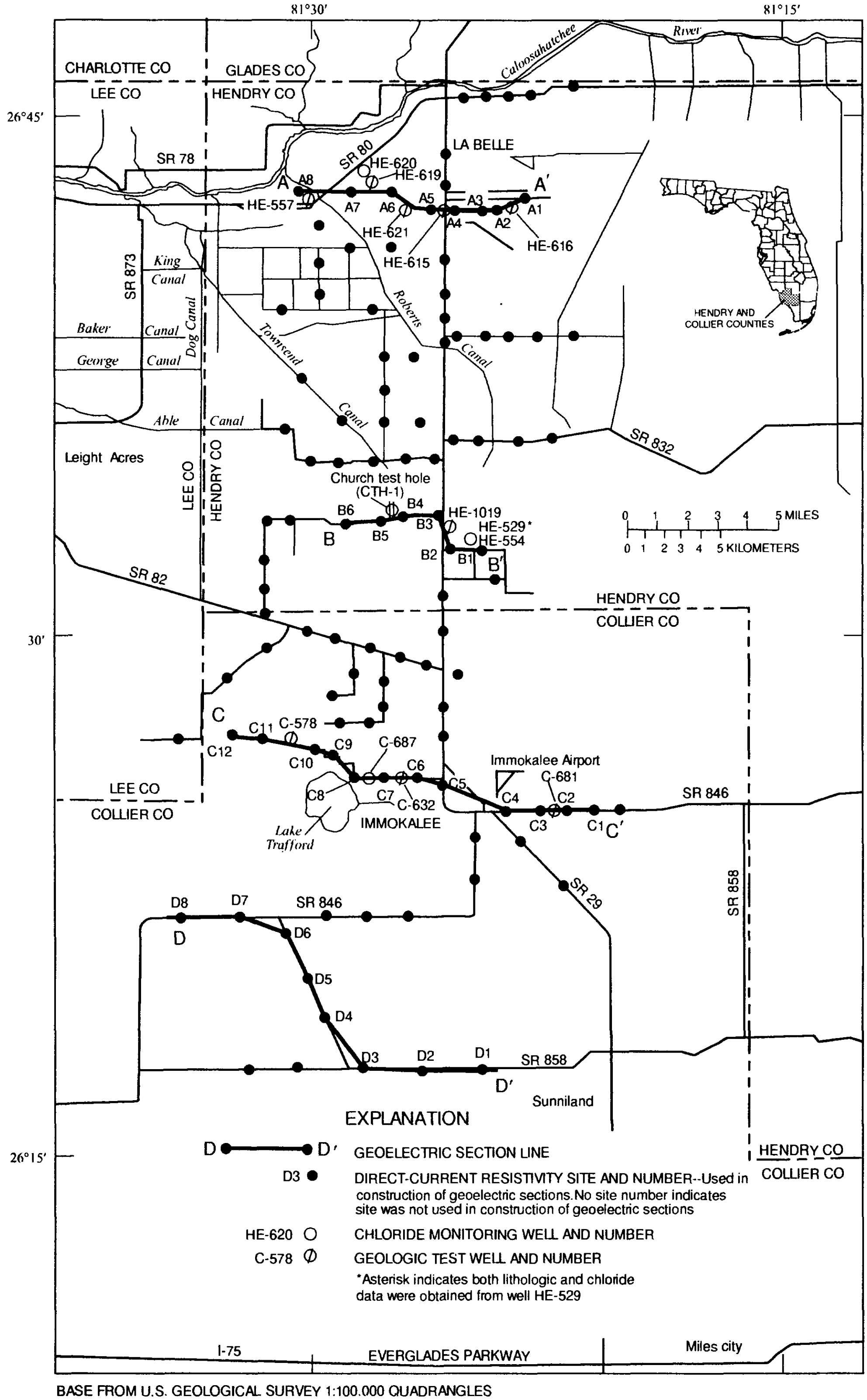


Figure 1. Study area in southwestern Florida showing locations of chloride monitoring wells, geologic test wells, a borehole geophysical test hole, and direct-current electrical resistivity sites.

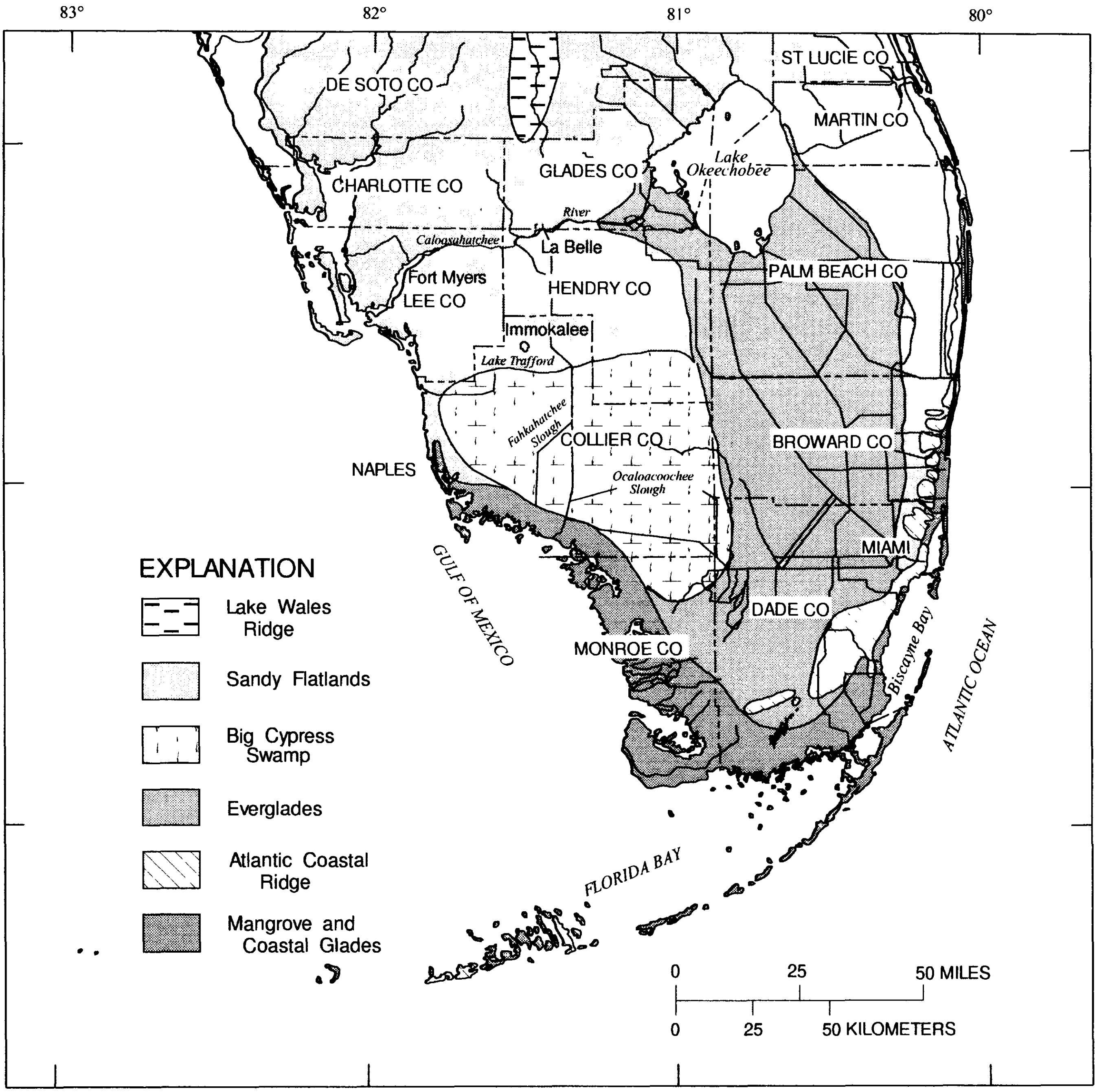


Figure 2. Physiographic setting and surface drainage patterns in southern Florida, including Hendry and Collier Counties (modified from Parker and others, 1955).

General Geology

The stratigraphic succession of formations in southern Florida was formed, with few exceptions, under a marine environment. The exceptions occur in the lacustrine and swamp deposits of the Lake Okeechobee-Everglades depression and the connecting Kissimmee River Valley (Parker and others, 1955). These deposits include the freshwater beds of the Fort Thompson Formation, the freshwater Lake Flirt marl, and organic soils of mostly peat and muck. In west-central Florida, there are deltaic, lacustrine, and alluvial deposits that are believed to be contemporaneous with certain Pliocene marine beds (Parker and Cooke, 1944). Most of the shallow geologic materials of southern Florida are limestones, marls, silts, clays, shell, sand, gravel, and mixtures of these.

The southern part of the study area is encompassed by the Big Cypress Swamp drainage area (fig. 2). The Big Cypress Swamp is a flat, swampy land of about 3,120 km^2 (square kilometers) west of the Everglades (McPherson, 1974). It differs from the Everglades in its relatively high land elevations, its thinner soils of marl and sand, and its forest vegetation (Gleason, 1974). In some areas, limestone of the Tamiami Formation of late Miocene age (fig. 3) and limestone of the Anastasia Formation of Pleistocene age are exposed at land surface or overlain by a thin veneer of soil. The limestone surface is scalloped by many small depressions and elongated troughs (Hoffmeister and others, 1967).

The underlying Hawthorn Formation of Miocene age (fig. 3) is composed predominantly of relatively impermeable clay. It also contains lenses of sand and gravel and thin layers of limestone and shell. This formation probably ranges in depth from less than 30 m near Immokalee to more than 60 m near Naples (McCoy, 1962). The Tampa Formation of early Miocene age underlies the Hawthorn Formation. In the Big Cypress area, the Tampa Formation is primarily a sandy limestone with quartz sand or a calcareous sandstone. Below these rocks lie the Suwannee Limestone of Oligocene age. The Suwannee Limestone (of unknown thickness but greater than 600 m) is the hydrostratigraphic equivalent of the Floridan aquifer system.

Hydrogeologic Setting

Three major aquifer systems present within the study area are the surficial, intermediate, and Floridan aquifer systems (fig. 3). These three aquifer systems include the following locally recognized aquifers: the surficial aquifer (water-table aquifer), lower Tamiami aquifer, sandstone aquifer, mid-Hawthorn aquifer, lower Hawthorn aquifer, and the Suwannee aquifer (the upper part of the Floridan aquifer system). A buried channel system in southwestern Florida appears to incorporate the lower Tamiami and sandstone aquifers. Smith and Adams (1988, p. 34) first mapped a buried channel zone, known as the clastic zone in the sandstone aquifer. In general, the water table ranges from 0 to 5 m below the surface, but can vary locally.

The surficial aquifer system is composed primarily of unconsolidated, fine- to medium-grained, quartz sand and is interbedded with sandy limestone and shell fragments and gray-green, sandy clay. Two water-yielding units comprise the surficial aquifer system, the surficial aquifer and the lower Tamiami aquifer (fig. 3). These two aquifers are separated by a section of sediments of low permeability that retards circulation of ground water between the permeable units. Detailed hydrogeologic descriptions of the surficial aquifer system are presented by Boggess (1981), Boggess and Watkins (1986), Smith and Adams (1988), and La Rose (1990).

The top of the intermediate aquifer system consists of a regionally extensive, confining, silty, green clay and coincides with the base of the surficial aquifer system (fig. 3). Aquifers in the intermediate aquifer system are the sandstone aquifer, mid-Hawthorn aquifer, and lower Hawthorn aquifer.

The sandstone aquifer (fig. 3) is composed of gray, calcareous sandstone and loose quartz sand and is divided into two zones (a clastic zone and a carbonate zone). The sandstone aquifer principally is used by the agricultural and citrus industry in the study area. Although water in the sandstone aquifer generally is more mineralized than water in the surficial aquifer, water quality usually is within potable water-supply standards.

The mid-Hawthorn aquifer (fig. 3) is composed of gray-white, phosphatic limestone and dolomite and is separated from the sandstone aquifer by 10 m or more of a confining unit of sandy, phosphatic marl and marly, phosphatic limestone. The top of the mid-Hawthorn aquifer is overlain by an erosional deposit, the locally named "rubble zone" (fig. 3), which consists of a mixture of phosphate nodules, quartz sand, clay, lime mud, shells, and shark teeth. Water in the study area is generally good (not very mineralized) due to an abundance of freshwater aquifers at shallower depths.

The lower Hawthorn aquifer (fig. 3) consists of gray-white, yellow, and tan phosphatic limestones. Chloride concentrations in the lower Hawthorn aquifer

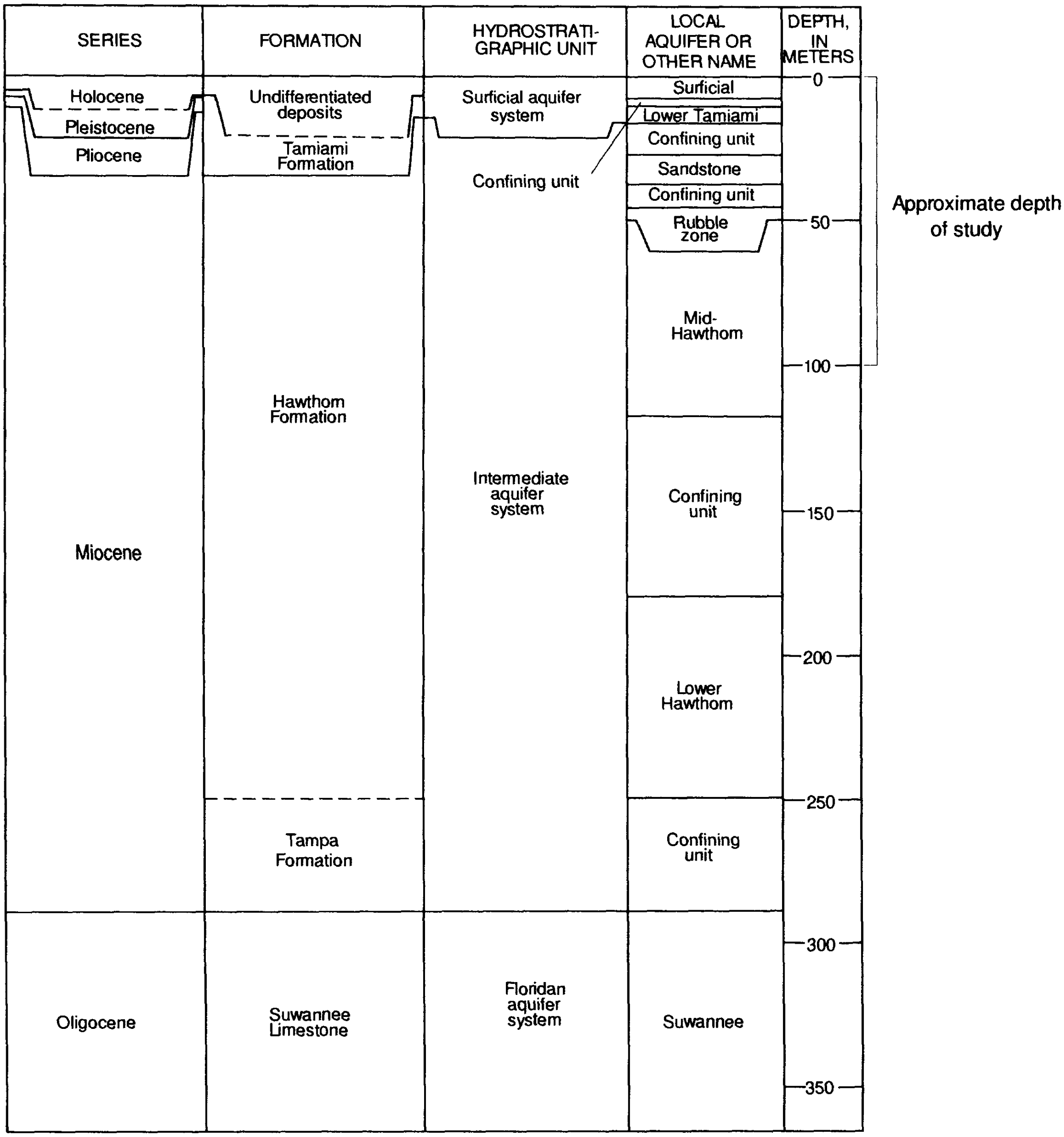


Figure 3. Hydrostratigraphic column for southwestern Florida, including Hendry and Collier Counties. See Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition (1986).

exceed 250 mg/L (milligrams per liter), making this aquifer a less desirable source of water supply if a better source is available.

The Floridan aquifer system (fig. 3) is a thick sequence of mostly fine-grained limestones and dolomites. The aquifer system is extensively developed in northern and central Florida, but salinity increases toward the south. Therefore, the Floridan aquifer system is not used as a source of water supply in the study area.

METHODS OF INVESTIGATION

The present study has been conducted along four lines of research: (1) DC-electrical resistivity methods, (2) examination of lithologic data, (3) examination of chloride data from exploratory test wells, and (4) borehole geophysical methods. This section presents a description of the methods that were used to assess the hydrogeologic characteristics associated with the study of aquifer systems in southwestern Florida. The first part describes the DC-electrical resistivity method that was used for the surface-geophysical survey to determine the areal extent, thickness, and lithology of the aquifers in Hendry and Collier Counties. The second part describes the geologic test wells that were used in conjunction with the application of surface and borehole geophysical techniques. The third part describes the chloride data that were collected for this study. The fourth part discusses the borehole geophysical techniques that were used in this study.

Direct-Current Electrical Resistivity Method

The DC-electrical resistivity method uses DC-electrical energy to determine the apparent resistivity of hydrogeologic units. Apparent resistivities of hydrogeologic units are dependent upon three factors: (1) porosity, (2) mineralogy, and (3) conductivity of fluids within the pore space of the unit (Stewart and others, 1982). Typical sediments that occur in the study area include quartz sand, clay minerals, and carbonate minerals such as limestone and dolomite. Quartz and carbonate rocks exhibit greater resistivities than clay minerals; however, as the porosity of more resistive units increases, their resistivity decreases. Resistivities of units with water containing high concentrations of dissolved solids will be lower than for units of the same mineral composition and porosity which contain water with low concentrations of dissolved solids. These three factors controlling the resistivity of geologic units can occur in various combinations, leading to error in geologic interpretations. Therefore, correlations must be made with both lithologic and water-quality (chloride) data so that geologic assignments can be made appropriately.

Apparent resistivity was measured in this study using the Schlumberger electrode array (Zohdy and Bisdorf, 1989) to obtain vertical electrical soundings (fig. 4). Four electrodes (two current and two potential electrodes) were placed in the ground along a straight line at predetermined intervals. When specific electrical current is transmitted into the ground through the two current electrodes, ellipsoidal lines of equipotential energy develop around the electrodes. The potential difference between the inner electrodes is measured using a volt meter (Zohdy and others, 1974). This electrical potential depends on the conductivity of interstitial fluids, porosity, and lithology of the earth materials present. The input current and the change in potential between the potential electrodes are measured to calculate an apparent resistivity for the earth material. Apparent resistivity is calculated using the formula (Zohdy and others, 1974):

$$\rho a = \pi \frac{(\overline{AB}/2)^2 - (\overline{MN}/2)^2}{\overline{MN}} \cdot \frac{\Delta V}{I} \qquad (1)$$

where ρa is the apparent resistivity, in ohm-meters; $\pi = 3.1416$; $\overline{AB}$ is the current electrode spacing, in meters; $\overline{MN}$ is the potential electrode spacing, in meters; ΔV is the measured change in potential, in volts; and I is the current applied to the current electrodes, in amps.

The center of the electrode configuration remains fixed as the current electrodes are spread farther apart at predetermined intervals and the potential electrodes are spread farther apart as needed to measure a change in potential between the electrodes. As the distance between the current electrodes increases, so does the exploration depth of the survey. The effective depth of penetration of the vertical electrical soundings is about one-half the total current electrode spacing ($\overline{AB}$) and is limited by transmitter power and receiver sensitivity.

Apparent resistivity values obtained in the field are not equal to the actual resistivity of the geologic units which affect the potential measured at the potential electrodes, unless the measurements are being made over homogeneous ground (Telford and others, 1990). At shallow exploration depths and short current electrode spacing, the measured apparent resistivity is most influenced by shallow layers through which most of the current flows. As electrode spacings increase, a greater proportion of the induced current flows into deeper geologic layers. Thus, the response measured at the surface is reflective of the resistivities of increasingly deeper geologic units as the electrode

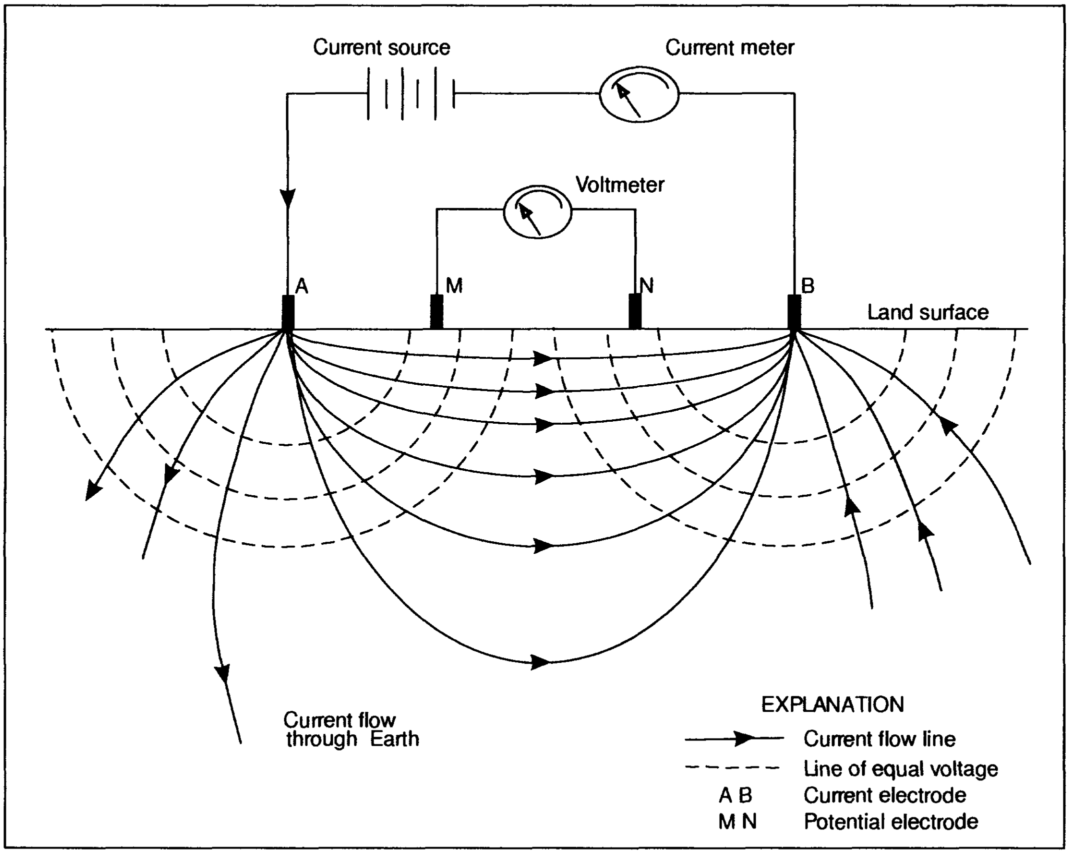


Figure 4. Schlumberger electrode array.

spacings are increased in subsequent measurements. The resulting sounding curves of apparent resistivity versus depth show inflections brought about by resistivity contrasts between neighboring geologic units. When the units are thin or not laterally extensive, as is the case in the study area, the effect of the unit on the apparent resistivity measured at the surface may not be significant enough to be measurable. It is, therefore, difficult to resolve differences between many thin layers or thin layers within thicker units of a geologic section.

Geologic Test Wells

The exploratory well-drilling program was a joint effort by the U.S. Geological Survey and the South Florida Water Management District to obtain point geologic data in the study area where such data were lacking. Drilling was completed at the Church test hole (fig. 1), CTH-1, which was drilled to 91 m below land surface. Mud-rotary techniques were used and samples were collected continuously and logged at CTH-1. The test hole was logged upon completion with borehole geophysical equipment supplied by the South Florida Water Management District.

Various types of geophysical logs (shown later) were run at CTH-1 and at four other geologic test wells in the study area (HE-529, HE-616, HE-619, and HE-1019). The location of the geologic test wells used to obtain lithologic data are shown in figure 1. Geologic test well numbers and their latitudes and longitudes are presented in table 1.

Available Chloride Data Collection

Water samples were collected periodically at four U.S. Geological Survey chloride monitoring wells (fig. 1 and table 2) as part of the ground-water data-collection program. Samples were collected in April 1993 for chloride determinations. DC-electrical resistivity methods were used to identify zones of high and low conductivity within the aquifer. High-resistivity zones are associated with coarse-grained aquifer material saturated with low conductivity water, whereas low-resistivity zones are composed of fine-grained materials with more conductive water (Haeni, 1995). Chloride data were then used to help ascertain the quality of water in selected sampled zones and to calibrate resistivity data obtained from the DC-electrical resistivity surveys and geophysical logs.

