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HYDROGEOLOGY OF THE SHALLOW AQUIFER SOUTH OF NAPLES, COLLIER COUNTY

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HYDROGEOLOGY OF THE SHALLOW AQUIFER

SOUTH OF NAPLES, COLLIER COUNTY

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ABSTRACT

The Shallow Aquifer south of Naples, Collier County, consists of a series of sands, sandstones, and limestones extending from land surface to approximately 200 feet below ground level. The base of the aquifer is a clayey layer of variable but low permeability which confines groundwater in an underlying aquifer. The most permeable part of the aquifer consists of limestone between about 20 to 50 feet below ground. In places, a semi-confining zone of clayey and calcareous strata at a depth of about 8 feet separates the main producing zone from overlying sands. The transmissivity of the aquifer determined from pumping tests ranges from about 230,000 to 290,000 gpd/ft. The storage coefficient varies from about 0.0005 to 0.003. The coefficient of leakance varies from 0.40 to 5.73 gpd/ft^3.

Water quality in the aquifer varies widely. The depth to the saltwater/freshwater interface (defined as the 250 mg/l isochlor) averages approximately 60 feet below land surface. The saline water that lies at the bottom of the aquifer may be the result of direct intrusion of sea water from the Gulf of Mexico, relict sea water from wave inundations, or upward leakage of water from the underlying artesian aquifer.

Good quality groundwater can be developed at shallow depths throughout the area. Major wells and wellfields should preferably be sited north of Route 41, where individual wells can produce up to 500 gallons per minute without deleterious effects. Individual domestic wells for small withdrawals may be developed throughout the area.

ACKNOWLEDGEMENTS

This report was prepared under the direction of Mr. Abe Kreitman, Director of the Groundwater Division of the South Florida Water Management District, to whom the author is most grateful for his support. Gratitude is also expressed to the staff of the Groundwater Division for technical assistance throughout the course of this study. Thanks are extended to the residents of the study area for allowing access to many of the well sites, and to Mr. Fred Vidzes and Mr. Jay Samples for their help in obtaining well construction permits. The study was completed under the supervision of Dr. Leslie A. Wedderburn, Supervising Hydrogeologist, South Florida Water Management District.

INTRODUCTION

Purpose and Scope

The purpose of this study is to define the hydrogeologic properties of the shallow aquifer in an area south of Naples, Florida, bordering U.S. Route 41. The study area is presently undergoing rapid urban and agricultural growth with accompanying increases in water demand. The existing hydrogeologic information is insufficient to quantify the available groundwater resources or to develop a framework for its optimal utilization and management.

The objectives of this study were to:

(1) define the vertical and horizontal extent of the shallow aquifer;

(2) determine the hydraulic properties of the aquifer;

(3) evaluate the groundwater quality with special emphasis on the relationship between fresh and saline groundwater; and

(4) provide a preliminary assessment of groundwater availability with suggestions for development and management.

The area of investigation encompasses approximately 65 square miles and extends from County Route 864 on the north to Collier-Seminole State Park on the south (Figure 1). The depth of investigation was approximately 200 feet. A thorough review of the available hydrogeologic information was supplemented by exploratory well drilling and geologic and geophysical logging. In addition, water levels and quality were monitored and aquifer pumping tests performed. From the data obtained, descriptions were made of the lithology, hydraulic properties, water quality distribution, and surface water-groundwater relationships. In the final section of this report, the groundwater development potential of the area is discussed.

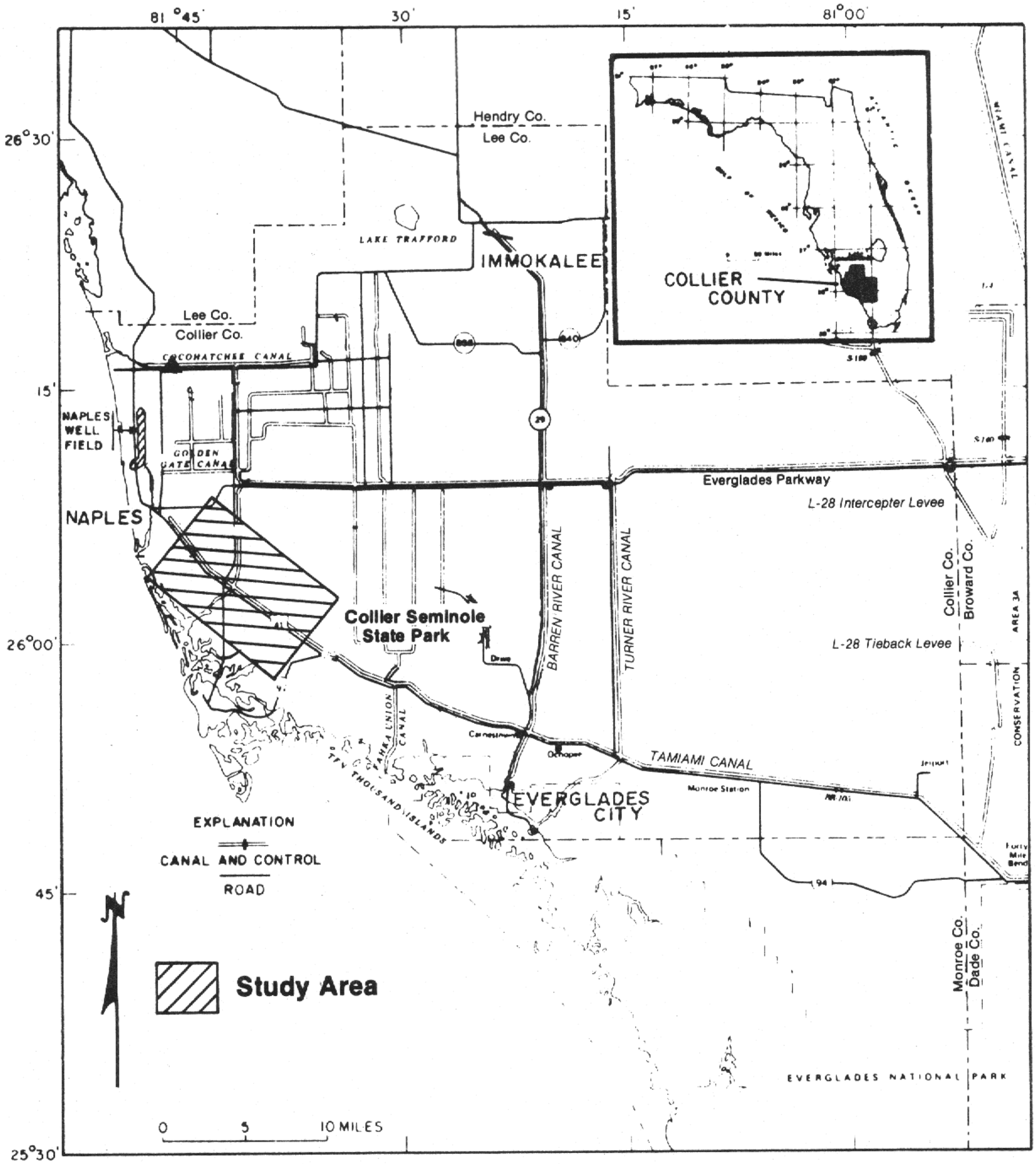


Figure 1. LOCATION MAP OF STUDY AREA

Previous Investigations

During the last thirty years, the U. S. Geological Survey conducted several investigations of the shallow aquifer in the Greater Naples Area. Special emphasis has been on the shallow, coastal ridge aquifer which is utilized by the city of Naples for its water supply. These investigations have provided stratigraphic and hydrogeologic definition within the Naples area. Studies by Klein (1954) and McCoy (1962 and 1972) described the shallow aquifer away from the coastal ridge as having a limited supply potential due to poor water quality. Recent site-specific studies conducted principally by Missimer and Associates, Inc. (1978 and 1980) and Gee and Jenson, 1980, within the study area and to the north have added significantly to the degree of hydrogeologic and stratigraphic knowledge of the area. Preliminary work by Meeder (1979) identified a reef structure that appears to extend into the study area from the north. This structure may have major hydrogeologic significance within all of western Collier County. Recent DC resistivity investigations by Stewart et al. (1982) and Layton et al. (1982) have added considerably to knowledge of the lithology and saltwater/freshwater relationships in the area.