Table 1. U.S. Geological Survey well numbers, depths, and latitudes and longitudes for test sites used in the study and type of data used in report

Well number	Well depth (meters)	Latitude	Longitude	Lithologic data	Borehole geophysics	Chloride data
CTH-1	91	263335	812715	No	Yes	No
HE-529	126	263310	812509	Yes	Yes	Yes
HE-554	5	263310	812509	No	No	Yes
HE-557	104	264235	813106	Yes	No	No
HE-615	91	264200	812612	Yes	No	No
HE-616	97	264302	812335	Yes	Yes	No
HE-619	106	264301	812825	Yes	Yes	No
HE-620	104	264353	812811	No	No	Yes
HE-621	106	264258	812757	Yes	No	No
HE-1019	115	263332	812610	Yes	Yes	No
C-578	79	262640	813101	Yes	No	No
C-632	104	262602	812703	Yes	No	No
C-681	165	262509	812237	Yes	No	No
C-687	95	262554	812838	No	No	Yes

Table 2. U.S. Geological Survey monitoring wells used for determination of chloride data in the study area

[Well depth shown in meters; chloride concentration shown in milligrams per liter]

Well number	Well depth (meters)	April 1993 chloride concentration (milligrams per liter)	Lithologic unit sampled	Screened interval depth (meters)
HE-529	126	38	Limestone	41 - 47
HE-554	5	12	Sandstone	1.5 - 5
HE-620	104	290	Limestone	52 - 104 (open hole)
C-687	94	68	Sandstone	88 - 94 (open hole)

Borehole Geophysical Techniques

The analysis of borehole geophysical logs is needed to determine the complex geology and hydrology of the study area in Hendry and Collier Counties. The spontaneous potential, short- and long-normal resistivity, and natural gamma (gamma ray) logs are often useful in determining formation responses associated with water quality and lithology.

The spontaneous potential log measures natural electrical potential between the borehole fluid, formation fluid, and the surrounding rock. Generally, conductivity of the borehole fluid is less than that of the formation fluid and surrounding rock, causing apparent negative spontaneous potential deflections to the right opposite clean sand and positive deflection to the left opposite shale.

The electrical resistivity of a rock depends on the resistivity of the rock-mineral matrix and its contained fluid. Rocks composed primarily of quartz and feldspar, which are poor conductors, contain water that is usually a better conductor. Thus, the resistivity of a sandstone generally depends on the geometry of its pore space and the resistivity (or salinity) of its contained fluid. As permeability and porosity decrease, resistivity usually increases if there is no change in formation fluid. The log response corresponding to the difference in resistivity of different lithologies is useful in determining the vertical distribution and thickness of rock types. Conventionally, some type of resistivity curve is recorded with a spontaneous potential log. The spontaneous potential-resistivity log combination is useful in ground-water studies to identify the more permeable, water-yielding zones. Single-point resistance logs are highly useful for geologic correlation because of their unique response to changes in lithology and the good detail obtained in formations of low to moderate resistivity.

The gamma-ray tool measures the natural emission of gamma-ray radiation by the borehole environment resulting from the decay of radioactive minerals. Measurement generally is made with a borehole scintillation counter and recorded in American Petroleum Institute (API) units or counts per second (CPS). The gamma-ray log is very useful in identifying clean (nonshaley) rock and clay-rich formations; shaley or clay-rich zones are indicated by higher CPS as will be shown later. Resistivity logs may give similar signatures for clean sandstone intervals containing saline water and for shale or clay intervals. The gamma-ray log, however, would not respond similarly unless phosphatic grains containing uranium are present in the sandstone or clean formation.

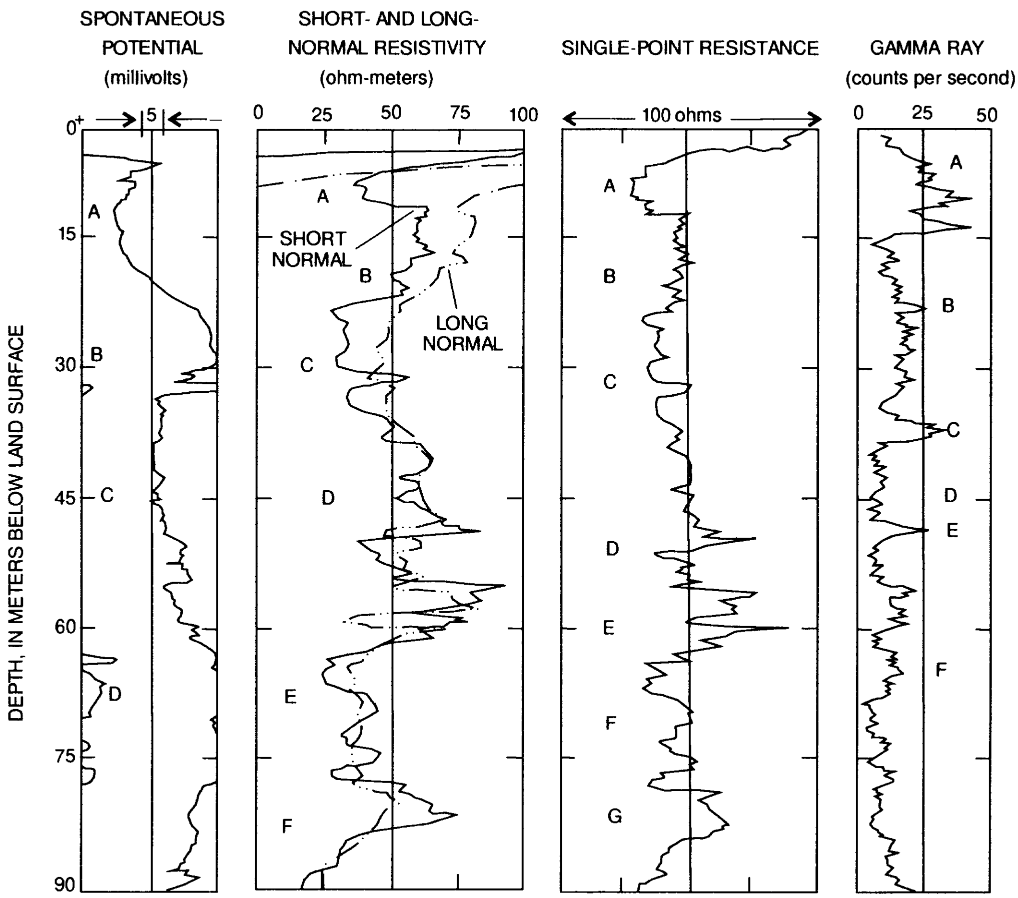
DESCRIPTION AND ANALYSIS OF GEOPHYSICAL LOGS FOR CHURCH TEST HOLE (CTH-1)

Deflections in spontaneous potential values occur throughout the length of the log for the Church test hole, CTH-1 (fig. 5), indicating that the fluid and rock properties vary with depth. There are four major fluctuations in the spontaneous potential curve that correspond with large fluctuations on other logs. The intervals are marked A to D on the spontaneous potential log (fig. 5).

The short- and long-normal resistivity log of CTH-1 shows six major fluctuations in the curves (fig. 5). The single-point resistance log has the same major pattern but more and smaller fluctuations in the curve (fig. 5), indicating that the layers are not very homogeneous in the test hole. The single-point resistance log can be used to detect very thin layers (Keys and MacCary, 1971). The intervals are marked A to F on the short- and long-normal resistivity log and A to G on the single-point resistance log in figure 5.

Examination of the gamma-ray log for CTH-1 (fig. 5) leads one to conclude that at least six phosphatic or clay/shale and clean rock (clay free) intervals exist in the rock section. These clay/shale intervals can cause anomalously low electrical resistivity values to be measured for a given rock section. The intervals are marked A to F on the gamma-ray log in figure 5.

In summary, borehole geophysical logs for CTH-1 (fig. 5) highlight differences in composition of rock layers in the subsurface that can then be correlated with lithology. The short- and long-normal resistivity log shows two distinct resistivity trends in the rock layers: those layers with resistivities less than 50 ohm-m and those with resistivities greater than 50 ohm-m. The gamma-ray log shows that some rock intervals exhibit the characteristics of a clean or nonshaley rock. Further division of these layers (defined by natural gamma) is possible if one overlays resistivity logs, which can emphasize differences in water characteristics in rock intervals. Log analysis of CTH-1 indicates that thick nonshaley rocks can have different water and porosity characteristics, as in the rock intervals throughout the depth of the test hole which contain very little if any clay, except at the bottom of the test hole. The gamma-ray log shows that this entire thick section contains very thick beds of phosphatic sandstone or limestone, and the amount of clay is not the controlling factor influencing resistivities (intervals C and D on the single-point resistance and short- and long-normal resistivity logs in fig. 5). The single-point resistance log exhibits a similar pattern to the short- and long-normal resistivity log in



Major fluctuations are marked by letters.

FIG 5

Figure 5. Borehole geophysical logs for Church test hole (CTH-1).

other wells studied. The logs suggest that some rocks in this section might be permeable sand (detrital) or carbonate rock zones that probably contain freshwater or nearly freshwater. The lithology in CTH-1 is shown in more detail in a geohydrologic section presented later in this report.

HYDROGEOLOGIC ASSESSMENT OF SHALLOW CLASTIC AND CARBONATE ROCK AQUIFERS

Direct-current (DC) electrical resistivity data were measured at 109 sounding sites in northwestern Hendry County and northern Collier Counties (fig. 1). Selected DC-electrical resistivity surveys, together with available borehole geologic and geophysical data, were used to determine the approximate areal extent of the shallow aquifers containing thick sands and carbonate lithologies in the study area. Field data were analyzed using the Automatic Processing Program (referred to as the ATO program) for the inversion of field resistivity data (Zohdy, 1989; Zohdy and Bisdorf, 1989). Models obtained from the program usually consisted of 11 to 13 geoelectric layers, which appear on the output as a stairstep curve (shown later). To design a model that conforms better to the site geology and consists of three to five layers, layers of similar resistivity were combined by drawing from the center of one line segment to the center of an adjacent segment (Zohdy, 1989). The ensuing curve exhibited inflections, interpreted as layer interfaces, which resulted from the resistivity contrasts between adjacent layers. These curves usually produced a three- to five-layer model.

Because of lateral and vertical influences, the ATO program yields models that may or may not represent the actual configuration of earth layers at sites where data were obtained. This program was used in the study to locate areas that have the greatest probability of containing higher resistivity layers at depth and freshwater. If the earth that is being studied is comprised of horizontal, homogeneous, and isotropic layers, electrical sounding data represent only the variation of resistivity with depth (Zohdy and others, 1974). In practice, however, DC-electrical resistivity sounding data are influenced by both vertical and horizontal heterogeneities. Geophysical and lithologic logs are necessary to properly analyze DC-electrical resistivity sounding data and to correctly identify resistivity anomalies.

Correlation of Resistivity, Lithologic, and Geophysical Data

Several geohydrologic and geoelectric sections were constructed using data from selected DC-electrical resistivity sounding sites in northwestern Hendry and northern Collier Counties and existing lithologic data and geophysical logs from selected wells in the study area. All of these data were correlated to determine the approximate areal extent of the shallow clastic and carbonate rock aquifers and associated clays in Hendry and Collier Counties.

Geohydrologic Section A-A′

Geohydrologic section A-A′ was constructed from available data for the survey line containing resistivity sites A1 through A8 (figs. 1 and 6). A contoured apparent resistivity section is shown in figure 7 (geoelectric section A-A′). Lithologic data that were obtained for wells HE-557, HE-615, HE-616, HE-619, and HE-621 (app. I) provided ground-truth data. These wells, located near geoelectric section A-A′ (fig. 7), are shown in figure 1. Borehole geophysical logs were obtained for wells HE-616 (fig. 8) and HE-619 (fig. 9). Chloride data were collected from well HE-620 (which is near the resistivity sites of geoelectric section A-A′), and the results are presented in table 2. Graphical results for the resistivity sites along geoelectric section A-A′ (fig. 7) are presented with layer determinations in appendix II. All of these data were correlated together to determine the approximate areal extent of the aquifers in this part of the study area.

Sounding data from the sites (fig. 7 and app. II) indicated that all of the resistivities of very shallow earth materials, except those at site A6, were greater than 100 ohm-m, which is typical for unsaturated surface materials. Apparent resistivity values decreased with depth in most of the section to less than 40 ohm-m at all sites; the lowest measured value was about 6.57 ohm-m for a thick clay or clayey limestone unit that is confined by clay at site A8 (figs. 6 and 7 and app. II). Lithologic data for well HE-619 and HE-621 (app. I) indicate that a clay unit is present between about 15 and 30 m below land surface, and lithologic data for well HE-615 (app. I) indicate that a sand and gravel unit is present between about 10 and 52 m below land surface (fig. 6). Porosity of the sand units would be expected to be moderately high because the sand units are not highly indurated. The chloride concentration in water at well HE-620 (near well HE-619) was 290 mg/L at a depth of 104 m (table 2), but more data are needed to substantiate water-quality aspects.

The relatively low apparent resistivity (less than 30 ohm-m) throughout most of geoelectric section A-A′ (fig. 7) indicates that a thick channel sand located under sites A1 to A7 probably does not contain freshwater or contains freshwater of relatively high chloride concentration. Although the clastic units identified in figure 6 within the target depth could serve as aquifers, the chloride concentration of the water in these units is probably above the acceptable drinking water standard of 250 mg/L established by the Florida Department of Environmental Protection (1993), as indicated by the chloride concentration (290 mg/L) in the lower limestone unit just below the clastic units in well HE-620 (table 2). The clay units shown in figure 6 correlate with low apparent resistivity values in some areas. Well logs were necessary to describe and analyze the subsurface layering in this area, but general trends and patterns in the apparent resistivity data are correlative to the lithologic changes occurring in the rock section.

Geohydrologic Section B-B′

Geohydrologic section B-B′ was constructed from available data for the survey line containing resistivity sites B1 through B6 (figs. 1 and 10). A contoured apparent resistivity section is shown in figure 11 (geoelectric section B-B′). Lithologic data that were obtained for wells HE-529 and HE-1019 (app. I) provided ground-truth data. Borehole geophysical logs were obtained for wells HE-529 (fig. 12), HE-1019 (fig. 13), and the Church test hole, CTH-1 (fig. 5). These three test sites, located near geoelectric section B-B′ (fig. 11), are shown in figure 1. Chloride data were collected from wells HE-529 and HE-554 (located at the same site), and the results are presented in table 2. Graphical results for the resistivity sites along geoelectric section B-B′ (fig. 11) are presented with layer determinations in appendix II. All of these data were correlated together to determine the approximate areal extent of the aquifers in this part of the study area.

Sounding data from sites B1 through B6 indicate a three- to five-layer geoelectric section (fig. 11 and

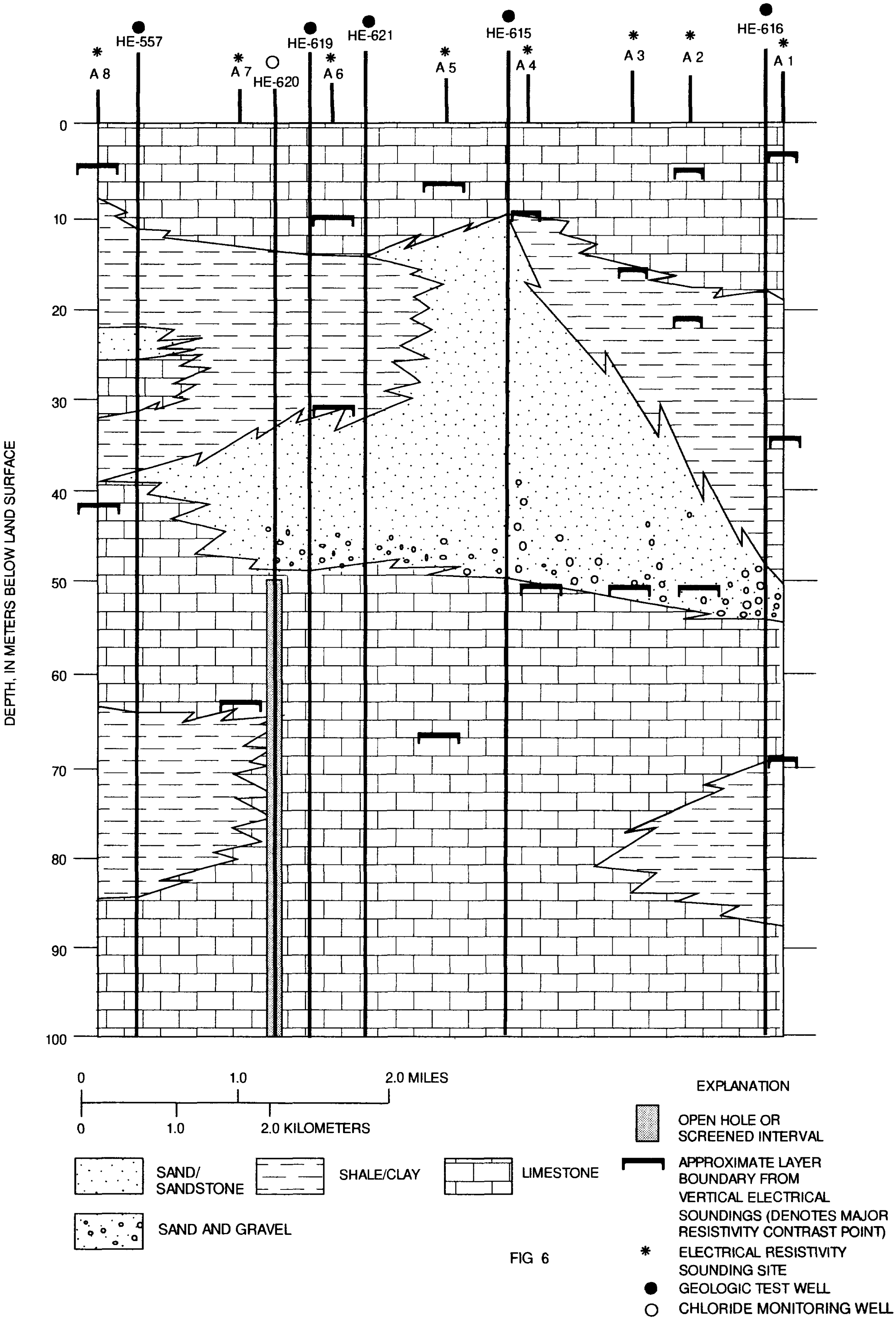


Figure 6. Geohydrologic section A-A′ showing geoelectric sounding sites, test well locations, lithologic log data, and approximate layering from electrical resistivity analysis.

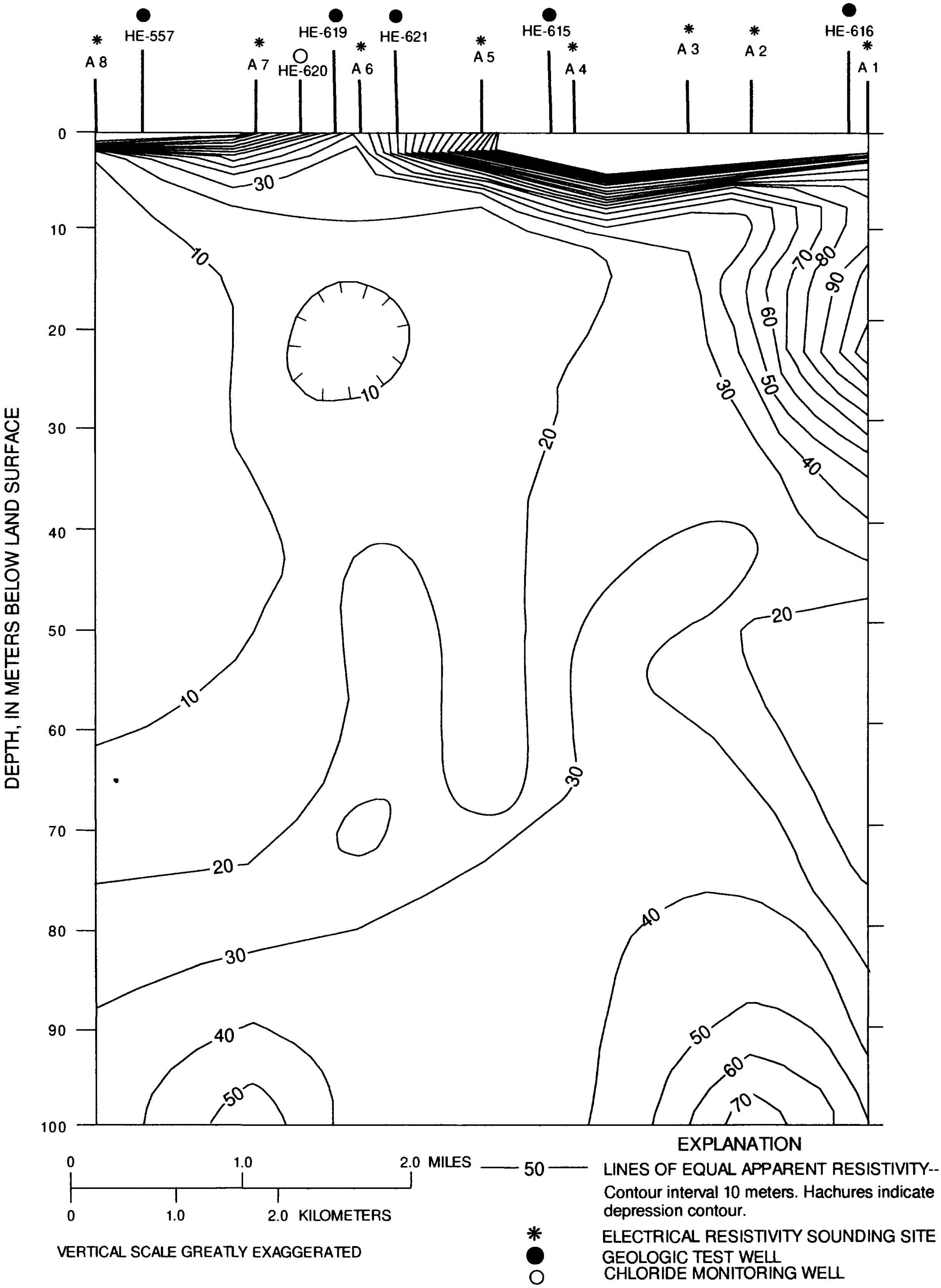


Figure 7. Geoelectric section A-A′.

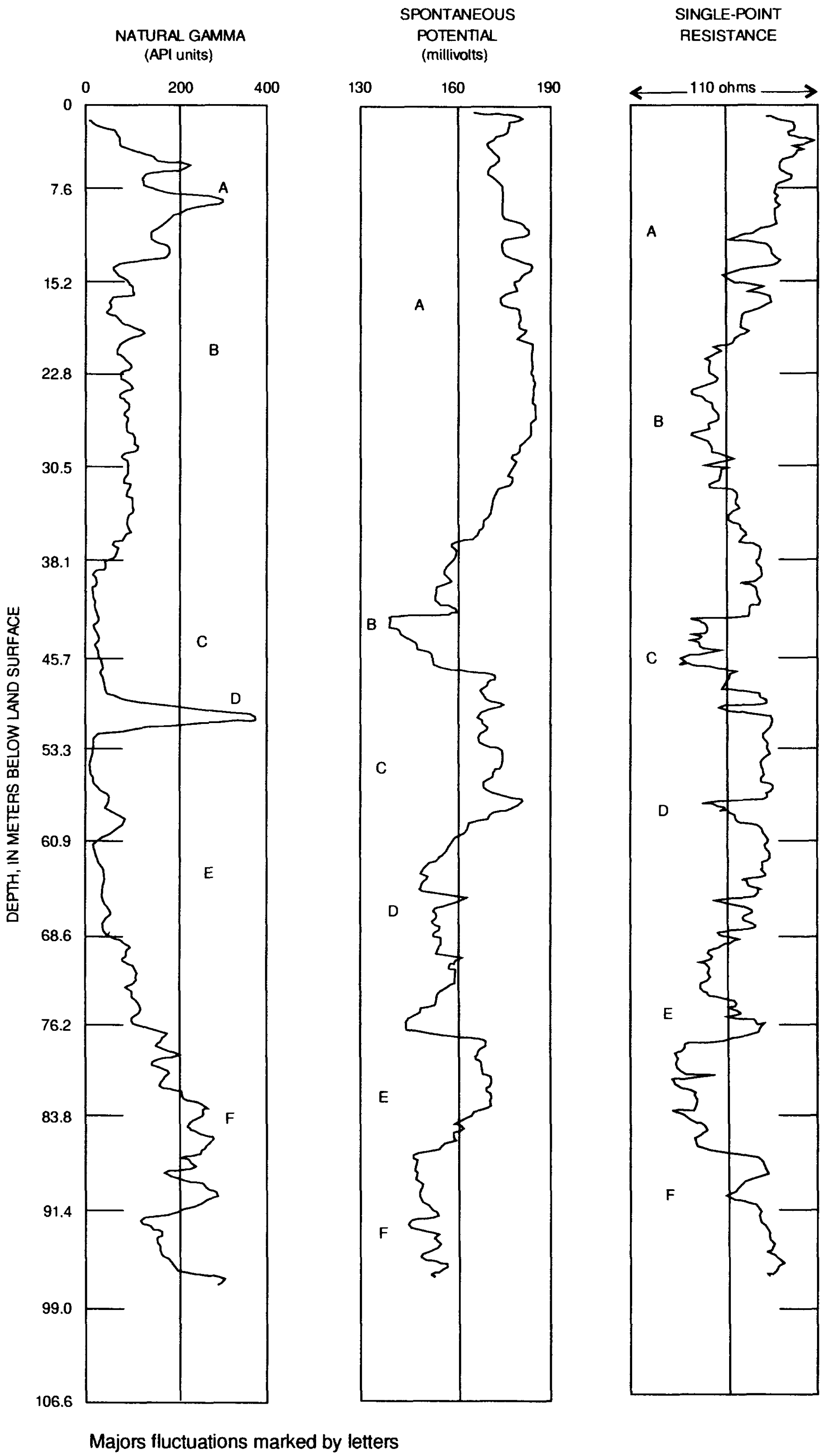


Figure 8. Borehole geophysical logs for well HE-616.