HYDROLOGIC ENVIRONMENT

Although this study focused mainly on the hydrogeologic properties of the rocks in the study area, a number of other factors affected both the availability and demand for water. Probably the most important of these factors is the areal and temporal distribution of rainfall. The average annual rainfall over the study area is about 53 inches (South Florida Water Management District, 1981). Approximately 65 percent of the annual rainfall occurs during the wet season (June through September) due mainly to local convective storms. Approximately 20 percent of the annual rainfall occurs during the dry season (November through April) due mainly to frontal systems from northern latitudes. The months of May and October are considered transitional and account for the remaining 15 percent of rainfall.

Extreme rainfall events caused by tropical storms and hurricanes have historically been major considerations affecting water managment schemes in south Florida. Depending on shoreline configuration, off-shore depth, wind direction, and degree of tidal synchronization with the approach of hurricane force winds, surges of sea water may result to elevations of 20 feet or more. Since much of western Collier County has topographic elevation of less than 15 feet above National Geodetic Vertical Datum of 1929 (NGVD), periodic inundations of parts of the area probably occur.

Topography and vegetation are two other important aspects of the hydrologic environment. Slight differences in the land surface elevation can determine the native vegetation and the depth of the freshwater/saltwater interface. Low elevation and dense vegetative cover are contributing factors to the loss of water from the area by evapotranspiration. Natural vegetation within the area ranges from cypress and pine in higher elevations, to mangrove swamps along the coast.

Land use practices also have a significant impact on the hydrologic regime. Within the study area, land use trends are directed toward suburban residential and agricultural development. These land uses increase water demand and the potential for groundwater pollution. Drainage channels which lower groundwater levels on adjacent land and facilitate residential and agricultural development have a detrimental effect on groundwater availability and quality.

Because of the generally warm climate, high water levels, and extensive bodies of shallow surface water, evaporative and transpirative losses are generally high. These losses account for approximately 60 percent of average annual rainfall (Burgess, personal communication, SFWMD).