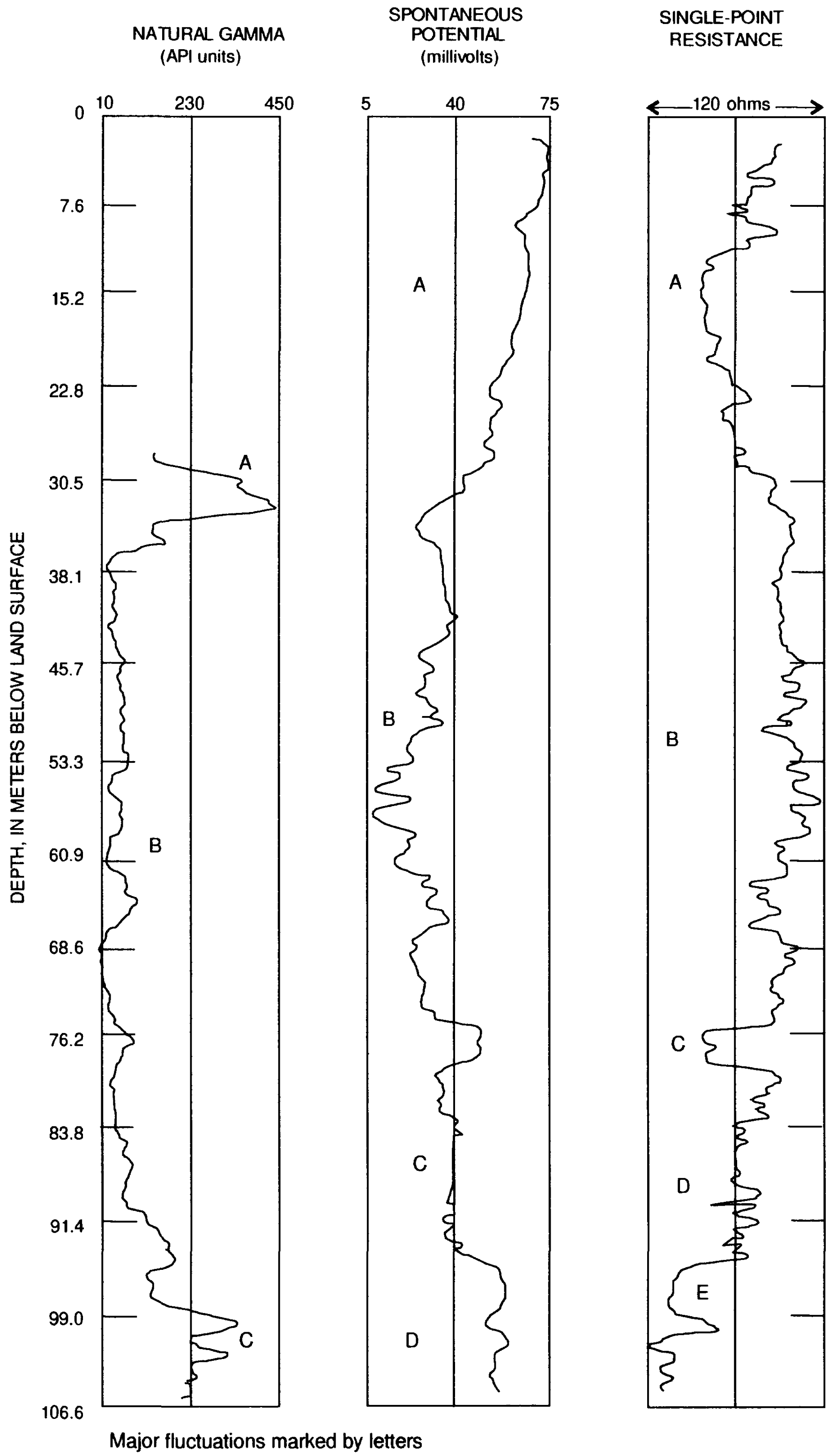


Figure 9. Borehole geophysical logs for well HE-619.

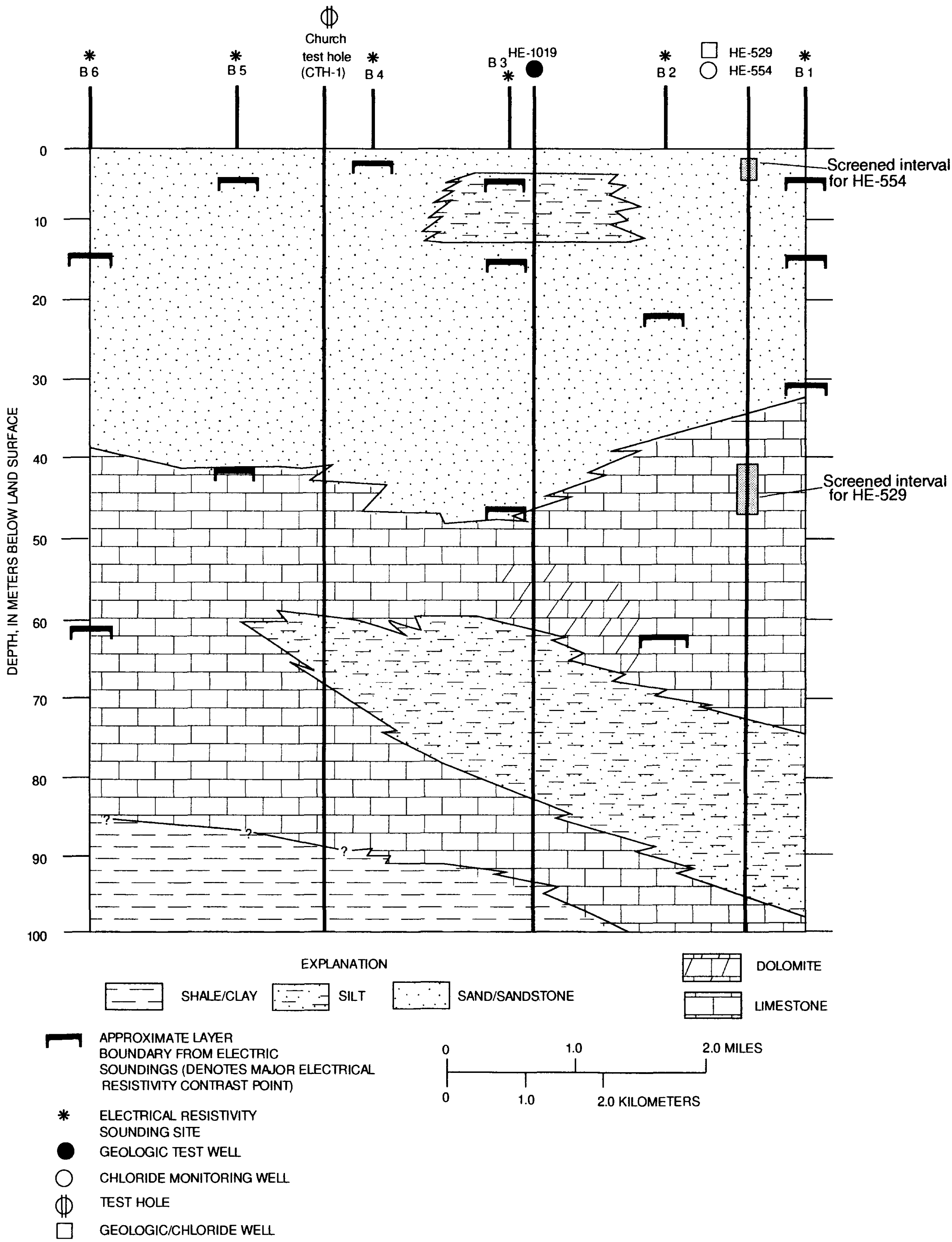


Figure 10. Geohydrologic section B-B′ showing geoelectric sounding sites, test well locations, lithologic log data, and approximate layering from electrical resistivity analysis.

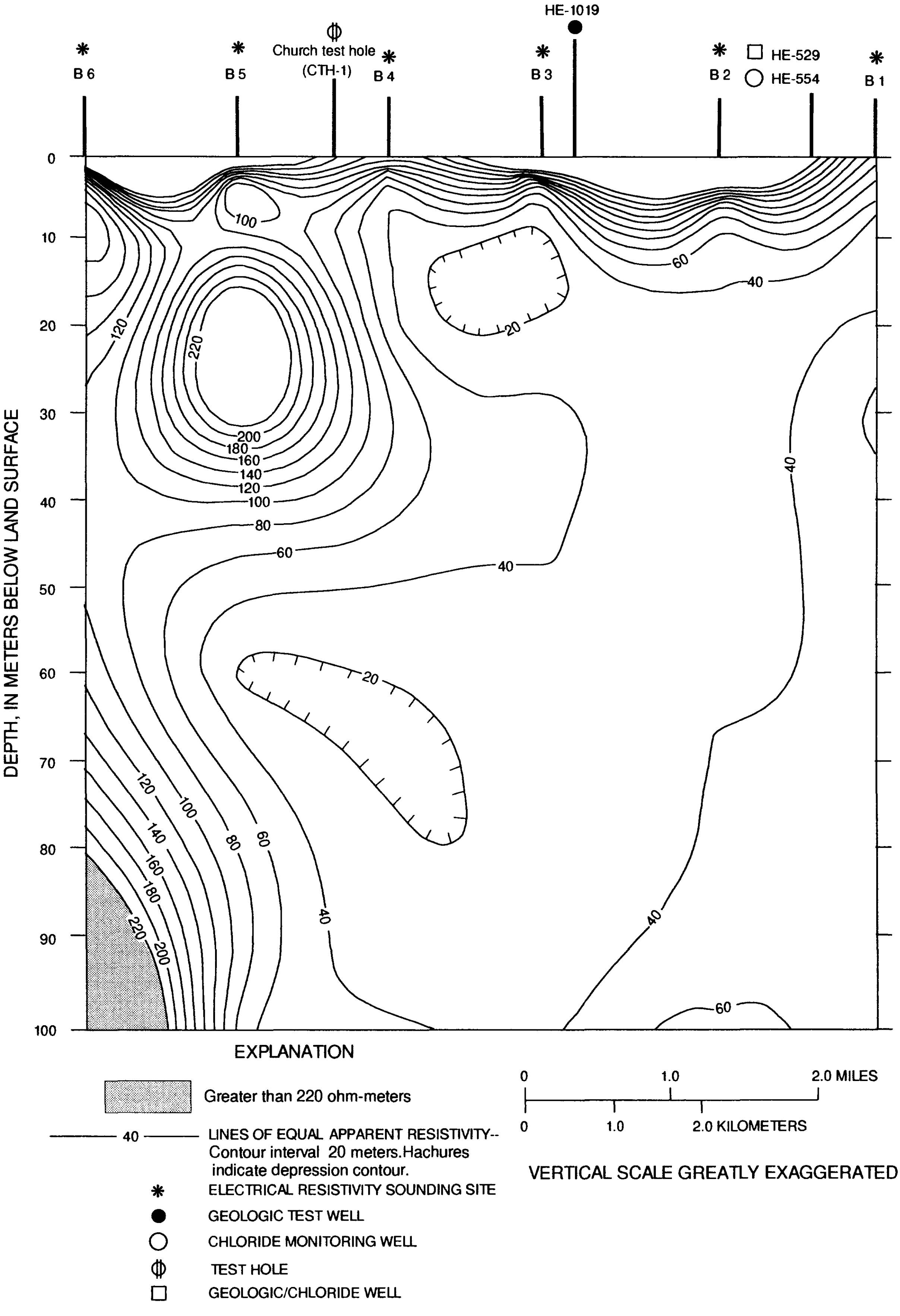


Figure 11. Geoelectric section B-B′.

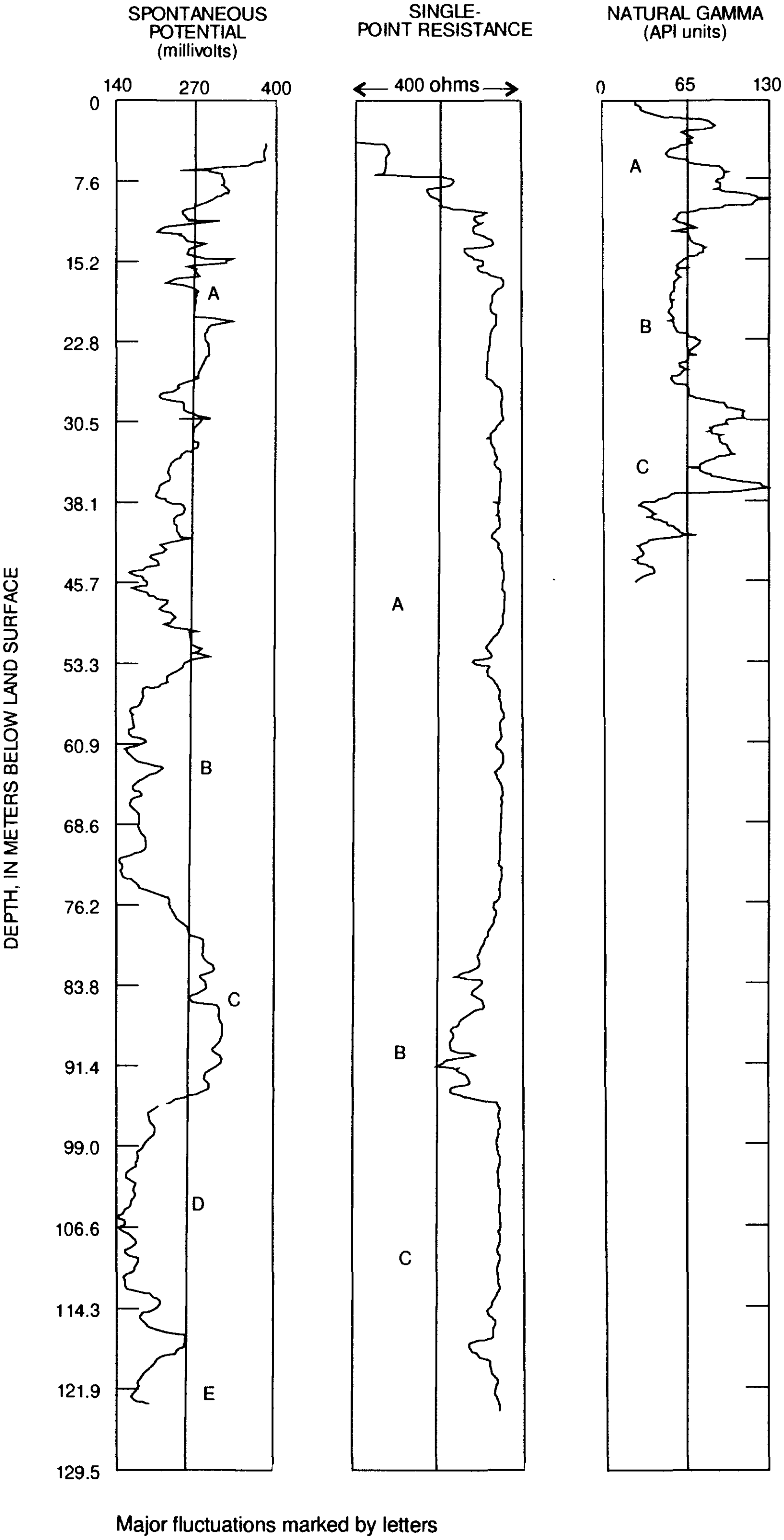


Figure 12. Borehole geophysical logs for well HE-529.

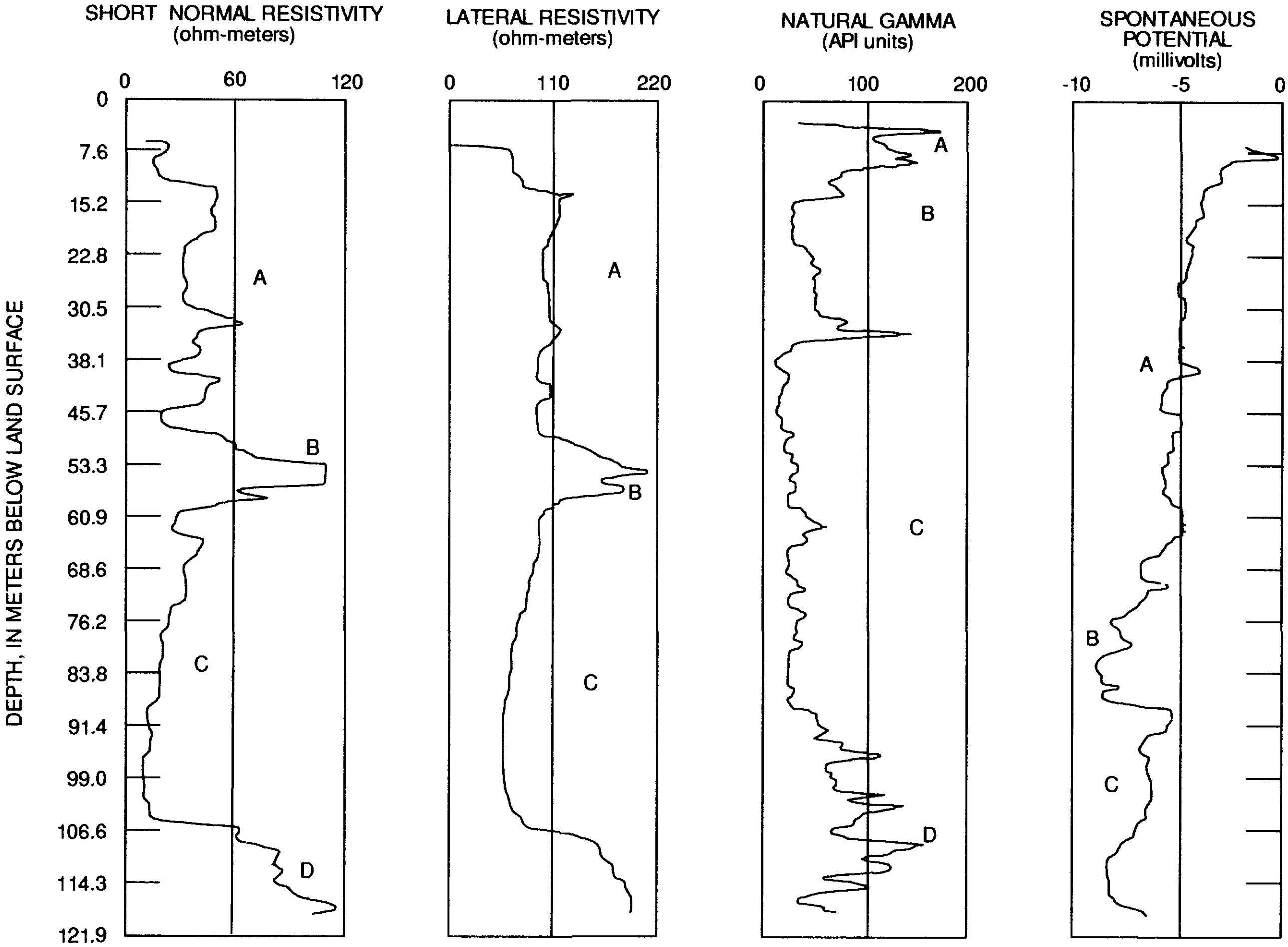


Figure 13. Borehole geophysical logs for well HE-1019.

app. II). Surface resistivities at all soundings were greater than 100 ohm-m. Resistivities from sites B1, B2, B3, B4, and B6 were less than 64 ohm-m in the first 10 m below land surface. Lithologic data for wells HE-529 and HE-1019 (app. I) show a thick sand unit is present in well HE-529 from land surface to about 36.5 m below land surface and in well HE-1019 from about 12 to 46.5 m below land surface (fig. 10). The chloride concentration in water within the limestone unit of well HE-529 was 38 mg/L at a depth of 126 m (table 2). Resistivities at site B5 (fig. 11 and app. II) decreased rapidly from the surface to a second-layer low of about 72 ohm-m at 4 m below land surface. Resistivities then increased in the third layer to a high of about 300 ohm-m at 18.9 m below land surface. Resistivities of the fourth geoelectric layer decreased to less than 17 ohm-m at 60 m below land surface. The long-normal resistivity log for CTH-1 (fig. 5) indicates a formational resistivity of about 50 ohm-m at 50 m below land surface. Although this agrees with the resistivity from site B5 at the same depth (50 m), there are no lithologic logs available at CTH-1 to correlate with these data. Geophysical logs for CTH-1 (fig. 5) indicate that the 50 ohm-m value is a value that best separates the lithologies at this test hole.

The sand units in wells HE-529 (about 0-36.5 m deep) and HE-1019 (about 12-46.5 m) may be potential aquifers (fig. 10), but resistivity values (less than 64 ohm-m) should be further analyzed to associate with and define water quality. The higher resistivity zones (intervals C and D in the short- and long-normal resistivity log of CTH-1 in fig. 5) have the highest potential for yielding freshwater. This interval is the bottom of the sand unit and the upper part of the limestone unit down to about 60 m (fig. 10). Chloride data, however, indicate that water of low dissolved-solids concentration might exist in some lithologic units (table 2, 38 mg/L in well HE-529 and 12 mg/L in well HE-554). Resistivities at site B5 are greater than 100 ohm-m between about 8 and 38 m below land surface (fig. 11 and app. II), suggesting the presence of an aquifer within this interval.

Geohydrologic Section C-C′

Geohydrologic section C-C′ was constructed from available data for the survey line containing resistivity sites C1 through C12 (figs. 1 and 14). A contoured apparent resistivity section is shown in figure 15 (geoelectric section C-C′). Lithologic data that were obtained for wells C-578, C-632, and C-681 (app. I) provided ground-truth data. These wells, located along geoelectric section C-C′ (fig. 15), are shown in figure 1. Borehole geological logs were not run for wells along this geoelectric section. Chloride data were collected from well C-687 (which also is located along geoelectric section C-C′), and the results are presented in table 2. Graphical results for the resistivity sites along geoelectric section C-C′ (fig. 15) are presented with layer determinations in appendix II. All of these data were correlated together to determine the approximate areal extent of the aquifers in this part of the study area.

Apparent resistivities at all soundings indicate that division of the section into three to six geoelectric layers is feasible, but four is the most common number of layers (app. II). The resistivities of the surface layers are commonly greater than 100 ohm-m, but are less than 100 ohm-m at some sites. Sites C5, C6, and C7, which have higher surface layer resistivity, are located where a thick sand unit overlies a thick clay and thick limestone unit (fig. 14).

Sounding data from sites C11 and C12 (fig. 15 and app. II) indicate that anomalously higher resistivities occur at about 10 and 60 m below land surface, respectively (in geoelectric layer 2). A thick sand unit in well C-578 (located between sites C10 and C11) is present from about 30 to 65 m below land surface (fig. 14). The resistivity data suggest that the lower, relatively high porosity sand unit occurring in well C-578 below 30 m deep may be a potential aquifer (figs. 14 and 15). If this sand unit has good properties, the lower-than-expected resistivity values could result from one factor or a combination of high porosity and high chloride concentration of water in the sand. More chloride data are needed to make an accurate determination in this area.

The lithologic data for well C-681 (located between sites C2 and C3) show a thick sand unit is present at about 10 to 40 m below land surface, and a second thick sand unit is present at 65 to 100 m below land surface (fig. 14). The upper and lower sand units seem to be potential aquifers, if the chloride concentration is determined to be low; however, no chloride data were available for well C-681.

Based on data presented for geoelectric section C-C′ (fig. 15), it seems likely that the best aquifer is the sand unit that occurs from land surface to about 60 m below land surface in well C-632 (fig. 14). This is because the DC-electrical resistivity sounding method is most accurate when used to distinguish relatively thick, laterally continuous layers as is the case in this section. The presence of an aquifer with freshwater cannot be ruled out solely because the resistivity curve shows a decrease in resistivity with depth. Chloride concentration in water in well C-687 was 68 mg/L at a depth of 94 m (table 2), suggesting that freshwater probably occurs in this limestone section.

Geoelectric Section D-D′

Geoelectric section D-D′ (figs. 1 and 16) was constructed using data collected at soundings D1 through D8 (app. II). No lithologic or chloride data were available near this section line. Graphical results for the resistivity sites along geoelectric section D-D′ (fig. 16) are presented with layer determinations in appendix II.

A resistivity maximum of about 140 ohm-m was measured at site D3 at about 28 m below land surface. This site exhibited a five-layer resistivity response model with a high resistivity surface layer. Sounding data from sites D1, D2, D3, and D7 exhibited a similar type of resistivity profile with depth (app. II). The resistivity maxima at sites D1, D2, D3, and D7 were about 99, 115, 140, and 114 ohm-m, respectively, and all occurred between about 10 and 30 m below land surface (these data do not include the shallowest depths). The resistivity profile for site D8 is comparable, but the resistivity maximum of 105 ohm-m is 10 m deeper, at about 40 m below land surface (app. II). Potential sites for further evaluation include sites D1, D2, D3, D7, and D8.

Further Research

The geohydrologic and geoelectric sections define areas where the potential for locating freshwater in sands is highest. The best areas are those with thick sands and anomalously high resistivity zones. Further study in these identified areas is likely to answer many other questions about the hydrogeologic characteristics of rocks in the study area. A number of buried channel sands (sands below clay or limestone) in the area exist and are shown in figures 6, 10, and 14. Electrical resistivity surveying, conducted in conjunction with borehole geophysical logging and examination of existing lithologic data, was critical in determining the depth of resistivity anomalies due to clay content and other rock characteristics. Areas requiring further study are those with anomalously

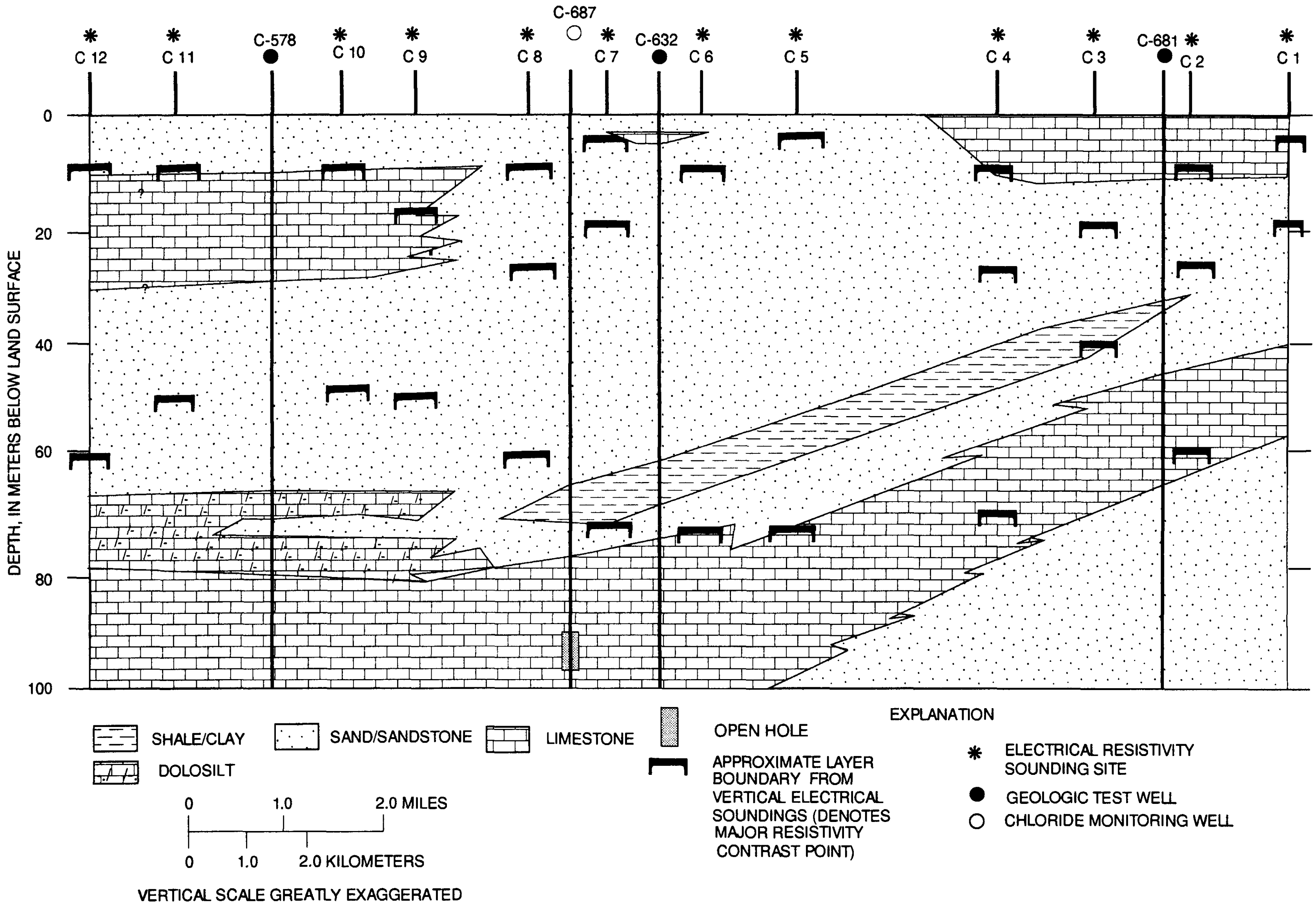


Figure 14. Geohydrologic section C-C′ showing geoelectric sounding sites, test well locations, lithologic log data, and approximate layering from electrical resistivity analysis.

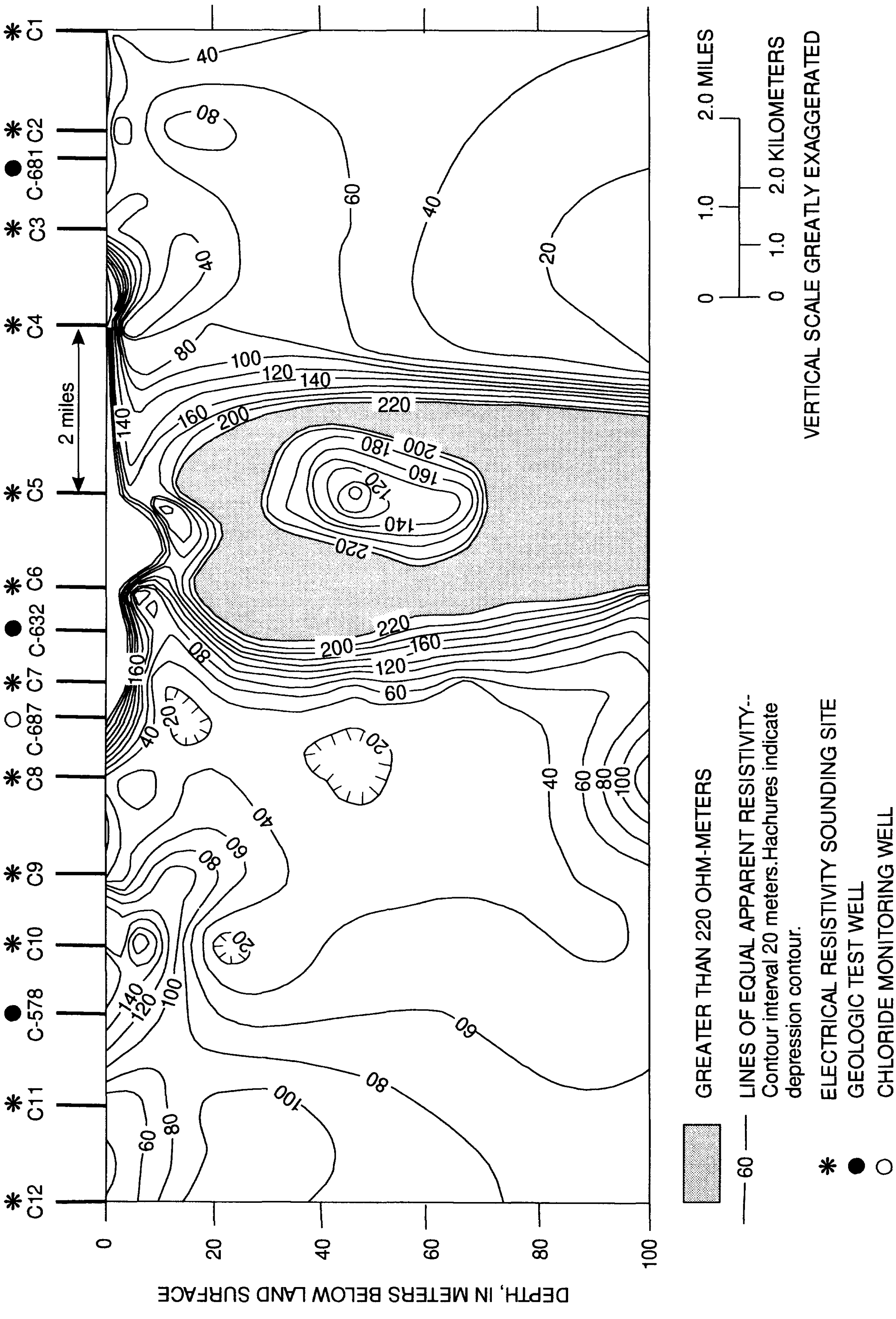


Figure 15. Geoelectric section C-C′.

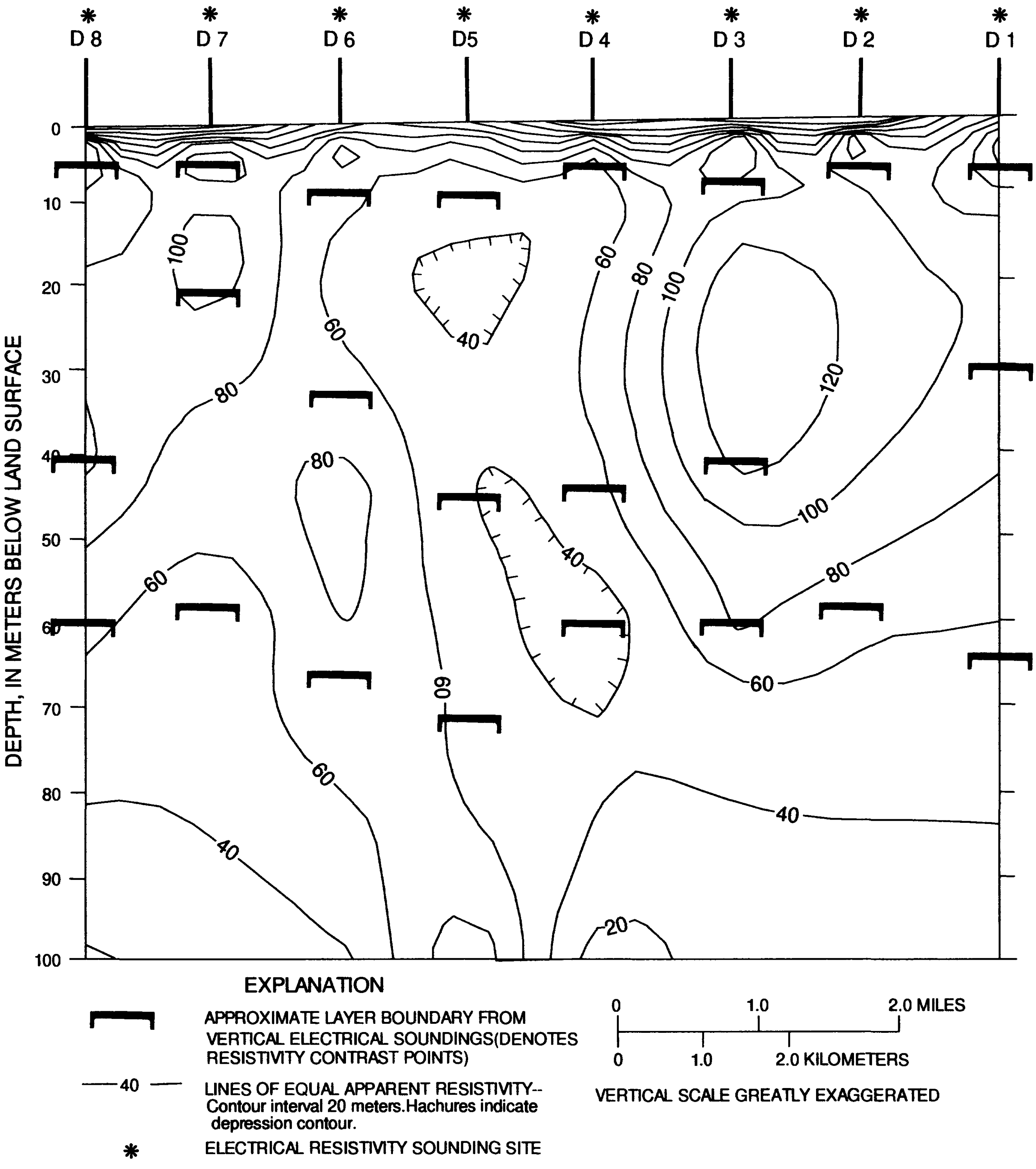


Figure 16. Geoelectric section D-D′ with approximate geoelectric boundaries.

higher resistivity values as indicated by geoelectric contours (figs. 7, 11, and 15). Additional well data are needed to identify and correlate the lithology of subsurface layers for sites along geoelectric section D-D′ (fig. 16). The best locations would be near sites D2, D3, and D7.

More chloride data should be collected to correlate with resistivity data from borehole geophysical logs and surface geophysical models and to ascertain the water quality of potential aquifers in the study area. Geoelectric sections also show areas of anomalously high values, and these areas should be further examined.

SUMMARY AND CONCLUSIONS

Direct-current (DC) electrical resistivity data were measured at 109 sounding sites in northwestern Hendry County and northern Collier County. Selected vertical electrical soundings were correlated with existing borehole lithologic, geophysical, and chloride data to determine the approximate areal extent of potential aquifers in the study area. Several geohydrologic and geoelectric sections were constructed to show the relation of vertical electrical soundings to lithologic data and geophysical logs. Electrical resistivity interpretations showed complex lithologic patterns. Geophysical logs, particularly gamma-ray and resistivity, were valuable in showing ranges in resistivity values and other rock property changes on a small scale. Thick clay units, evident in some of the geoelectric sections, do exist and make interpretation difficult.

Results show that thick buried channel sands with high-resistivity zones exist in the area, and these sands may represent potential aquifers in all of the geohydrologic sections. Some of the surficial sands are identified as very thick bodies. Results indicate that carbonate rocks are also potential aquifers in some areas. The maximum number of lithologic layers in the study area, indicated from the geoelectric modeling, is usually less than five and is more commonly three. The top 10 m in each section generally have several very thin layers that can be combined into one large, high-resistivity layer.

Using DC-electrical resistivity data collected at the surface as well as lithologic, geophysical, and chloride data collected from boreholes, generalized areas where aquifers may exist were determined. However, a more detailed study should be conducted to confirm all potential aquifers.

REFERENCES CITED

Boggess, D.H., 1981, Hydrogeologic sections through Lee County and adjacent areas of Hendry and Collier Counties, Florida: U.S. Geological Survey Water-Resources Investigations Open-File Report 85-4161, 59 p.

Boggess, D.H., and Watkins, F.A., Jr., 1986, Surficial aquifer system in eastern Lee County, Florida: U.S. Geological Survey Water-Resources Investigations Report 85-4161 59 p.

Florida Department of Environmental Protection, 1993, Drinking water standards, monitoring and reporting: Chapter 17-550, Florida Administrative Code, 38 p.

Gleason, P.J. (ed.), 1974, Environments of south Florida: Present and past: Miami Geological Society, Memoir 2, 452 p.

Haeni, F.P., 1995, Application of surface geophysical methods to investigations of sand and gravel aquifers in the glaciated northeastern United States: U.S. Geological Survey Professional Paper 1415-A, 70 p.

Hoffmeister J.E., Stockman, K.W., and Multer, H.G., 1967, Miami Limestone of Florida and its recent Bahamian counterpart: Geological Society of America Bulletin, v. 78, p. 175-190.

Keys, W.S., and MacCary, L.M., 1971, Application of borehole geophysics to water resources investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 2, chap. E1, 126 p.

La Rose, H.R., 1990, Geohydrologic framework and an analysis of a well-plugging program, Lee County, Florida, 1990: U.S. Geological Survey Water-Resources Investigations Report 90-4063, 26 p.

Matson, G.C., and Sanford, S., 1913, Geology and ground waters of Florida: U.S. Geological Survey Water-Supply Paper 319, 445 p.

McCoy, H.J., 1962, Ground-water resources of Collier County, Florida: Florida Geological Survey Report of Investigations 31, 82 p.

McPherson, B.F., 1974, The Big Cypress Swamp, *in* P.J. Gleason (ed.); Environments of south Florida: Present and past: Miami Geological Society, Memoir 2, p. 8-13.

Parker, G.G., and Cooke, C.W., 1944, Late Cenozoic geology of southern FLorida, with a discussion of the ground water: Florida Geological Survey Bulletin 27, 119 p.

Parker, G.G., Ferguson, G.E., and others, 1955, Water resources of southeastern Florida, with special reference to the geology and ground water of the Miami area: U.S. Geological Survey Water- Supply Paper 1255, 965 p.

Smith, K.R., and Adams, K.M., 1988, Ground water resources assessment of Hendry County, Florida: South Florida Water Management District Technical Publication 88-12, 109 p.

Southeastern Geological Society Ad Hoc Committee on Florida Hydrostratigraphic Unit Definition, 1986, Hydrogeological units of Florida: Florida Department of Natural Resources, Bureau of Geology, Special Publication 28, 9 p.

Stewart, M.J., Lizanee, T., and Layton, M., 1982, Application of direct-current resistivity surveys to regional hydrologic investigations, Collier County, Florida: University of South Florida/South Florida Water Management District Cooperative Program, Phase I and II, Collier County Direct Current Resistivity Mapping Project Technical Publication 82-6, 95 p.

Stringfield, V.T., 1933, Ground water in the Lake Okeechobee area, Florida: Florida Geology Survey Report of Investigations 2.

Telford, W.M., Geldart, L.P., and Sheriff, R.E., 1990, Applied geophysics (2d ed.): London, Cambridge University Press, 860 p.

Zohdy, A.A.R., 1989, A new method for the automatic interpretation of Schlumberger and Wenner sounding curves: Geophysics, v. 54, no. 2, p. 245-253.

Zohdy, A.A.R., and Bisdorf, R.J., 1989, Programs for the automatic processing and interpretation of Schlumberger sounding curves in Quickbasic 4.0: U.S. Geological Survey Open-File Report 89-137 (A and B).

Zohdy, A.A.R., Eaton, G.P., and Mabey, D.R., 1974, Application of surface geophysics to ground-water investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 2, chap. D1, 116 p.

Appendix I

Lithologic Logs of Geologic Test Wells

WELL HE-529

Description	Thickness (meters)	Depth (meters)
Sand, light-olive-gray (5 Y 6/1); quartz, fine to medium, moderately sorted, subangular to subrounded; some clay and muck	4.6	0.0 - 4.6
Sand, very pale orange (10 YR 8/2); quartz, fine to medium, well sorted, subangular to subrounded; shelly; some calcareous clay	4.6	4.6 - 9.2
Same as above; some limestone, yellowish-gray (5 Y 8/1), sandy micrite	1.5	9.2 - 10.7
Limestone yellowish-gray (5 Y 8/1); fossiliferous micrite, sandy; loosely consolidated	1.2	10.7 - 11.9
Sand, yellowish-gray (5 Y 8/1); quartz, coarse to granules, well sorted, subrounded to rounded; some limestone, yellowish-gray (5 Y 8/1); sandy micrite	0.3	11.9 - 12.2
Sand, yellowish-gray (5 Y 8/1); quartz, very fine to coarse, poorly sorted, subangular to rounded; some calcareous clay	1.5	12.2 - 13.7
Sand, yellowish-gray (5 Y 8/1); quartz, very fine to fine, well sorted, angular to subangular; clayey, calcareous; some phosphorite	12.2	13.7 - 25.9
Sand, olive-gray (5 Y 4/1); quartz, fine to coarse, moderately sorted, angular to subrounded; some clay; some phosphorite; some shell fragments	4.6	25.9 - 30.5
Sand, light-olive-gray (5 Y 5/2); quartz, very fine to medium, well sorted, angular to rounded; clayey; some phosphorite	3.0	30.5 - 33.5
Sand, variable in color; quartz, coarse to granules, well sorted, subrounded to well rounded; some phosphorite granules	3.0	33.5 - 36.5
Limestone, white (N 9); micrite; loosely consolidated; some quartz and phosphorite granules	4.6	36.5 - 41.1
Limestone, yellowish-gray (5 Y 8/1); fossiliferous micrite; moderately consolidated	9.2	41.1 - 50.3
Limestone, white (N 9); micrite, silty; loosely consolidated; some quartz sand and granules	9.1	50.3 - 59.4
Limestone, white (N 9); micrite, silty; moderately consolidated; some quartz sand	3.1	59.4 - 62.5
Limestone, white (N 9); micrite, silty; loosely consolidated	13.7	62.5 - 76.2
Siltstone, yellowish-gray (5 Y 7/2); quartzose; calcareous clay; some coarse grains of phosphorite in places	19.8	76.2 - 96.0
Limestone, yellowish-gray (5 Y 8/1); micrite, silty, phosphatic; some shell fragments	19.9	96.0 - 115.9
Limestone, pale-olive-green (10 Y 6/2); micrite, silty; some shell fragments	3.0	115.9 - 118.9
Limestone, yellowish-gray (5 Y 8/1); micrite, silty, phosphatic; some shell fragments	6.1	118.9 - 125.0

WELL HE-557

Description	Thickness (meters)	Depth (meters)
Sand, moderate-yellowish-brown (10 YR 5/4); quartz, fine to medium, well sorted, subangular to rounded; traces of quartzose sandstone	1.5	0.0 - 1.5
Shells; some quartz sand; clayey, calcareous	10.7	1.5 - 12.2
Claystone, light-olive-gray (5 Y 6/1)	10.7	12.2 - 22.9
Sand, light-olive-gray (5 Y 5/2); quartz, silt to coarse, poorly sorted, very angular to well rounded; clayey; some phosphorite	1.5	22.9 - 24.4
Sand, very pale orange (10 YR 8/2); quartz, very fine to fine, well sorted, very angular to subrounded; clayey, calcareous	1.5	24.4 - 25.9
Limestone, light-olive-gray (5 Y 6/1); sparse biomicrite, sandy; well consolidated; some calcareous quartzose sandstone; some shell fragments	4.6	25.9 - 30.5
Claystone, light-olive-gray (5 Y 6/1); sandy, slightly phosphatic; some limestone as above; traces of limestone, sandy sparite	7.6	30.5 - 38.1
Limestone, yellowish-gray (5 Y 8/1); micrite; well consolidated	4.6	38.1 - 42.7
Limestone, yellowish-gray (5 Y 8/1); micrite; well consolidated; some biosparite	1.5	42.7 - 44.2
Limestone, yellowish-gray (5 Y 8/1); biosparite	1.5	44.2 - 45.7
Limestone, yellowish-gray (5 Y 8/1); micrite; well consolidated, becoming loosely consolidated in some places	6.1	45.7 - 51.8
Limestone, yellowish-gray (5 Y 8/1); micrite, silty, slightly phosphatic; moderately consolidated	13.7	51.8 - 65.5
Clay, light-olive-gray (5 Y 6/1); silty, slightly phosphatic, calcareous; some shell fragments	19.8	65.5 - 85.3
Limestone, yellowish-gray (5 Y 8/1); micrite, silty, phosphatic; loosely consolidated; some shell fragments	18.3	85.3 - 103.6