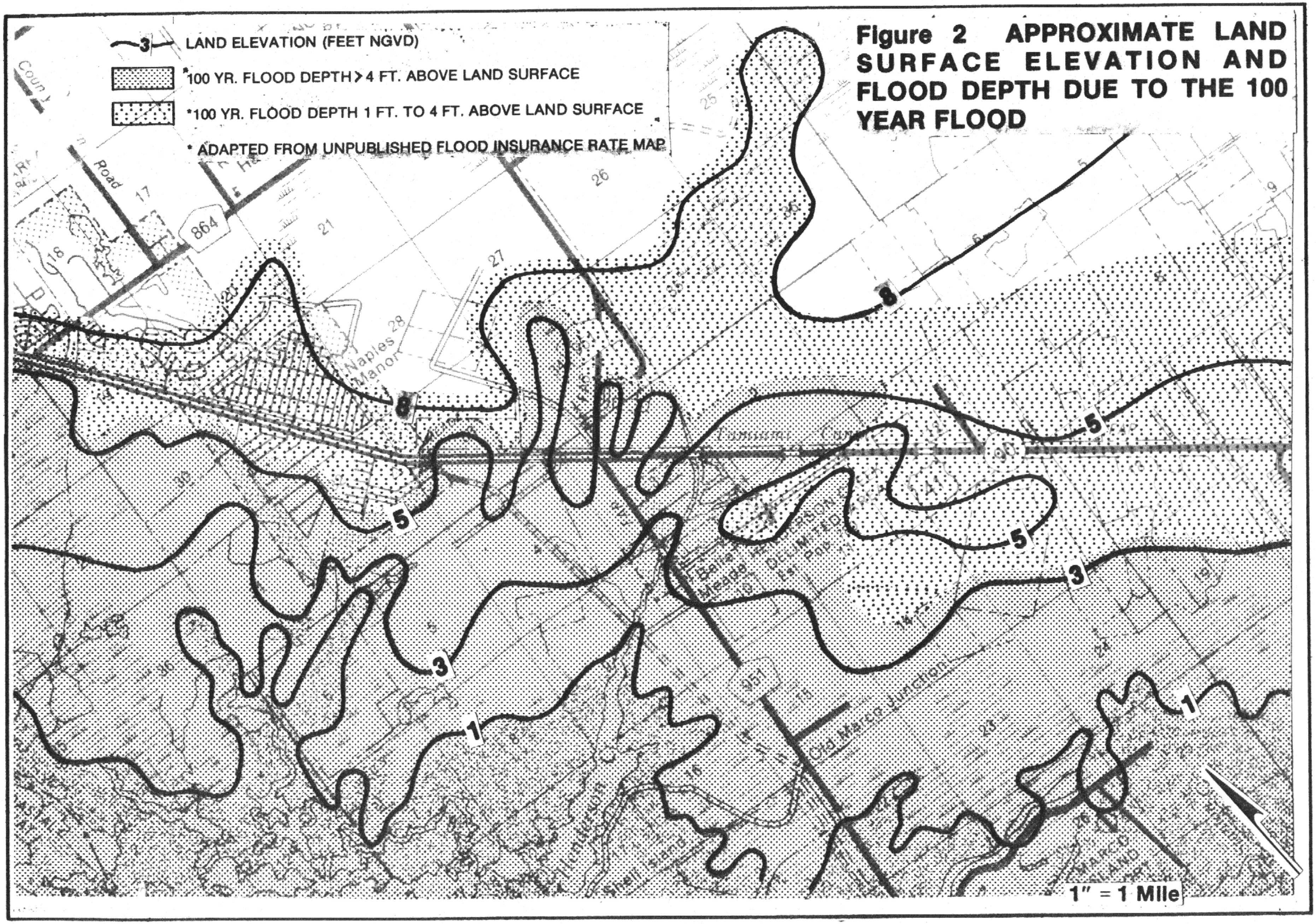
PHYSIOGRAPHY AND GEOLOGIC SETTING

Collier County is situated on the south-southwestern margin of the Florida Peninsula. In Collier County, about 13,000 feet of sedimentary rocks overlie a crystalline rock basement (Applin and Applin, 1965). This sequence of sedimentary rocks is the result of more than 100 million years of nearly continuous marine deposition on a gradually subsiding platform. White (1970) classified the study area physiographically as being part of the Southern or Distal zone, which is characterized by a broad, flat, gently-sloping and poorly-drained plain.

Ground surface elevations in the study area range from sea level to about 10 feet above NGVD along the northeastern boundary of the study area (Figure 2). Several natural depressions lie in a northeast to southwest orientation; the dominant topographic slope however is towards the southwest and the coastline of the Gulf of Mexico.

The sediments of the shallow aquifer range in age from Miocene to Pleistocene. The oldest formation is the Hawthorn Formation of Miocene age. Parker et al. (1942) described this formation as a sandy, phosphatic marl interbedded with clay, shell, and silt, containing beds of flattened, well-worn quartzite and phosphate pebbles half an inch or more in diameter. Overlying the Hawthorn Formation is the Tamiami Formation, described by Parker as a cream, white, and greenish-gray clayey marl with silty and shelly sands and shell marl, locally indurated to limestone. Since it was first described by Parker as Miocene, the Tamiami Formation has also been placed in the Pliocene, and in both by some investigators. The boundary between the Tamiami Formation and the underlying Hawthorn Formation is still a matter of controversy. For the purpose of this report, the top of the Hawthorn Formation is considered to be the green-gray, silty clays which occur at depths between 150 and 220 feet in the study area.

Figure 2 APPROXIMATE LAND SURFACE ELEVATION AND FLOOD DEPTH DUE TO THE 100 YEAR FLOOD



The surficial deposit which overlies the Tamiami Formation is referred to as the Pamlico sand or Pamlico Formation. Parker et al. (1942) described this formation as a very fine to coarse quartz sand, white to black or red in color, depending upon the nature of staining materials. In the study area, this formation is a terrace sand, formed when the sea level stood approximately 25 feet above the present mean sea level (Cooke, 1945). Other terraces formed at higher elevations are found in northeastern Collier County and in central Florida.

METHODS OF INVESTIGATION

The methods used in this investigation include a literature survey, an inventory and collection of data from existing wells, exploratory well drilling, geologic and geophysical logging, and aquifer testing. Initial field activity included depth measurement and water quality sampling of selected private wells (see Figure 3 for well locations); Table 1 presents data on well construction and water quality for these wells. Samples were analyzed in the field for chloride ion content with a field titration kit or tested for their specific conductance with a portable meter. Based on the literature survey and the initial well inventory, an exploratory well-drilling program was designed and implemented. Locations of exploratory wells are shown on Figure 4; Table 2 provides data on well completion and well dimensions. The drilling program consisted initially of 6 wells, 4 of which (Wells C-2002D, C-2003D, C-2004D, and C-2005D) were approximately equally distributed throughout the study area and drilled to the bottom of the aquifer as established by the presence of a clay layer which marks the top of the Hawthorn Formation. To locate the saltwater/freshwater interface in more seaward locations, the remaining two wells (C-2006D and C-2007D) were drilled to depths of 70 feet. Near five of the wells in this initial series,