WELL HE-615

Description	Thickness (meters)	Depth (meters)
Sand, pale-yellowish-brown (10 YR 6/2); quartz, medium, well sorted, subangular to subrounded; traces of organic soil	1.8	0.0 - 1.8
Limestone, grayish-orange (10 YR 7/4); micrite, sandy; well consolidated	4.3	1.8 - 6.1
Limestone, grayish-orange (10 YR 7/4); micrite, silty to sandy; loosely consolidated	4.6	6.1 - 10.7
Sand, yellowish-gray (5 Y 7/2); quartz, silt to fine, well sorted, very angular to subangular; clayey, calcareous	3.0	10.7 - 13.7
Claystone, olive-gray (5 Y 4/1); sandy, slightly phosphatic; some shell fragments; loosely consolidated	1.5	13.7 - 15.2
Sand, light-olive-gray (5 Y 6/1); quartz, very fine to fine, well sorted, very angular to subangular; clayey, slightly calcareous; some shell fragments	30.5	15.2 - 45.7
Gravel, variable in color; quartz and phosphorite, granules to pebbles, poorly sorted, rounded to well rounded; same sand as above	6.1	45.7 - 51.8
Limestone, yellowish-gray (5 Y 8/1); micrite, slightly phosphatic; well consolidated	9.1	51.8 - 60.9
Limestone, yellowish-gray (5 Y 8/1); fossiliferous micrite, sandy, slightly phosphatic; well consolidated to moderately consolidated in places	17.4	60.9 - 78.3
Limestone, yellowish-gray (5 Y 8/1); packed biomicrite; well consolidated	4.0	78.3 - 82.3
Limestone, yellowish-gray (5 Y 8/1); packed biomicrite, sandy, slightly phosphatic; loosely consolidated	9.1	82.3 - 91.4

WELL HE-616

Description	Thickness (meters)	Depth (meters)
Soil and muck, dusky-brown (5 YR 2/2); sandy	0.9	0.0 - 0.9
Sand, brownish-gray (5 YR 4/1); quartz, fine to medium, well sorted, subangular to subrounded	1.5	0.9 - 2.4
Shells; some quartz sand; traces of clay	2.5	2.4 - 4.9
Limestone, yellowish-gray (5 Y 8/1), unsorted biosparite, sandy; well consolidated; some shell fragments	1.2	4.9 - 6.1
Limestone, yellowish-gray (5 Y 8/1); biomicrite, sandy; unconsolidated to loosely consolidated	6.1	6.1 - 12.2
Limestone, yellowish-gray (5 Y 8/1); sparse biomicrite, sandy; loosely consolidated	6.1	12.2 - 18.3
Clay, light-olive-gray (5 Y 6/1); sandy; some shell fragments; traces of phosphorite	30.5	18.3 - 48.8
Gravel, variable in color; quartz and phosphorite, fine sand to pebbles, poorly sorted, subangular to well rounded; traces of clay	6.1	48.8 - 54.9
Limestone, yellowish-gray (5 Y 8/1); sparse biomicrite, sandy; loosely consolidated; some clay, slightly phosphatic; some shell fragments	15.2	54.9 - 70.1
Clay, light-olive-gray (5 Y 6/1); calcareous; sandy, phosphatic; some shell fragments	18.3	70.1 - 88.4
Shells; some phosphorite; traces of micrite	3.0	88.4 - 91.4
Limestone, yellowish-gray (5 Y 8/1); micrite, sandy, phosphatic; loosely consolidated; abundant shells	3.7	91.4 - 95.1
Shells, some phosphorite; traces of micrite	3.4	95.1 - 98.5

WELL HE-619

Description	Thickness (meters)	Depth (meters)
Sand, moderate-yellowish-brown (10 YR 5/4); quartz, fine to medium, moderately sorted, subangular to subrounded; limestone, very pale orange (10 YR 8/2); micrite, sandy; well consolidated; some limonite; some peat and muck	1.2	0.0 - 1.2
Limestone, very pale orange (10 YR 8/2); micrite, sandy; well consolidated; some limonite; some shell fragments	4.9	1.2 - 6.1
Sand, yellowish-gray (5 Y 7/2); quartz, fine to medium, well sorted, subangular to angular; some clay, calcareous; traces of shell fragments	3.0	6.1 - 9.1
Limestone, yellowish-gray (5 Y 7/2); micrite, clayey; moderately consolidated; some sand, quartz and phosphorite; some shell fragments	1.6	9.1 - 10.7
Limestone, very pale orange (10 YR 8/2); micrite, silty; moderately consolidated	4.5	10.7 - 15.2
Clay, light-olive-gray (5 Y 6/1); traces of quartz, phosphorite, and shell fragments	15.3	15.2 - 30.5
Gravel, variable in color; quartz and phosphorite, ranging in size from medium sand to pebbles, poorly sorted, rounded to well rounded	13.7	30.5 - 44.2
Same as above; some limestone, white (N 9); micrite	6.1	44.2 - 50.3
Limestone, white (N 9); biomicrite; loosely consolidated	3.0	50.3 - 53.3
Limestone, yellowish-gray (5 Y 8/1); packed biomicrite; moderately consolidated	16.8	53.3 - 70.1
Limestone, yellowish-gray (5 Y 8/1); micrite, sandy; loosely consolidated	15.2	70.1 - 85.3
Limestone, yellowish-gray (5 Y 8/1); micrite, silty, phosphatic; moderately consolidated; some sand, quartz, and phosphorite, coarse	13.8	85.3 - 99.1
Limestone, yellowish-gray (5 Y 8/1); micrite, silty; loosely consolidated; sand, quartz, and phosphorite, coarse to granules	6.4	99.1 - 105.5

WELL HE-621

Description	Thickness (meters)	Depth (meters)
Limestone, grayish-orange (10 YR 7/4); fossiliferous micrite, sandy; well consolidated; some shell fragments	4.6	0.0 - 4.6
Limestone, yellowish-gray (5 Y 8/1); micrite, sandy; loosely consolidated	4.5	4.6 - 9.1
Sand, yellowish-gray (5 Y 7/2); quartz, fine, well sorted, angular to subangular; clayey; calcareous; some shell fragments; traces of phosphorite granules	1.6	9.1 - 10.7
Limestone, yellowish-gray (5 Y 7/2); micrite, sandy, clayey; loosely consolidated	3.0	10.7 - 13.7
Limestone, yellowish-gray (5 Y 7/2); micrite, silty, clayey; loosely consolidated; some shell fragments	1.5	13.7 - 15.2
Claystone, light-olive-gray (5 Y 6/1); calcareous, silt; moderately consolidated	18.3	15.2 - 33.5
Gravel, variable in color; quartz and phosphorite, coarse sand to pebbles, poorly sorted, rounded to well rounded	12.2	33.5 - 45.7
Same as above; some limestone, white (N 9); biomicrite, silty; loosely consolidated	3.1	45.7 - 48.8
Limestone, white (N 9); biomicrite, silty; loosely consolidated	9.1	48.8 - 57.9
Limestone, yellowish-gray (5 Y 8/1); packed biomicrite; well consolidated; molds are evident; porous	3.0	57.9 - 60.9
Limestone, yellowish-gray (5 Y 8/1); sparse biomicrite; loosely consolidated	6.2	60.9 - 67.1
Limestone, yellowish-gray (5 Y 8/1); sparse biomicrite, silty; loosely consolidated	27.4	67.1 - 94.5
Limestone, yellowish-gray (5 Y 8/1); packed biomicrite, clayey, slightly phosphatic	6.1	94.5 - 100.6
Limestone, yellowish-gray (5 Y 8/1); packed biomicrite, phosphatic, clayey; some phosphorite granules	6.1	100.6 - 106.7

WELL HE-1019

Description	Thickness (meters)	Depth (meters)
Sandstone, grayish-orange; 15 percent porosity, intergranular, pinpoint vugs; medium grain size, very fine to coarse; subangular; some calcilutite, sparite, and phosphatic sand	3	0 - 3
Limestone, very pale orange; 12 percent porosity, intergranular, pinpoint vugs; calcilutite, intraclasts; very fine grain size, microcrystalline to coarse; some quartz sand, sparite, and phosphatic sand	3	3 -6
Silt, very light gray; some quartz sand, clay, and dolomite; iron stained; calcareous	6	6 - 12
Sand, yellowish-gray to light-gray; 25 percent porosity, intergranular; very coarse grain size, fine to granule; subangular to rounded; some calcilutite and dolomite	6	12 - 18
Sand, yellowish-gray to light-gray; 12 percent porosity, intergranular, low permeability; very fine grain size, microcrystalline to granule, subangular to rounded; some calcilutite and phosphatic gravel	3	18 - 21
Sand, grayish-olive; 12 percent porosity, intergranular, low permeability; fine grain size, microcrystalline to granule; angular to subangular; some clay	3	21 - 24
Same as above with large mollusk fragments and some micrite cement and quartz granules	3	24 - 27
Sand, light-olive-gray; 15 percent porosity, intergranular; very coarse grain size, medium to granule; subangular; some dolomite and phosphatic gravel	7	27 - 34
Same as above with some micrite cement	3	34 - 37
Sand, very light gray; 12 percent porosity, intergranular; very fine grain size, microcrystalline to granule; subangular; some calcilutite	3	37 - 40
Sandstone, white to light-gray to light-greenish-yellow; 10 percent porosity, intergranular, low permeability; fine grain size, very fine to granule; subangular; some calcilutite, dolomite, and clay	6	40 - 46
Limestone, white; 12 percent porosity, pinpoint vugs, intergranular; microcrystalline grain size, cryptocrystalline to fine; some quartz sand and dolomite	6	46 - 52
Dolomite, moderate-orange-pink; 12 percent porosity, pinpoint vugs, intergranular; microcrystalline grain size, cryptocrystalline to microcrystalline; some calcilutite and sparite	6	52 - 58
Silt, white to very light gray; 10 percent porosity, intergranular, low permeability; some calcilutite, dolomite, limestone, and quartz sand	15	58 - 73
Same as above with some shell fragments	3	73 - 76
Limestone, yellowish-gray; 13 percent porosity, intergranular, low permeability; microcrystalline grain size, cryptocrystalline to granule; some quartz sand, dolomite, and phosphatic sand	3	76 - 79
Sandstone, yellowish-gray; very coarse grain size, medium to granule; subangular; some dolomite, calcilutite, and phosphatic sand	3	79 - 82
Limestone, yellowish-gray; 13 percent porosity, intergranular, pinpoint vugs; microcrystalline grain size, cryptocrystalline to granule; some quartz sand, dolomite, and phosphatic sand	3	82 - 85
Silt, yellowish-gray. 10 percent porosity, intergranular; some quartz sand, calcilutite, and phosphatic sand	3	85 - 88
Clay, light-olive; 8 percent porosity, intergranular, low permeability; some quartz sand, phosphatic sand, phosphatic gravel, limestone, and phosphatic granules	13	88 - 101
Limestone, very light gray to light-olive to white; 10 to 12 percent porosity, intergranular, moldic; medium to very coarse grain size, microcrystalline to granule; some clay, quartz sand, and phosphatic sand	15	101 - 116

WELL C-578

Description	Thickness (meters)	Depth (meters)
Shell bed, white to very pale orange; 20 percent porosity, intergranular; some quartz sand and mollusks	2	0 - 2
Sand, yellowish-gray; 20 percent porosity, intergranular, low permeability; fine grain size, very fine to coarse; subangular; some calcilutite and mollusks	1	2 - 3
Sandstone, yellowish-gray; 15 percent porosity, intergranular; fine grain size, very fine to coarse; subangular; some calcilutite and mollusks	3	3 - 6
Sandstone, very pale orange to grayish-brown; 15 percent porosity, intergranular, moldic, possibly high permeability; fine grain size, very fine to coarse; subangular; some calcilutite and mollusks	6	6 - 12
Limestone, very pale orange; 20 percent porosity, intergranular, moldic; possibly high permeability; microcrystalline grain size, microcrystalline to coarse; some quartz sand, mollusks, and coral	5	12 - 17
Dolosilt, very pale orange to grayish-olive to yellowish-gray; 10 percent porosity, intergranular, low permeability; some clay, calcilutite, quartz sand, phosphatic sand, and mollusks	10	17 - 27
Limestone, very pale orange; 15 percent porosity, intergranular, moldic; microcrystalline grain size, microcrystalline to medium; some quartz sand and mollusks	3	27 - 30
Sandstone, very pale orange; 15 percent porosity, intergranular; medium grain size, very fine to medium; subangular; some calcilutite, sparite, phosphatic sand, and mollusks	13	30 - 43
Sand, white to very pale orange; 35 percent porosity, intergranular; medium grain size, very fine to coarse; subangular to rounded; some phosphatic sand and mollusks	9	43 - 52
Sand, white to light-gray; 35 percent porosity, intergranular; coarse to medium grain size, fine to very fine to coarse, subangular to rounded; some phosphatic sand, clay, and mollusks	12	52 - 64
Dolosilt, grayish-olive; 10 percent porosity, intergranular, low permeability; some calcilutite, clay, quartz sand, and mollusks	3	64 - 67
Sandstone, light-gray; 20 percent porosity, intergranular; coarse grain size, very fine to granule; subangular to rounded; some sparite and mollusks	5	67 - 72
Dolosilt, grayish-olive; 10 percent porosity, intergranular, low permeability; some calcilutite, clay, quartz sand, phosphatic sand mollusks	7	72 - 79

WELL C-632

Description	Thickness (meters)	Depth (meters)
Sand, grayish-orange (10 YR 7/4); quartz, very fine to fine, moderately sorted, angular to subrounded	3.0	0.0 - 3.0
Limestone, yellowish-gray (5 Y 8/1); micrite, sandy; loosely consolidated; traces of phosphorite	3.0	3.0 - 6.0
Sand, yellowish-gray (5 Y 8/1); quartz, very fine to medium, moderately sorted, very angular to rounded; traces of limestone, micrite; some phosphorite; minor shell fragments	30.5	6.0 - 36.5
Sand, yellowish-gray (5 Y 8/1); quartz, very fine to coarse, moderately sorted, angular to rounded; some limestone, micrite; some clay	4.6	36.5 - 41.1
Sand, yellowish-gray (5 Y 8/1); quartz, very fine sand to granules, poorly sorted, very angular to well rounded; some limestone, micrite, sandy; traces of phosphorite	4.6	41.1 - 45.7
Sand, yellowish-gray (5 Y 8/1); quartz, very fine to coarse, moderately sorted, angular to rounded; some limestone, micrite; some clay	1.5	45.7 - 47.2
Sand, yellowish-gray (5 Y 8/1); quartz, very fine to medium, moderately sorted, very angular to rounded; traces of limestone, micrite; some phosphorite; minor shell fragments	10.7	47.2 - 57.9
Sand, light-olive-gray (5 Y 5/2); quartz, very fine to medium, well sorted, angular to rounded; clayey	3.0	57.9 - 60.9
Clay, light-olive-gray (5 Y 5/2); sandy, slightly phosphatic	4.6	60.9 - 65.5
Sand, light-olive-gray (5 Y 5/2); quartz, very fine to medium, well sorted, angular to rounded; clayey	4.6	65.5 - 70.1
Limestone, yellowish-gray (5 Y 8/1); sparse biomicrite, sandy; well consolidated; some claystone	6.1	70.1 - 76.2
Limestone, yellowish-gray (5 Y 8/1); fossiliferous, micrite, sandy; loosely consolidated	1.5	76.2 - 77.7
Limestone, yellowish-gray (5 Y 8/1); fossiliferous micrite, silty; loosely consolidated	1.5	77.7 - 79.2
Limestone, yellowish-gray (5 Y 8/1); fossiliferous dismicrite; well consolidated; porous	6.1	79.2 - 85.3
Limestone, yellowish-gray (5 Y 8/1); sparse biomicrite, silty; moderately consolidated	10.7	85.3 - 96.0
Limestone, yellowish-gray (5 Y 8/1); fossiliferous micrite, sandy, clayey; loosely consolidated	3.0	96.0 - 99.0
Clay, light-olive-gray (5 Y 5/2); sandy, calcareous; some shell fragments; traces of phosphorite	4.6	99.0 - 103.6

WELL C-681

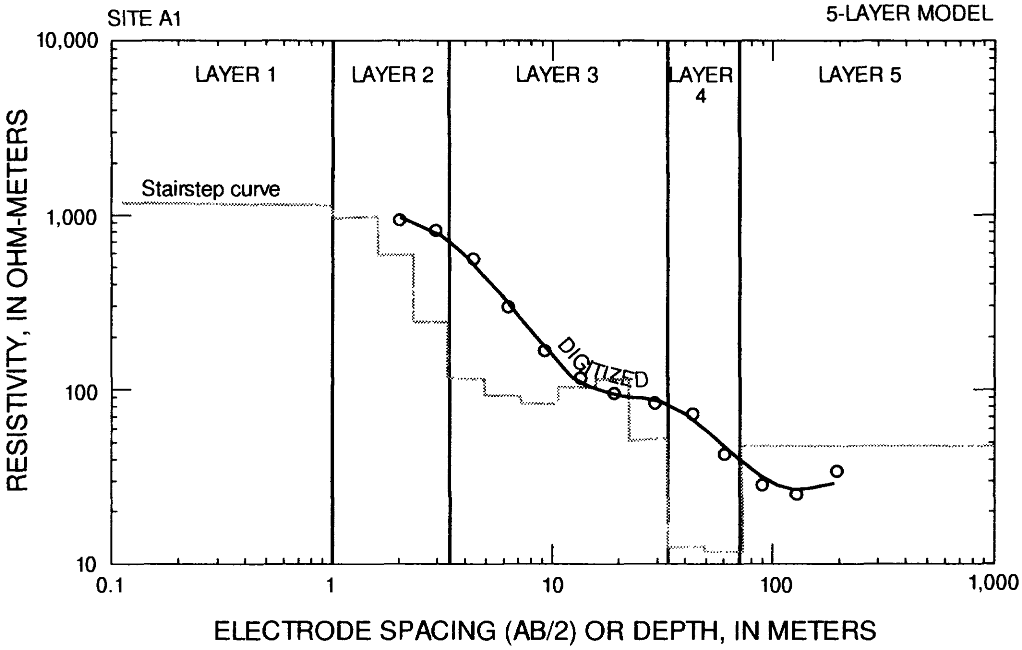
Description	Thickness (meters)	Depth (meters)
Limestone, white to very pale orange; 15 to 25 percent porosity, intergranular, moldic, possibly high permeability; microcrystalline to fine grain size, very fine to medium to coarse; some quartz sand, mollusks, and coral	9	0 - 9
Sand, white to very pale orange; 30 percent porosity, intergranular; coarse grain size, very fine to very coarse; subangular to rounded; some calcilutite, mollusks, phosphatic sand, and sandstone chips	6	9 - 15
Sandstone, very pale orange; 25 percent porosity, intergranular; medium grain size, very fine to very coarse; subangular to rounded; some calcilutite and mollusks	9	15 - 24
Sand, very pale orange; 20 percent porosity, intergranular; fine grain size, very fine to coarse, subangular to angular; some calcilutite	3	24 - 27
Sand, grayish-olive to light-olive; 10 percent porosity, intergranular, low permeability; fine grain size, very fine to coarse; subangular to angular; some clay, dolomite, phosphatic sand, and mollusks	10	27 - 37
Clay, light-olive; 10 percent porosity, intergranular, low permeability; some quartz sand, phosphatic sand, and mollusks	3	37 - 40
Sand, white; 40 percent porosity, intergranular; medium grain size, very fine to very coarse; subangular to rounded; some phosphatic sand, phosphatic gravel, mollusks, and dolosilt	9	40 - 49
Limestone, white to very pale orange; 15 percent porosity, intergranular, moldic; microcrystalline grain size, microcrystalline to very fine to coarse to medium; some quartz sand and mollusks	15	49 - 64
Sandstone, very pale orange; 10 percent porosity, intergranular, low permeability; medium grain size, very fine to coarse; subangular to rounded; some calcilutite, dolomite, and mollusks	3	64 - 67
Limestone, very pale orange; 15 percent porosity, intergranular, moldic; microcrystalline grain size, microcrystalline to coarse; some quartz sand and mollusks	3	67 - 70
Sandstone, very pale orange; 10 percent porosity, intergranular, low permeability; medium grain size, very fine to coarse, subangular to rounded; some dolomite	21	70 - 91
Sandstone, very pale orange; 15 percent porosity, intergranular; medium grain size, very fine to coarse; subangular to rounded; some dolomite and phosphatic sand; some granule size quartz from 104 to 107 meters	19	91 - 110
Clay, grayish-olive; 10 percent porosity, intergranular, low permeability; some quartz sand, phosphatic sand, and mollusks; phosphate rubble from 146 to 149 meters.	39	110 - 149
Limestone, white to very pale orange; 10 percent porosity, intergranular; microcrystalline grain size, microcrystalline to medium; some phosphatic sand and mollusks	16	149 - 165

BLANK

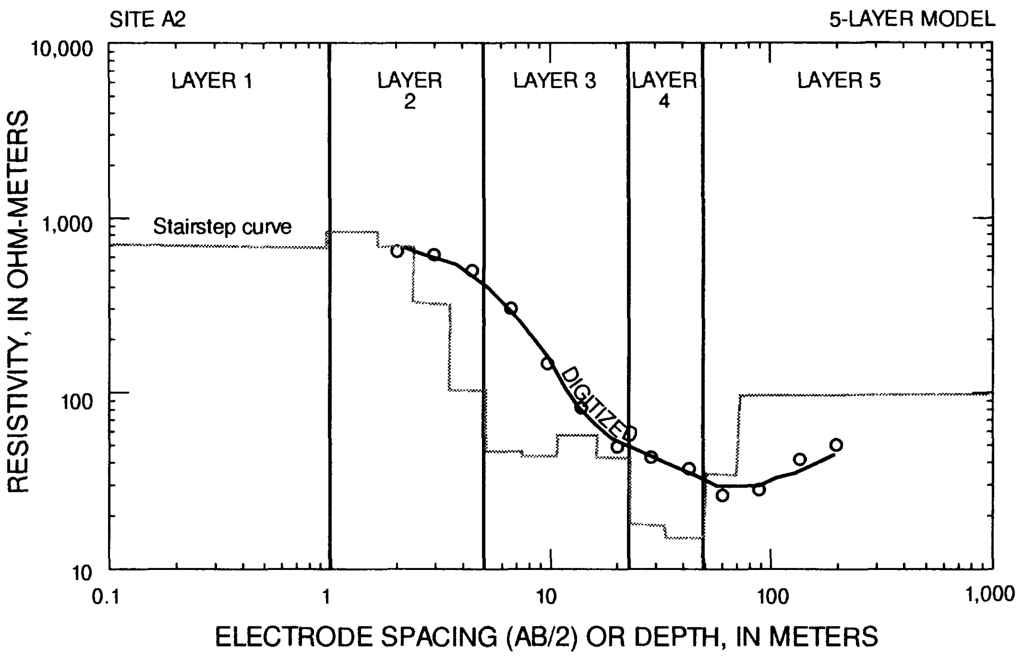
Appendix II

Resistivity-Depth Curves for Selected Sites

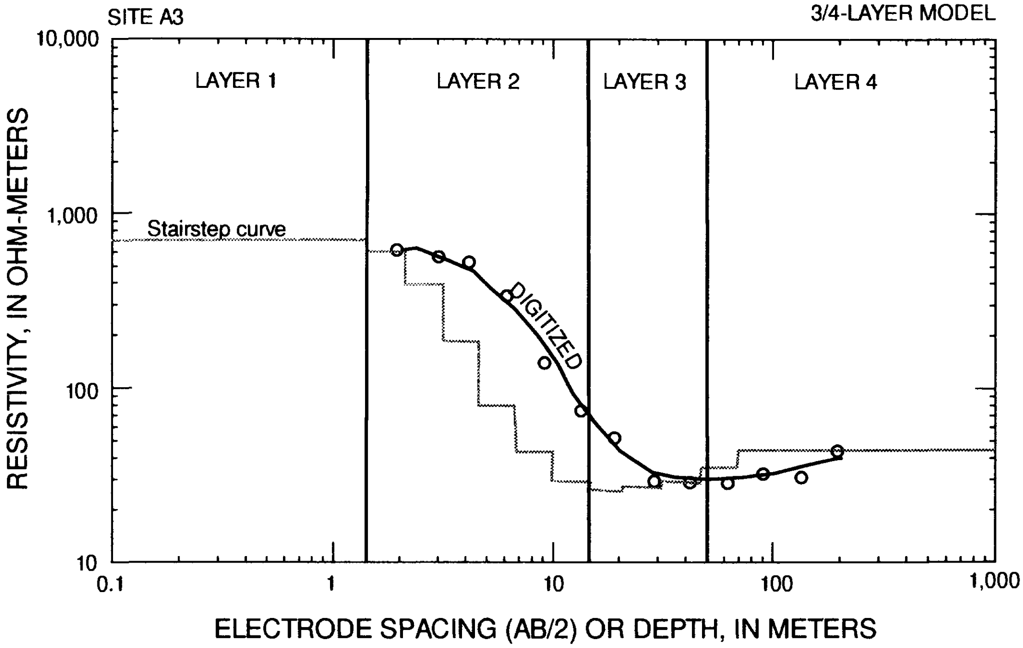
DEPTH	RESIS.	DEPTH	RESIS.
1.08	1142.06	10.80	85.64
1.59	967.57	15.85	105.57
2.33	593.30	23.27	114.38
3.42	252.94	34.15	53.76
5.01	115.66	50.13	13.13
7.36	89.85	73.58	11.97
		99.00	49.32