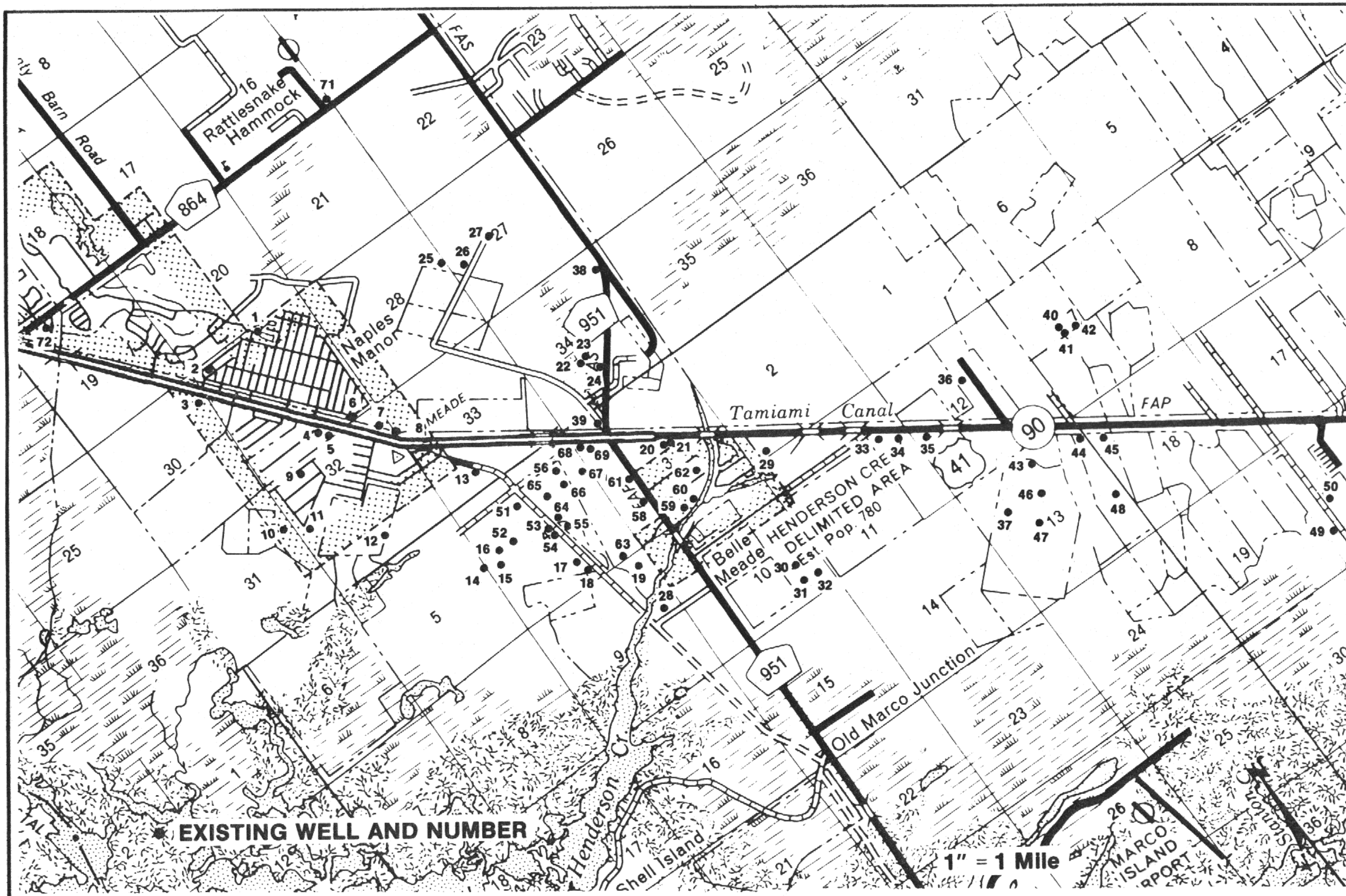


Figure 3 EXISTING WELLS INVENTORIED AND SAMPLED FOR WATER QUALITY

WELL NUMBER	WELL DEPTH IN FEET	CHLORIDE CONTENT in mg/l or SPECIFIC CONDUCTANCE in umhos/cm	WELL NUMBER	WELL DEPTH IN FEET	CHLORIDE CONTENT in mg/l or SPECIFIC CONDUCTANCE in umhos/cm	WELL NUMBER	WELL DEPTH IN FEET	CHLORIDE CONTENT in mg/l or SPECIFIC CONDUCTANCE in umhos/cm
1(a)	42	134	26	66	190	51(b)	44	220
2(a)	32	174	27	16	83	52(b)	40	300
3	42	144	28(a)	16	760	53(b)	21	220
4(a)	83	172	29(a)	28	156	54(b)	50	230
5(a)	33	130	30	38	80	55(b)	45	380
6(a)	32	130	31	39	160	56(b)	30	120
7(a)	34	56	32	31	182	58(b)	65	2600
8(a)	32	82	33	42	132	59(b)	40	300
9(a)	25	68	34	37	135	60(b)	40	240
10(a)	27	78	35	39	84	61(b)	63	440
11(a)	30	88	36	48	182	62(b)	34	260
12(a)	30	890	37	42	213	63(b)	12*	460
13	48	243	38	30	(1145)	64(b)	45	380
14	26	364	39	20	(650)	65(b)	65	420
15	26	515	40	48	(670)	66(b)	62	680
16	43	760	41	14	(550)	67(b)	66	400
17	29	395	42	21	(570)	68(b)	103	720
18	46	607	43	45±	(875)	69(b)	45	120
19(a)	27	424	44	45±	(870)	70(c)	84*	(1500)
20(a)	31	220	45	45±	(730)	71(c)	95*	(1500)
21	34	314	46	45±	(1310)			
22	49	160	47	45±	(1550)			
23	42	160	48	45±	(1480)			
24	42	181	49	65	(600)			
25	12	190	50	28	(1280)			

(a) from McCoy, 1962.
(b) from Missimer and Associates, Inc., 1980.
(c) from Gee and Jenson Engineers, Inc., 1980.
* less than total well depth.
( ) indicates specific conductance measurement.