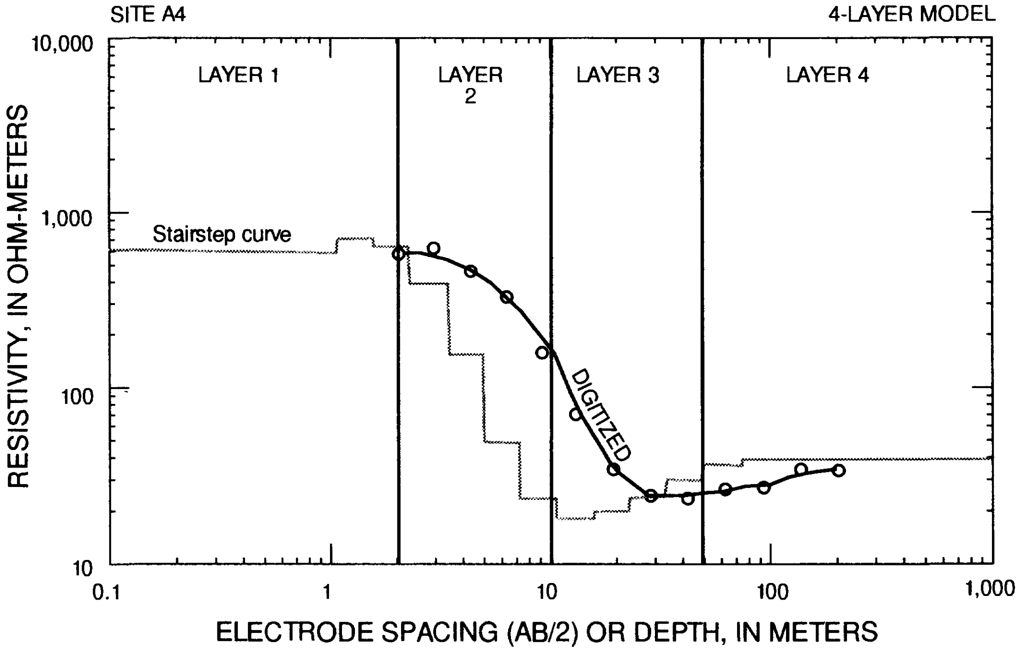
DEPTH	RESIS.	DEPTH	RESIS.
1.08	723.55	10.80	45.92
1.59	831.55	15.85	61.05
2.33	694.70	23.27	46.07
3.42	339.43	34.15	19.00
5.01	108.75	50.13	16.32
7.36	46.77	73.58	37.04
		99.00	97.34



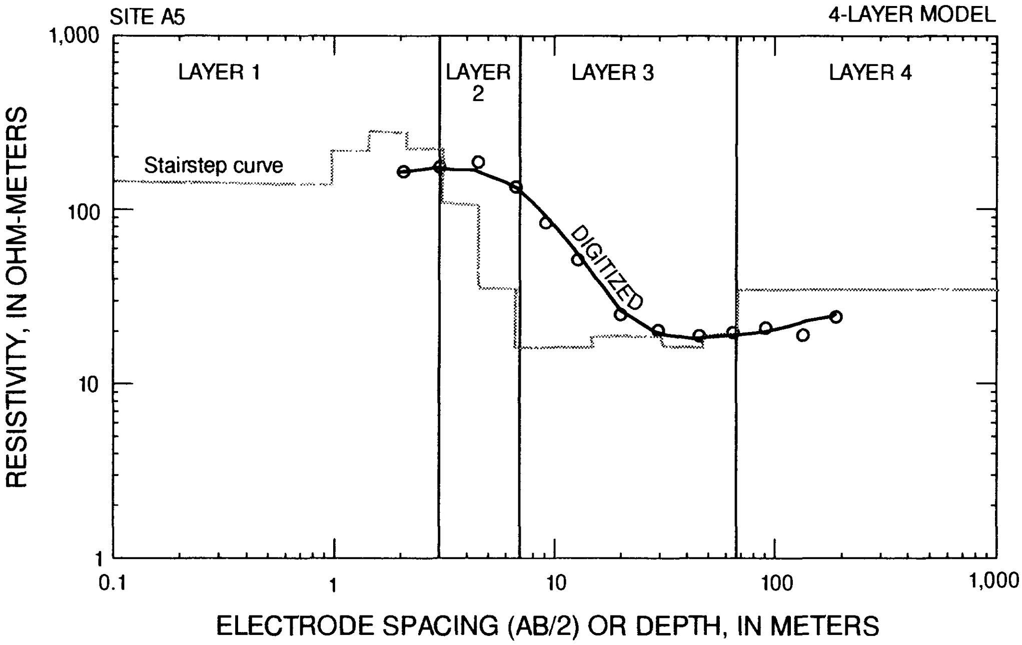
DEPTH	RESIS.	DEPTH	RESIS.
0.97	722.72	9.72	45.22
1.43	731.36	14.27	30.45
2.09	633.87	20.94	27.23
3.07	408.13	30.74	27.79
4.51	191.95	45.12	30.70
6.62	84.76	66.22	37.49
		99.00	48.47



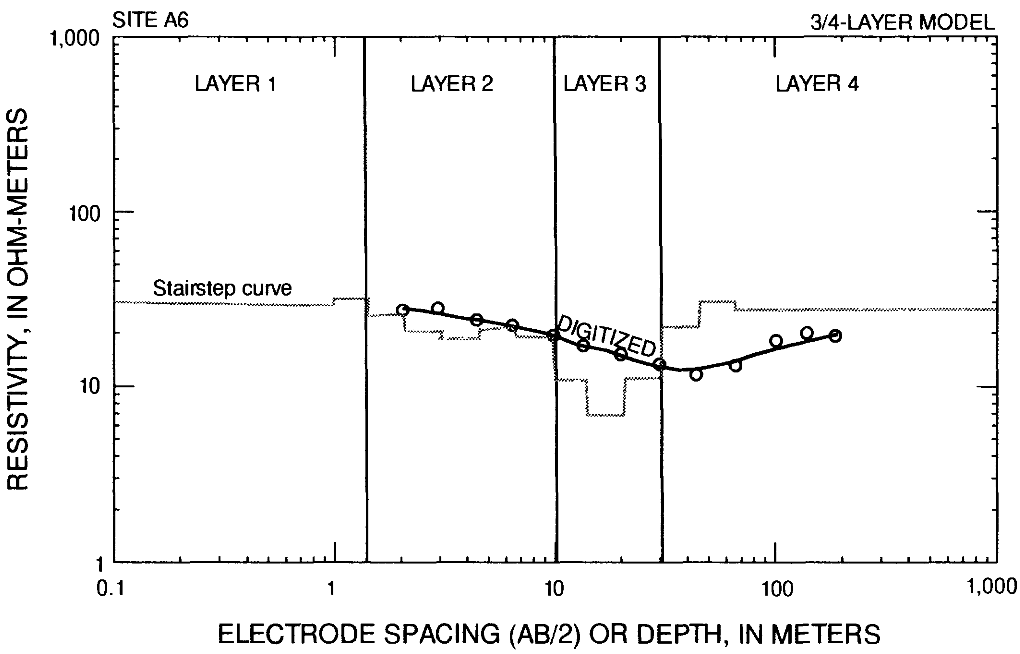
DEPTH	RESIS.	DEPTH	RESIS.
1.08	600.11	10.80	24.31
1.59	719.55	15.85	19.44
2.33	647.93	23.27	20.64
3.42	389.89	34.15	24.86
5.01	153.41	50.13	31.12
7.36	49.79	73.58	37.86
		99.00	41.29



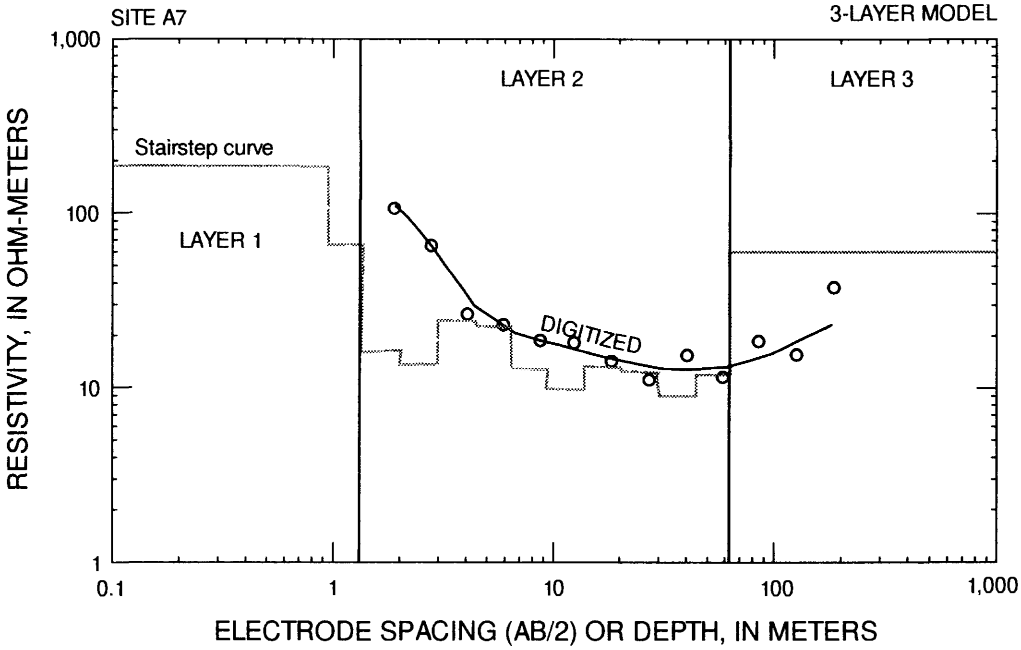
DEPTH	RESIS.	DEPTH	RESIS.
0.97	140.20	9.72	16.11
1.43	215.37	14.27	16.45
2.09	268.13	20.94	19.09
3.07	217.45	30.74	18.85
4.51	106.61	45.12	16.77
6.62	35.82	66.22	19.64
		99.00	34.83



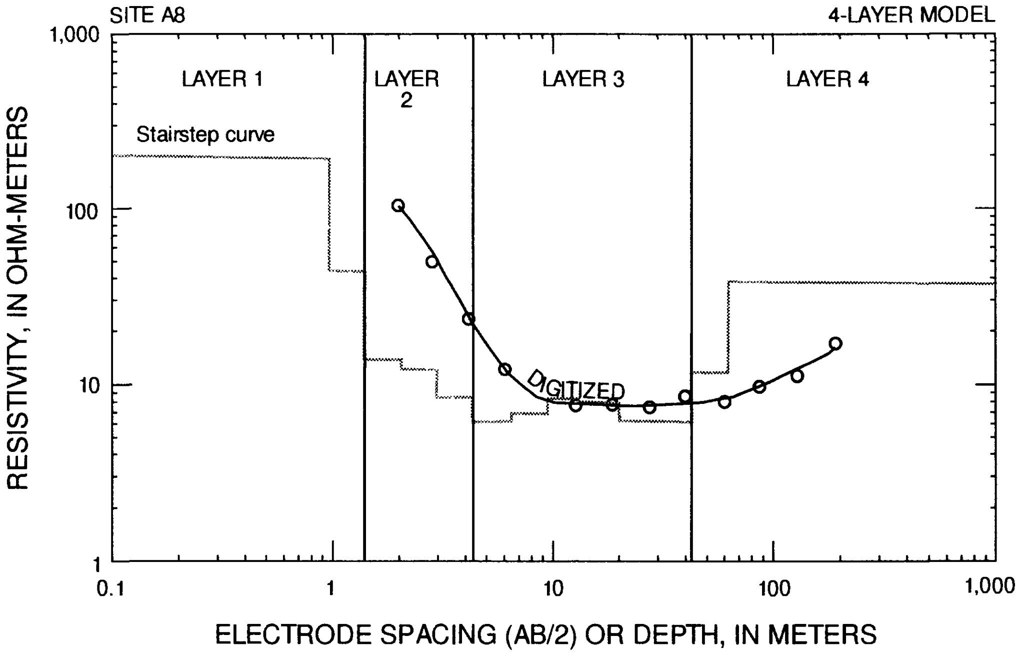
DEPTH	RESIS.	DEPTH	RESIS.
0.97	31.84	9.72	21.11
1.43	33.52	14.27	11.95
2.09	27.56	20.94	7.84
3.07	21.83	30.74	12.46
4.51	21.00	45.12	24.84
6.62	23.27	66.22	33.02
		99.00	27.37



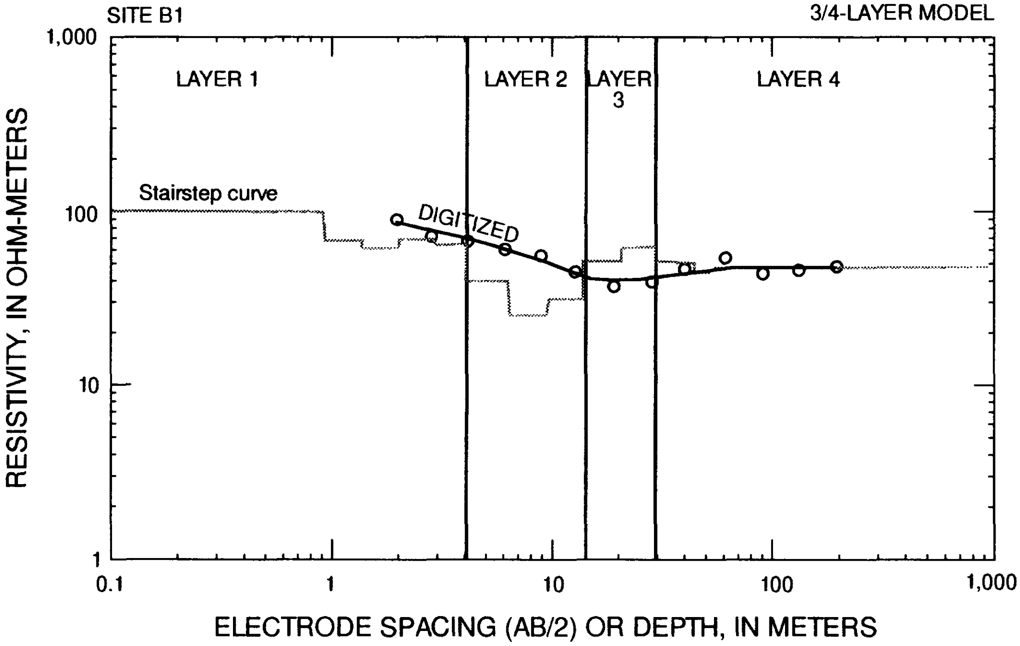
DEPTH	RESIS.	DEPTH	RESIS.
0.97	192.71	9.72	13.39
1.43	67.69	14.27	10.64
2.09	16.95	20.94	13.72
3.07	14.05	30.74	12.94
4.51	25.06	45.12	9.57
6.62	24.04	66.22	12.71
		99.00	62.55



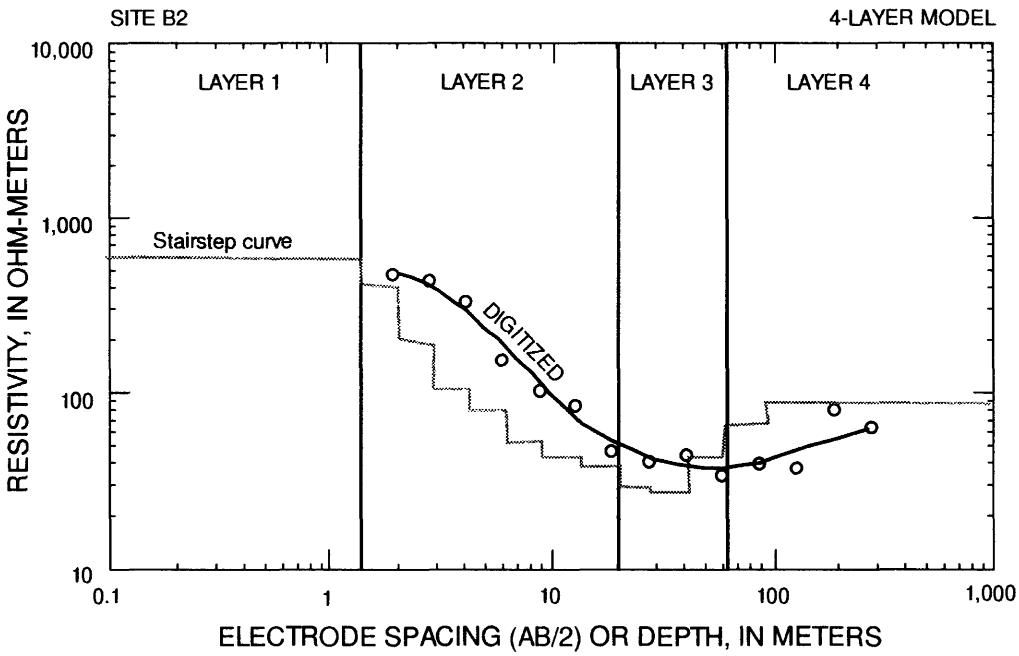
DEPTH	RESIS.	DEPTH	RESIS.
0.97	204.97	9.72	7.34
1.43	46.56	14.27	9.21
2.09	15.19	20.94	8.74
3.07	13.28	30.74	6.57
4.51	9.30	45.12	6.71
6.62	6.71	66.22	12.80
		99.00	37.70



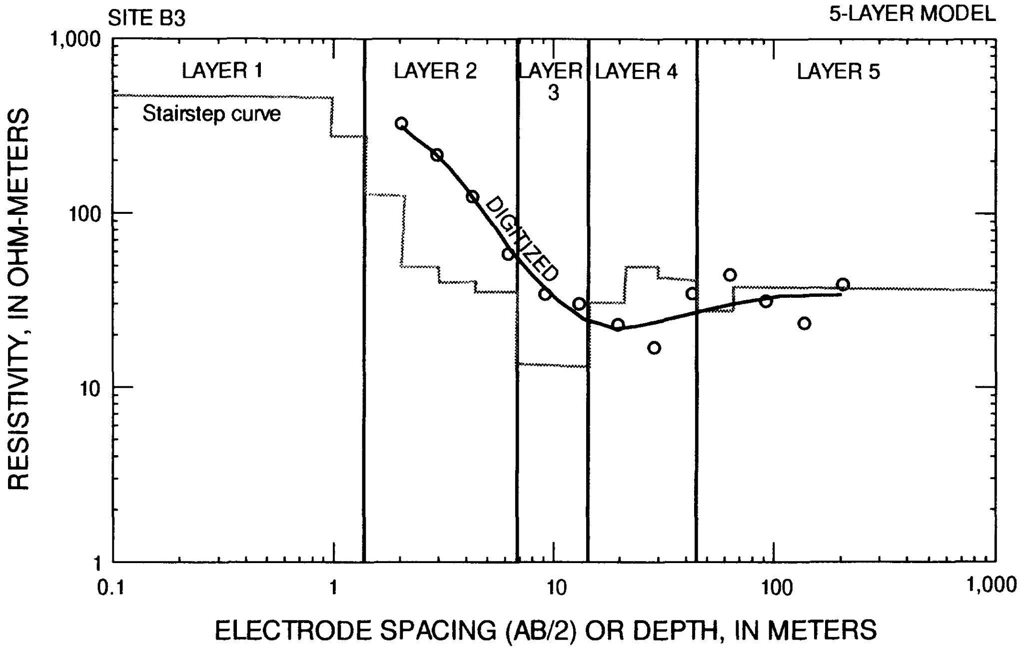
DEPTH	RESIS.	DEPTH	RESIS.
0.97	105.95	9.72	26.05
1.43	70.10	14.27	32.51
2.09	63.23	20.94	53.62
3.07	69.98	30.74	63.52
4.51	66.32	45.12	52.76
6.62	41.21	66.22	43.97
		99.00	48.33



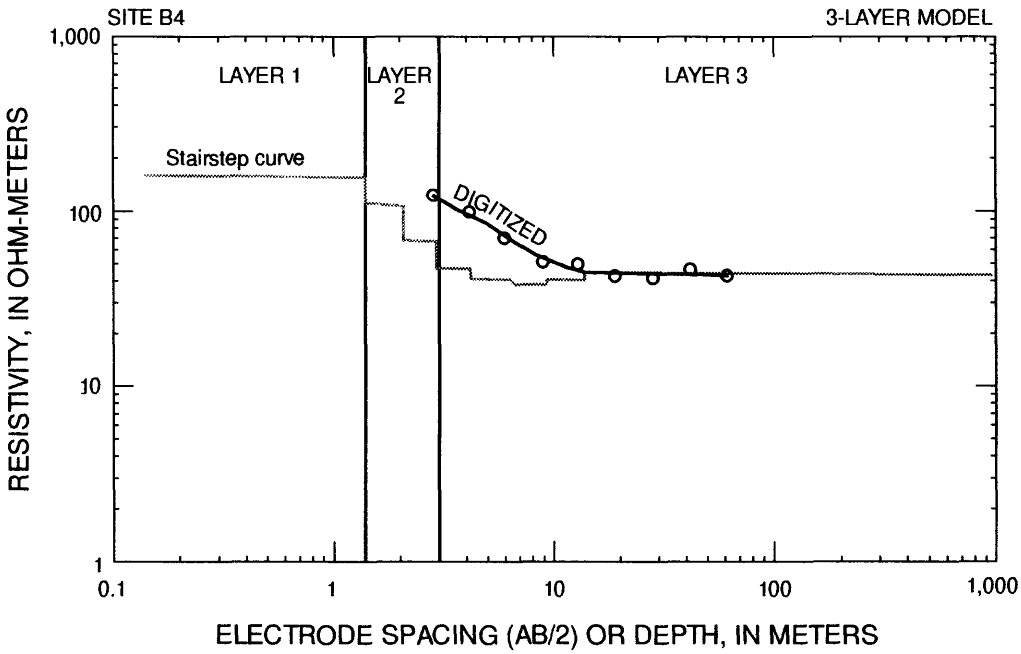
DEPTH	RESIS.	DEPTH	RESIS.
0.99	561.05	14.58	42.30
1.46	554.24	21.40	37.28
2.14	383.64	31.41	28.66
3.14	185.13	46.11	27.88
4.61	103.81	67.67	40.91
6.77	78.27	99.33	65.64
9.93	51.80	99.00	87.31



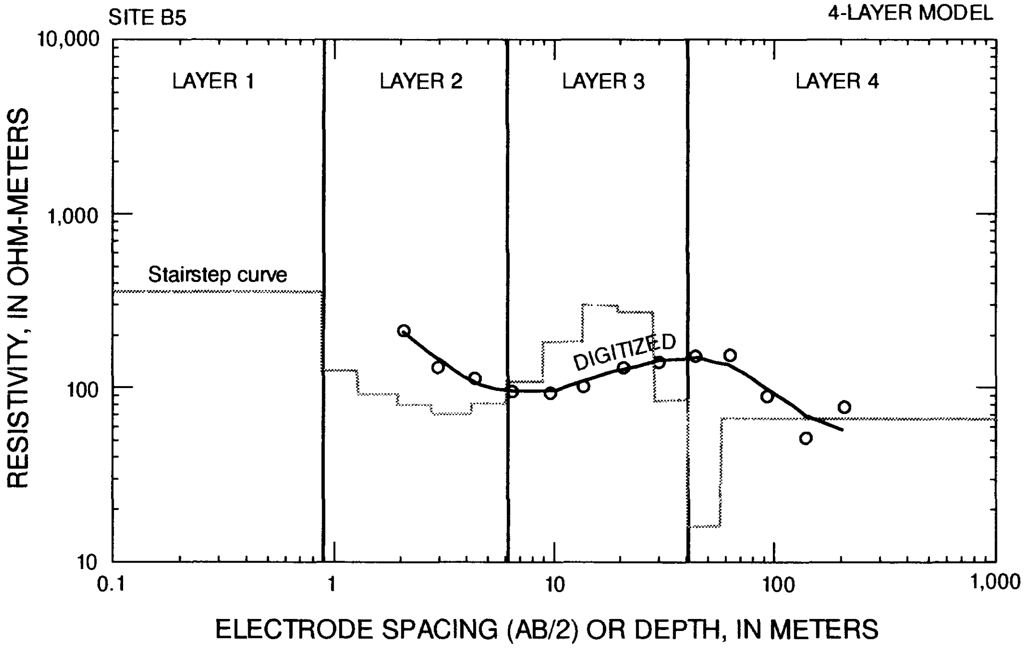
DEPTH	RESIS.	DEPTH	RESIS.
0.97	439.51	9.72	13.07
1.43	273.84	14.27	13.04
2.09	124.58	20.94	31.26
3.07	48.67	30.74	50.46
4.51	39.50	45.12	41.97
6.62	34.68	66.22	28.35
		99.00	36.41