TABLE 1. LISTING OF WELLS INVENTORIED IN THIS AND OTHER STUDIES, WITH WELL DEPTH AND WATER QUALITY.

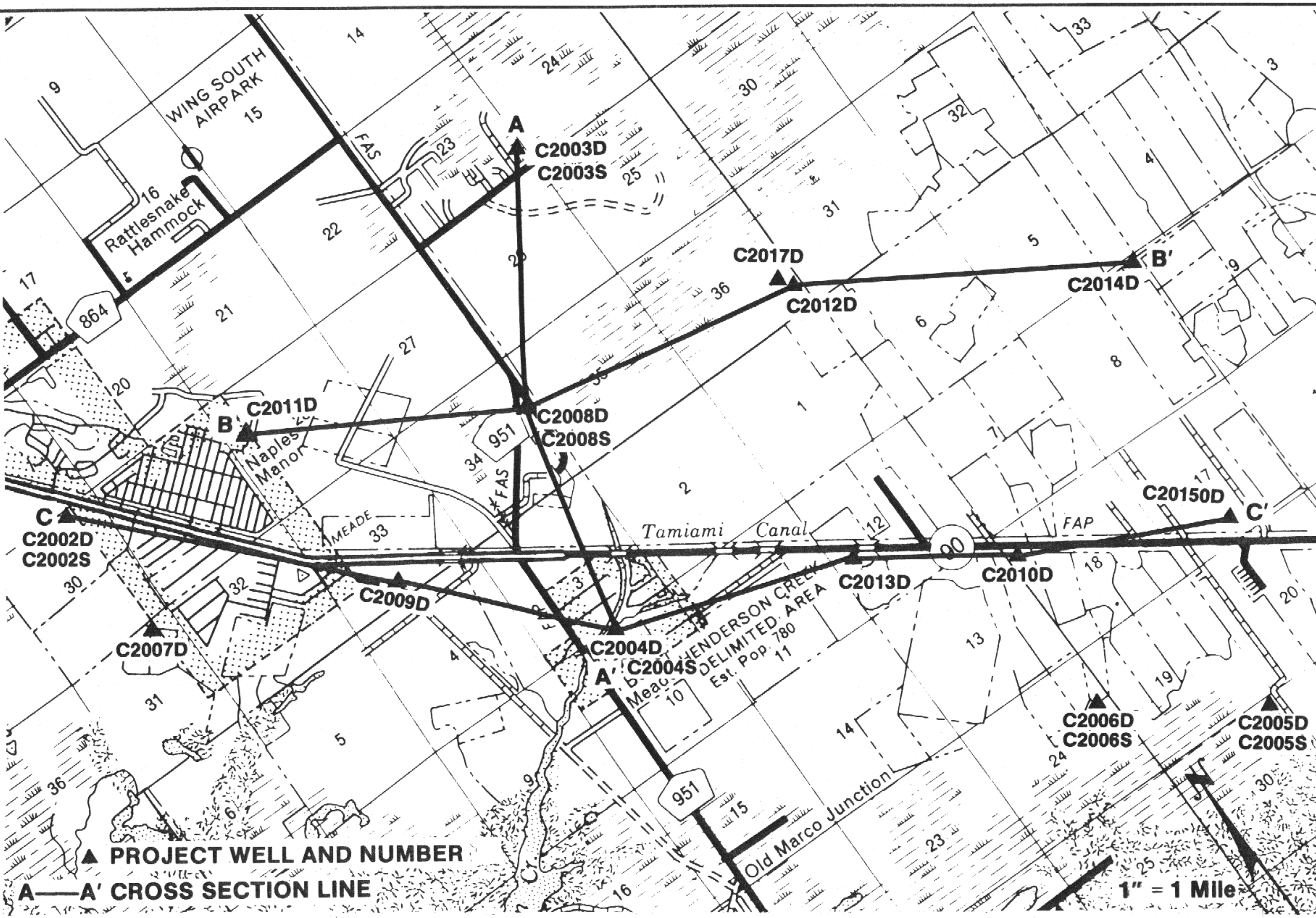


Figure 4 LOCATIONS OF PROJECT WELLS AND CROSS SECTION LINES

WELL NUMBER	DRILLING DATE	ROTARY DRILLING FLUID (AIR/MUD)	TOTAL DRILLING DEPTH (FEET)	SCREENED INTERVAL (FEET BELOW) LAND SURFACE)	SCREEN DIAMETER (INCHES)
C-2002S*	5/9/78	mud	167	30-35	1.25
C-2002D*				68-78	1.25
C-2003S	6/15/78	mud	179	40-45	1.25
C-2003D				138-143	1.25
C-2004S	7/18/78	mud	199	18-23	1.25
C-2004D				46-63	1.25
C-2005S	8/28/78	mud	198	43-48	1.25
C-2005D				72-78	1.25
C-2006S	9/26/78	mud	70	5-10	1.25
C-2006D				25-30	1.25
C-2007D	10/4/78	mud	69	21-69	2.0
C-2008S	9/18/79	mud	180	32-37	2.0
C-2008D				62-67	2.0
C-2009D	9/19/79	mud	190	57-62	2.0
C-2010D	9/20/79	mud	220	15-20	2.0
C-2011D	10/3/79	mud	140	19-140**	6.0**
C-2012D	10/4/79	mud	220	8-220**	6.0**
C-2013D	1/10/80	air	220	25-72**	6.0**
C-2014D	1/16/80	air	198	69-74	2.0
C-2015D	1/9/80	air	180	35-40	2.0
C-2017D	11/4/80	mud	340	310-330	2.0

* S and D indicate shallow and deep wells, respectively.
** Open hole.

TABLE 2. SUMMARY OF PROJECT WELL DATA.

a shallower well was also constructed to permit the sampling of water at depths less than 50 feet.

Analysis of the data from these wells and preliminary results from a surface D.C. resistivity survey, conducted subsequently in the vicinity of the study area (Stewart, 1982), indicated that the depth to saline water varied throughout the study area. This information made it clear that groundwater availability depends largely on the depth to saline water. On the basis of this assessment and with the intention of defining the thickness of the freshwater lense, eight additional wells were drilled at sites adjacent to major anomalies indicated by the resistivity