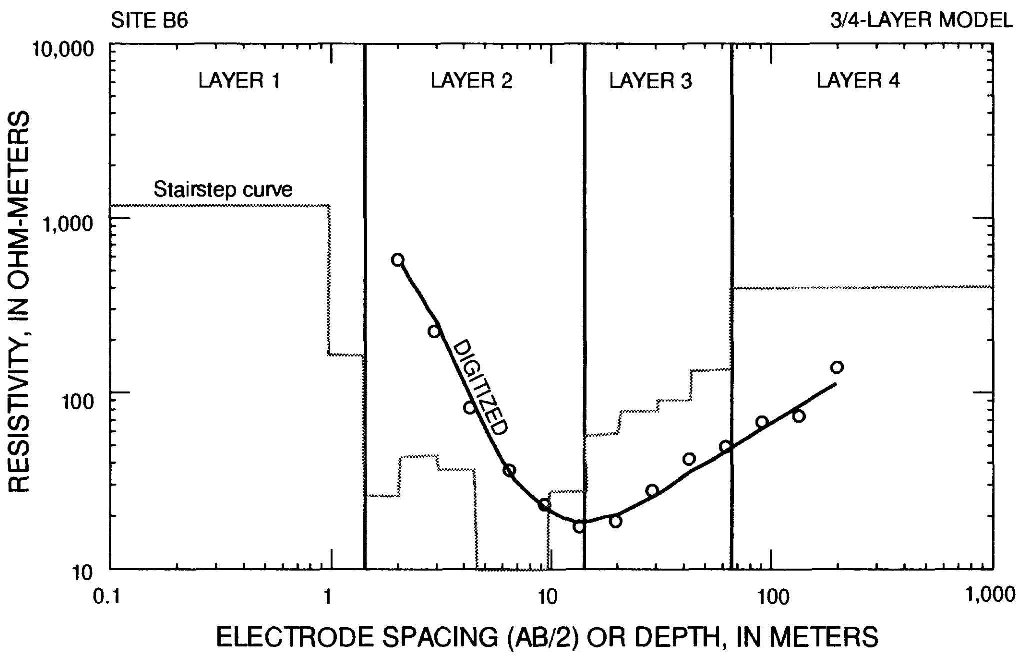
DEPTH	RESIS.	DEPTH	RESIS.
1.35	150.85	6.28	39.94
1.99	105.53	9.22	38.60
2.92	65.37	13.53	40.83
4.28	45.68	19.87	43.94
		99.00	44.00



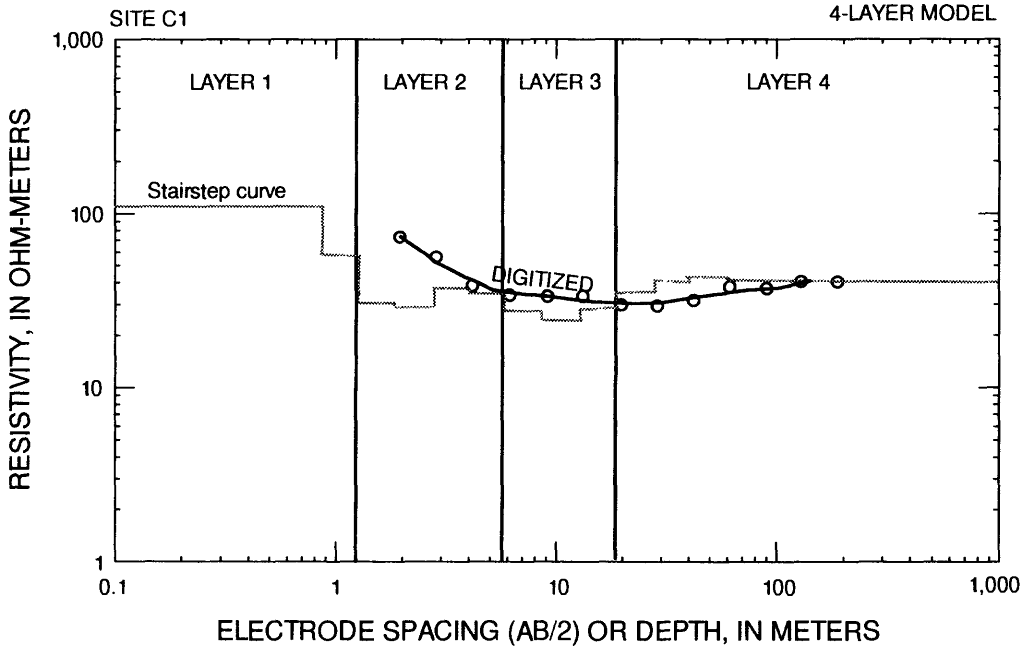
DEPTH	RESIS.	DEPTH	RESIS.
0.87	363.78	8.75	112.56
1.28	126.54	12.84	183.82
1.88	95.84	18.85	299.68
2.77	81.31	27.66	283.61
4.06	71.66	40.60	88.08
5.96	83.12	59.60	16.24
		99.00	66.59



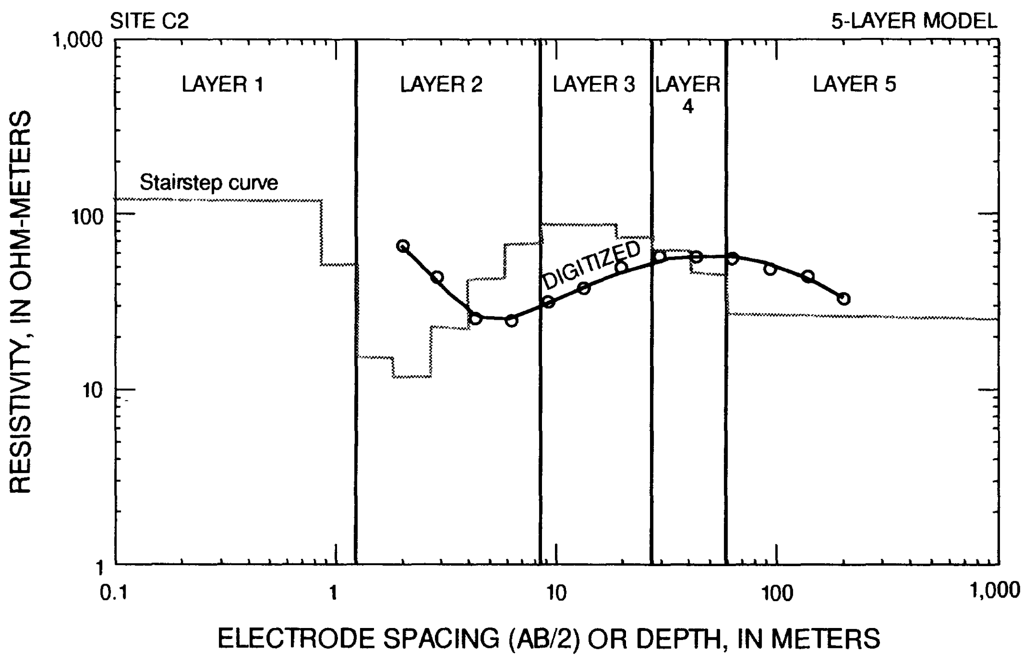
DEPTH	RESIS.	DEPTH	RESIS.
0.97	1252.88	9.72	9.57
1.43	167.88	14.27	27.06
2.09	27.40	20.94	57.74
3.07	45.79	30.74	81.09
4.51	38.17	45.12	92.19
6.62	8.44	66.22	137.07
		99.00	407.45



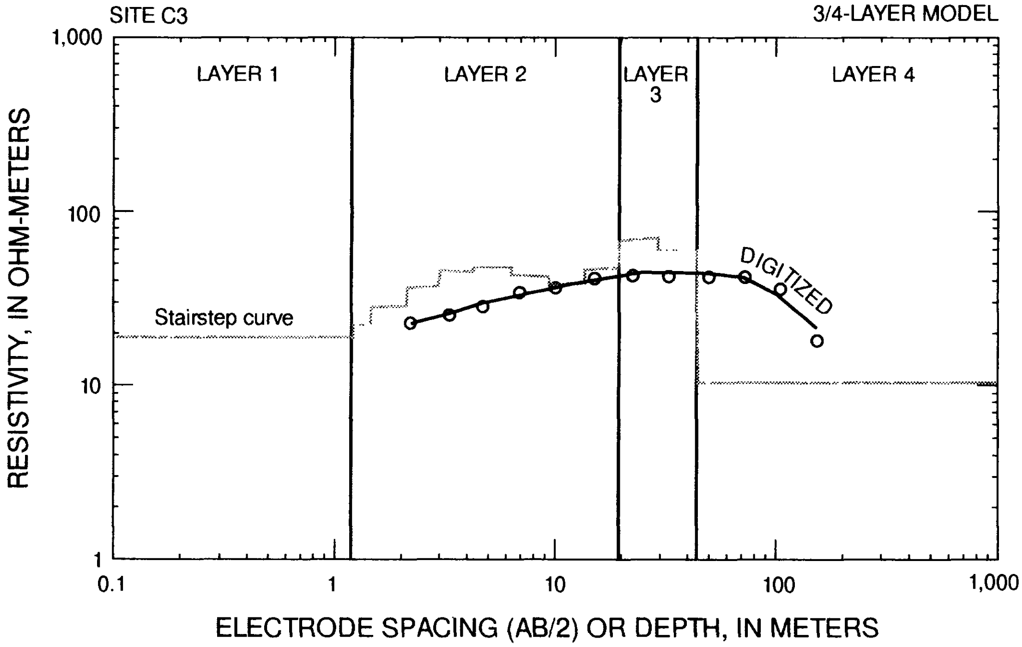
DEPTH	RESIS.	DEPTH	RESIS.
0.87	109.45	8.75	26.94
1.28	56.52	12.84	24.31
1.88	29.29	18.85	28.31
2.77	28.72	27.66	34.66
4.06	36.80	40.60	39.97
5.96	35.04	59.60	42.43
		99.00	41.37



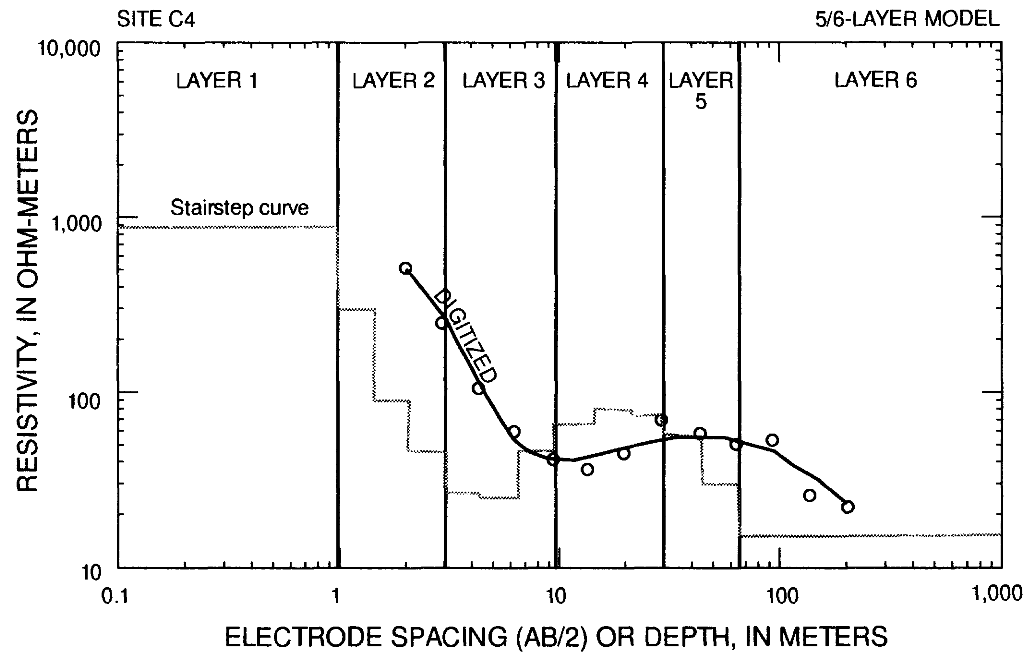
DEPTH	RESIS.	DEPTH	RESIS.
0.87	123.62	8.75	70.10
1.28	54.05	12.84	89.13
1.88	16.01	18.85	89.75
2.77	12.56	27.66	77.16
4.06	23.00	40.60	62.76
5.96	43.64	59.60	46.64
		99.00	27.07



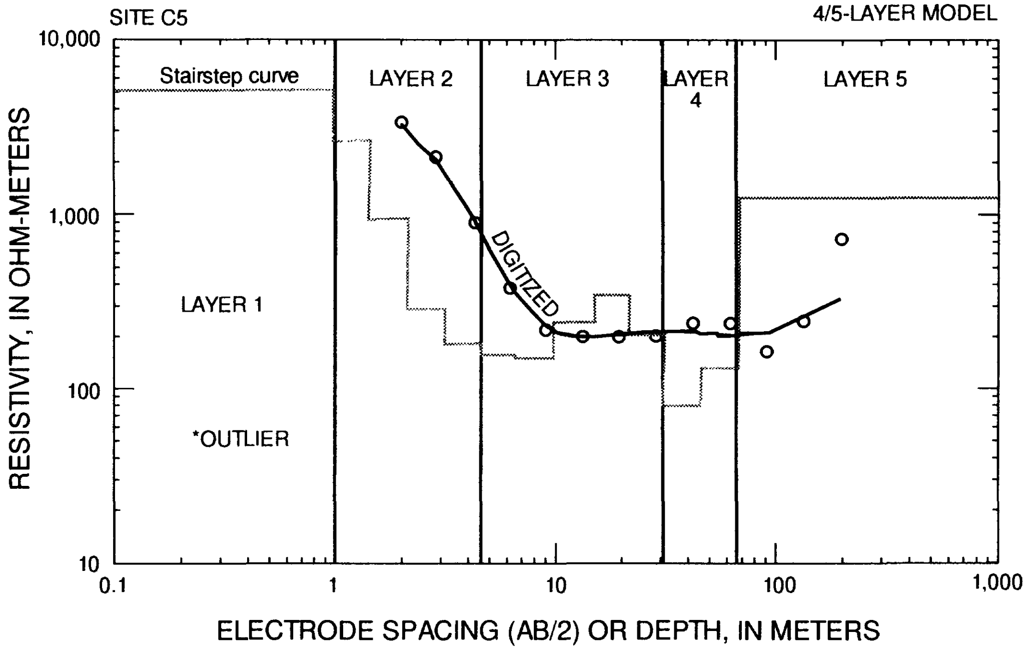
DEPTH	RESIS.	DEPTH	RESIS.
0.96	20.24	9.63	45.31
1.41	23.76	14.14	40.70
2.07	30.38	20.75	49.78
3.05	39.14	30.45	72.69
4.47	47.86	44.70	61.09
6.56	51.03	99.00	10.50



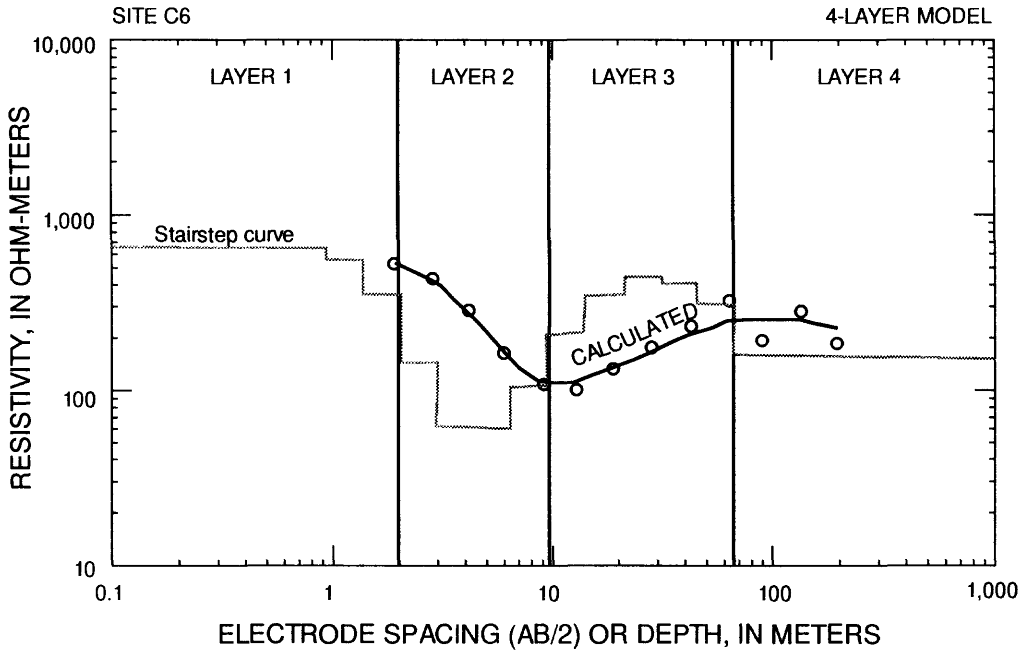
DEPTH	RESIS.	DEPTH	RESIS.
0.97	894.34	9.72	46.30
1.43	300.52	14.27	68.93
2.09	90.44	20.94	79.58
3.07	45.71	30.74	75.78
4.51	26.60	45.12	56.70
6.62	27.44	66.22	30.64
		99.00	15.40



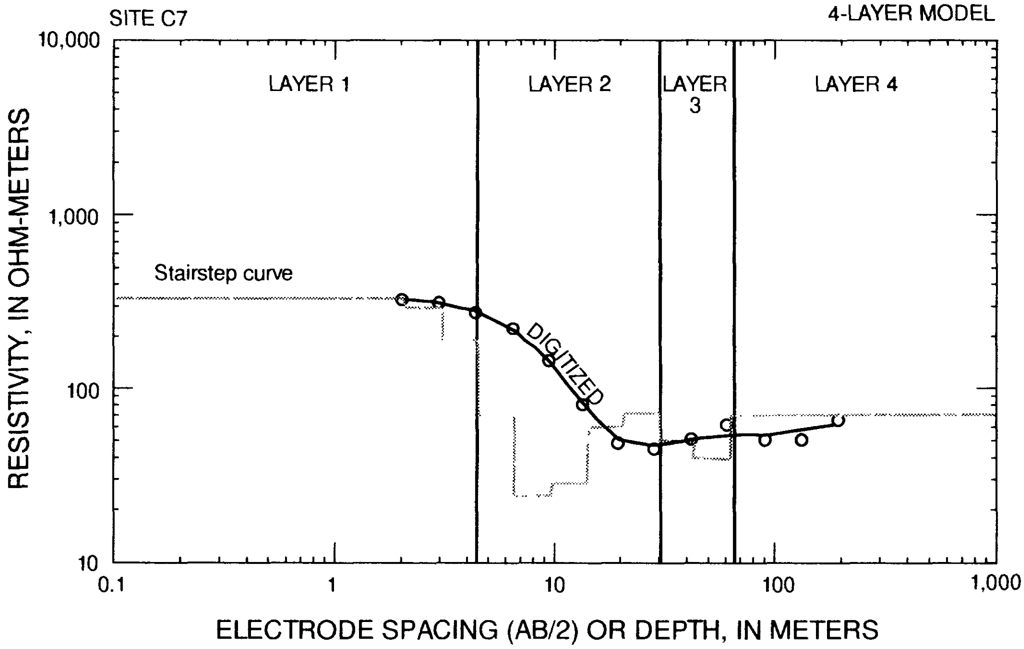
DEPTH	RESIS.	DEPTH	RESIS.
0.97	5208.73*	9.72	152.92
1.43	2832.80*	14.27	243.39
2.09	970.55	20.94	356.50
3.07	301.92	30.74	208.55
4.51	191.58	45.12	77.82
6.62	156.80	66.22	131.14
		99.00	1250.16*



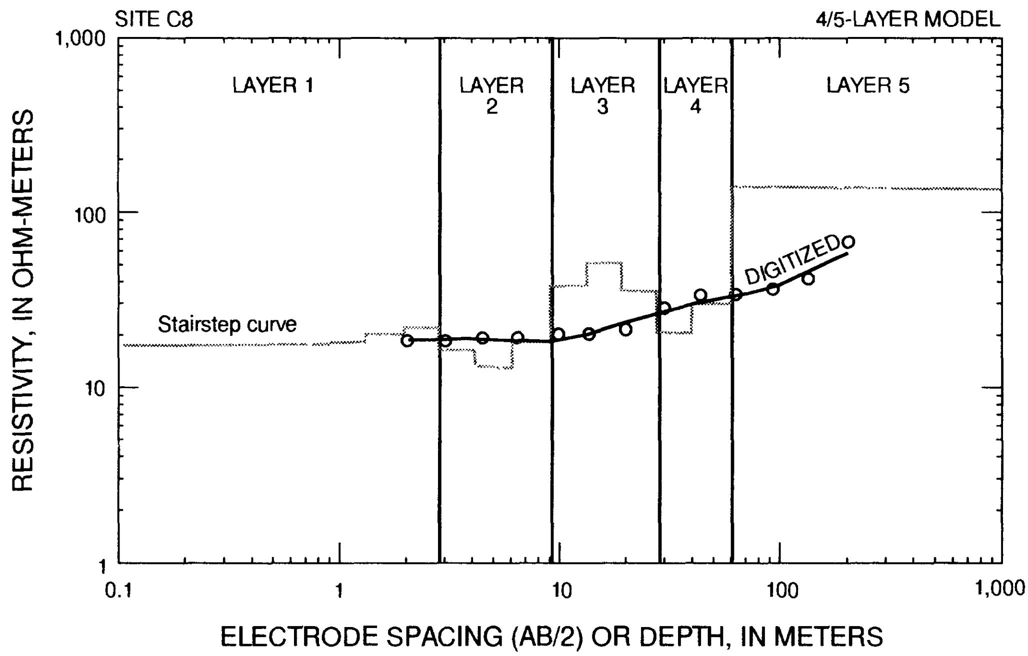
DEPTH	RESIS.	DEPTH	RESIS.
0.97	634.43	9.72	102.84
1.43	540.17	14.27	197.15
2.09	334.14	20.94	328.30
3.07	137.77	30.74	419.42
4.51	57.49	45.12	402.70
6.62	57.44	66.22	294.15
		99.00	149.28



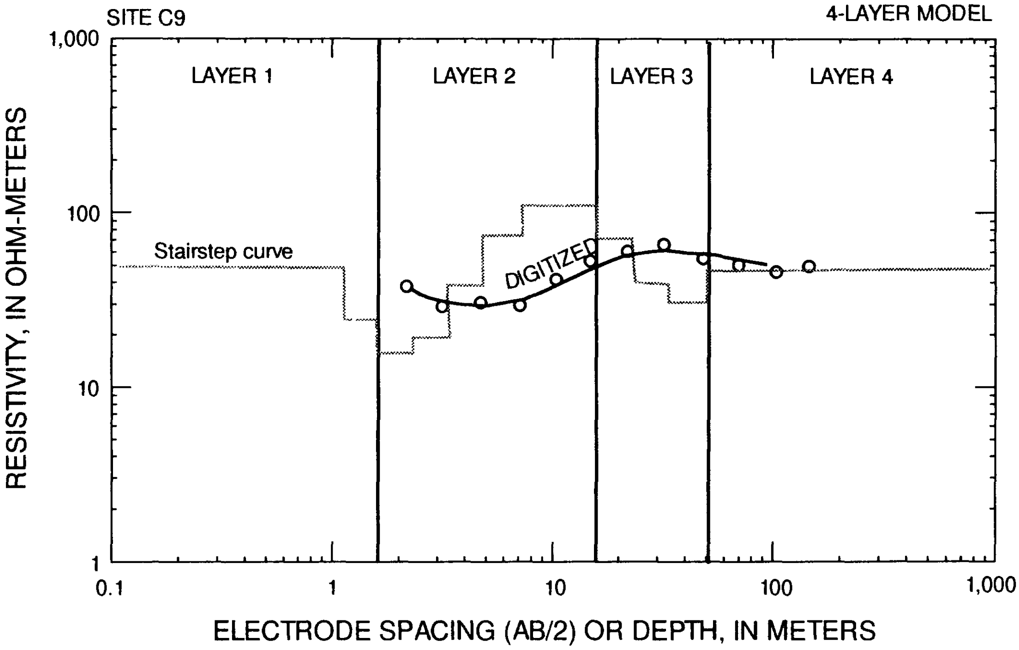
DEPTH	RESIS.	DEPTH	RESIS.
0.97	332.13	9.72	23.07
1.43	325.78	14.27	28.27
2.09	328.71	20.94	59.85
3.07	299.45	30.74	72.96
4.51	193.20	45.12	49.32
6.62	69.81	66.22	38.84
		99.00	71.07



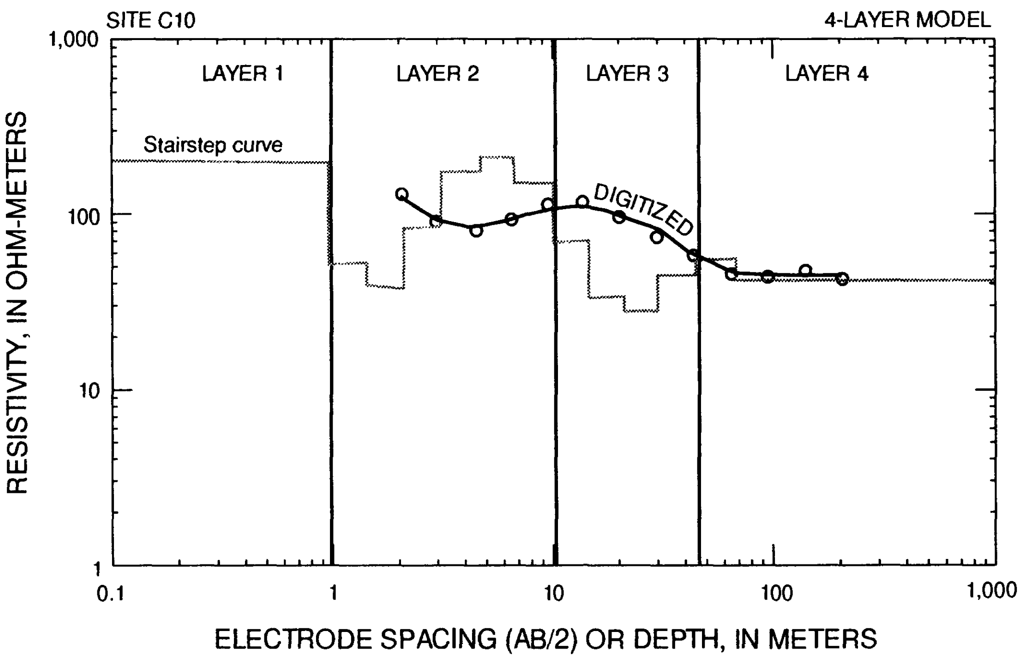
DEPTH	RESIS.	DEPTH	RESIS.
0.87	17.86	8.75	18.12
1.28	18.20	12.84	37.29
1.88	20.96	18.85	51.26
2.77	21.98	27.66	34.94
4.06	16.74	40.60	20.33
5.96	12.69	59.60	30.48
		99.00	144.09



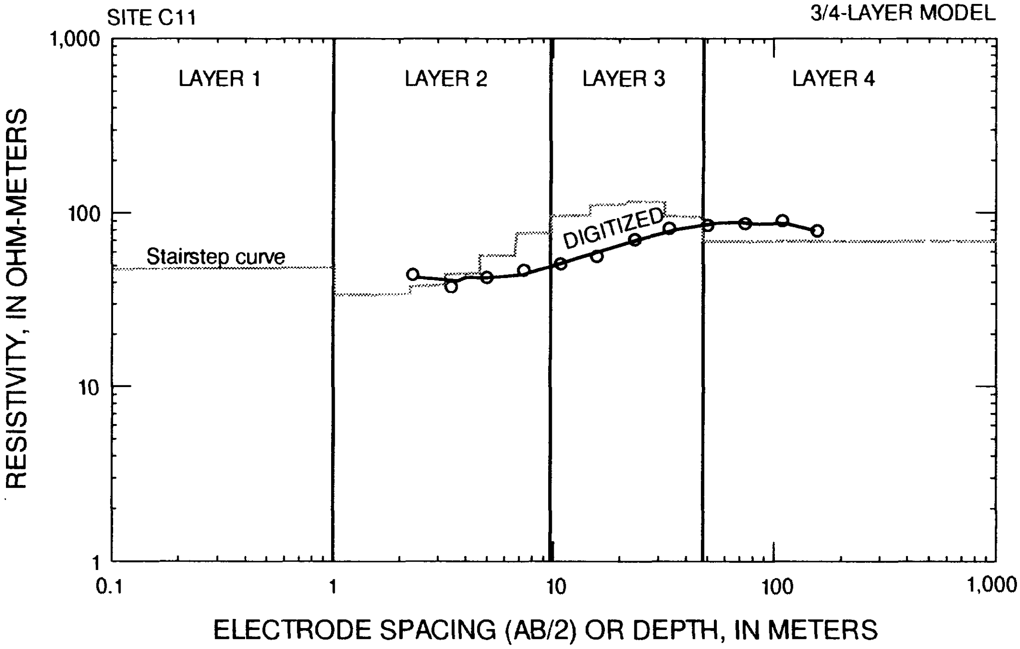
DEPTH	RESIS.	DEPTH	RESIS.
1.07	52.88	10.70	109.90
1.57	26.29	15.71	109.07
2.31	17.40	23.05	72.96
3.38	20.66	33.84	40.97
4.97	39.70	49.67	32.68
7.29	75.74	99.00	49.97



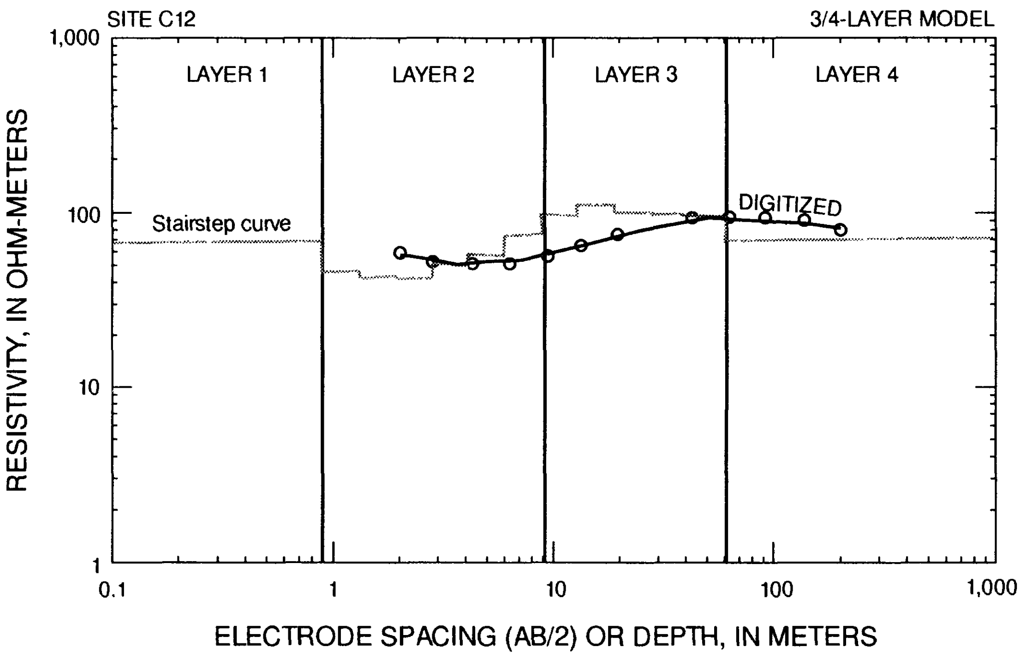
DEPTH	RESIS	DEPTH	RESIS
0.97	208.58	9.72	155.24
1.43	54.49	14.27	73.21
2.09	39.57	20.94	33.96
3.07	87.70	30.74	29.12
4.51	178.87	45.12	45.13
6.62	217.72	66.22	57.17
		99.00	43.04



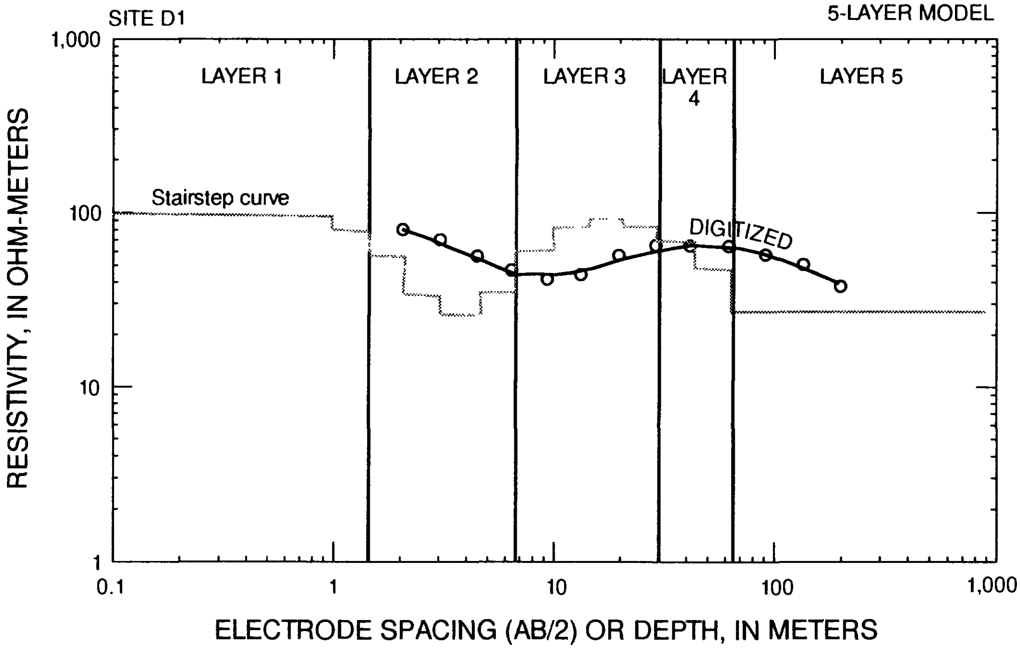
DEPTH	RESIS.	DEPTH	RESIS.
0.96	48.13	9.63	74.38
1.41	33.36	14.14	94.08
2.07	33.09	20.75	108.48
3.05	37.08	30.45	110.98
4.47	43.19	44.70	94.46
6.56	55.53	99.00	66.15



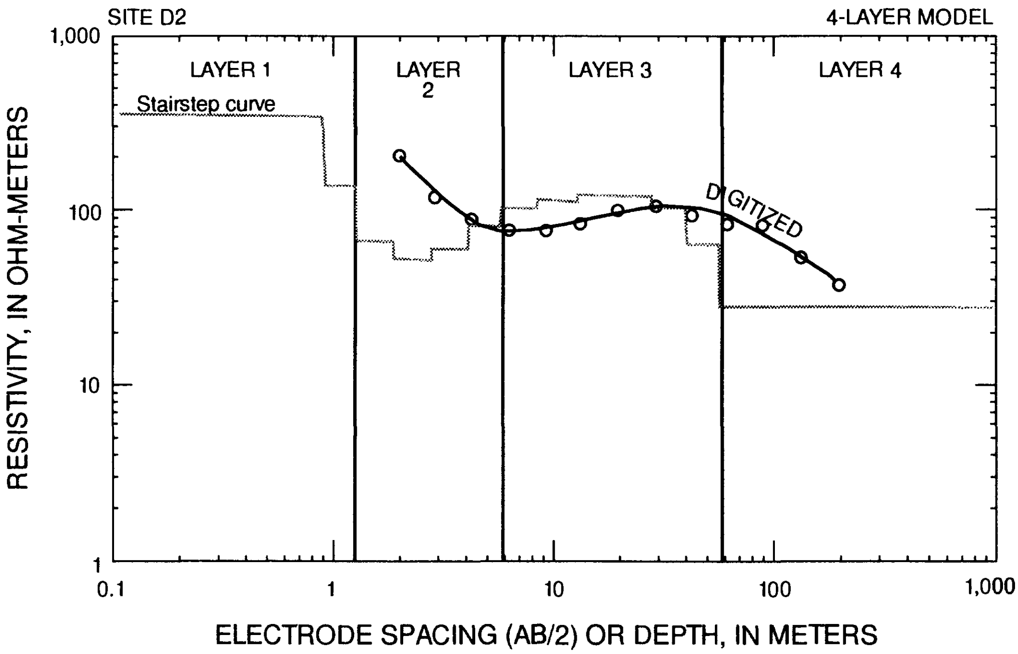
DEPTH	RESIS.	DEPTH	RESIS.
0.87	71.65	8.75	75.25
1.28	47.74	12.84	98.66
1.88	45.55	18.85	112.95
2.77	43.99	27.66	103.45
4.06	51.95	40.60	98.35
5.96	59.09	59.60	99.82
		99.00	70.02



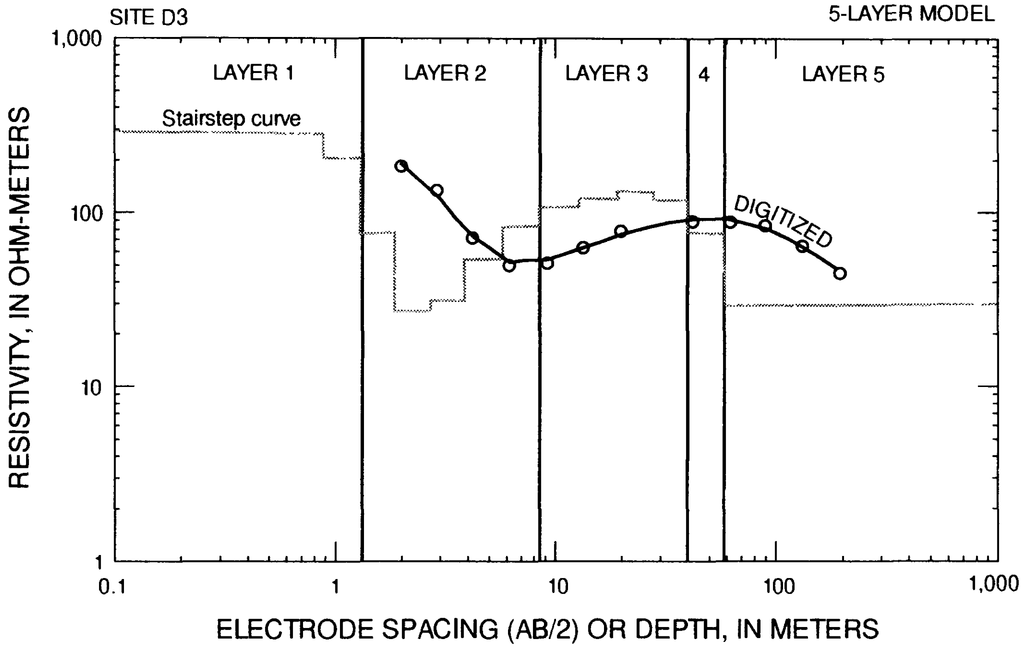
DEPTH	RESIS.	DEPTH	RESIS.
0.97	99.44	9.72	63.53
1.43	86.06	14.27	88.81
2.09	61.50	20.94	98.66
3.07	37.15	30.74	92.34
4.51	28.13	45.12	76.69
6.62	38.11	66.22	54.31
		99.00	30.56



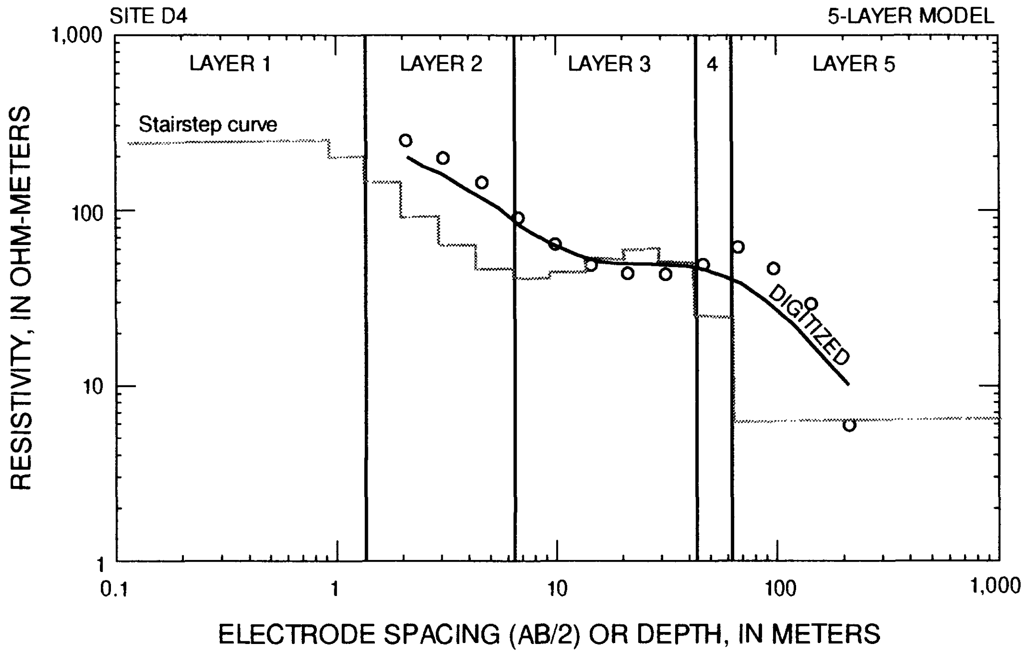
DEPTH	RESIS.	DEPTH	RESIS.
0.87	335.07	8.75	101.26
1.28	129.79	12.84	111.82
1.88	62.76	18.85	113.65
2.77	50.46	27.66	114.60
4.06	58.77	40.60	102.15
5.96	79.41	59.60	63.31
		99.00	27.66



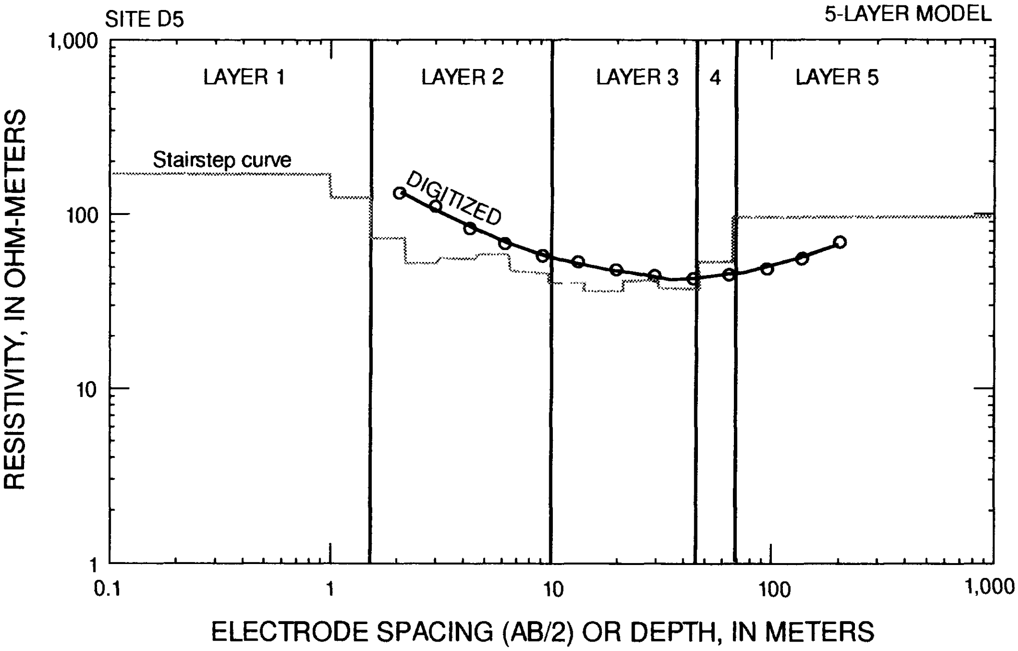
DEPTH	RESIS.	DEPTH	RESIS.
0.87	306.30	8.75	88.72
1.28	224.89	12.84	113.04
1.88	82.49	18.85	129.13
2.77	29.16	27.66	139.73
4.06	32.56	40.60	128.84
5.96	57.43	59.60	80.59
		99.00	31.51



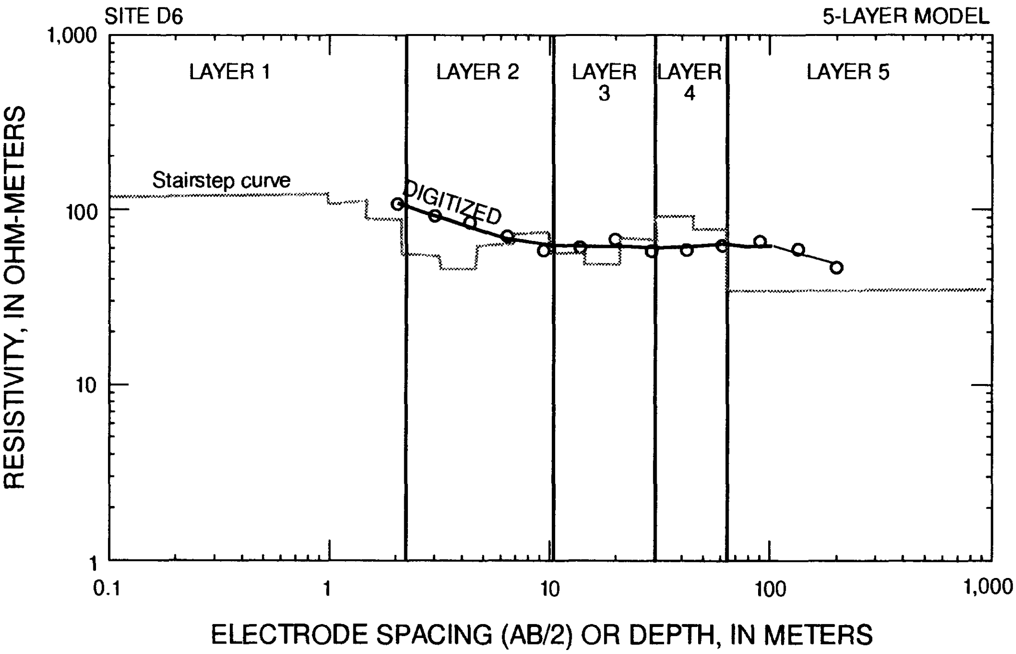
DEPTH	RESIS.	DEPTH	RESIS.
0.87	270.65	8.75	45.78
1.28	219.42	12.84	49.01
1.88	158.06	18.85	58.22
2.77	104.88	27.66	65.23
4.06	70.05	40.60	55.74
5.96	51.81	59.60	26.79
		99.00	6.77



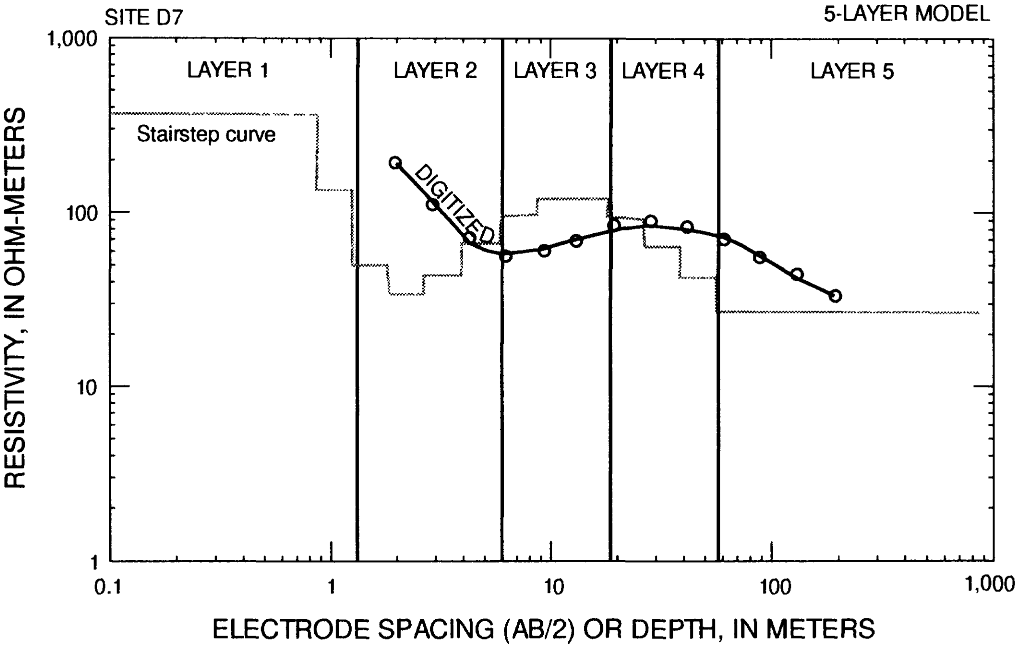
DEPTH	RESIS.	DEPTH	RESIS
0.97	168.26	9.72	47.13
1.43	125.27	14.27	42.21
2.09	74.52	20.94	36.98
3.07	55.12	30.74	41.57
4.51	57.19	45.12	38.57
6.62	57.87	66.22	54.02
		99.00	100.10



DEPTH	RESIS.	DEPTH	RESIS.
0.97	125.98	9.72	73.53
1.43	113.24	14.27	56.45
2.09	89.24	20.94	50.01
3.07	56.84	30.74	67.59
4.51	47.83	45.12	93.00
6.62	65.31	66.22	79.25
		99.00	35.18



DEPTH	RESIS.	DEPTH	RESIS.
0.87	336.84	8.75	93.30
1.28	128.72	12.84	114.49
1.88	46.94	18.85	113.04
2.77	32.20	27.66	90.50
4.06	41.87	40.60	63.46
5.96	64.47	59.60	41.77
		99.00	27.18



DEPTH	RESIS.	DEPTH	RESIS.
0.87	301.05	8.75	60.81
1.28	208.48	12.84	71.64
1.88	90.38	18.85	81.24
2.77	36.43	27.66	97.73
4.06	29.64	40.60	104.55
5.96	42.91	59.60	66.29
		99.00	17.53