survey, and at sites distributed among the first six wells. The first wells in this series (C-2008D and C-2008S) were constructed in close proximity to each other to allow shallow ("S") and deep ("D") water sampling. The fifteenth and last well was drilled through the confining zone at the base of the aquifer to assess the properties of the confining zone and to determine water quality and potentiometric pressure in the underlying water-bearing zone. Geologic logs of all wells were prepared from an examination of drill cuttings and are presented in Appendix 1. Borehole geophysical logs, including 16-inch and 64- inch Normal Resistivity, 6-foot Lateral Resistivity, Caliper, Neutron Porosity, Natural Gamma, Flowmeter, Fluid Resistivity and Temperature, were obtained from the exploratory wells and are presented in Appendix 2.

Based on analyses of the geophysical data, PVC well casing and short-length well screens were installed in the boreholes. Well screen bottoms were set at depths anticipated to be less than ten feet above the freshwater/saltwater interface. Where wells were paired, one well screen was set at the interpreted interface, with the other above the interface, to enhance monitoring of vertical water-quality variations. Because of uncertainties in the geophysical log interpretations, the well screens in some wells were set at depths below the interface.

In addition to geophysical logging, two other methods of interface depth determination were employed on an experimental basis before well completion:

1) An inflatable straddle packer was built, tested, and used successfully on two wells before failure of the inflation gland rendered it inoperable.
2) A second method was implemented whereby the mud-filled borehole was developed with compressed air from top to bottom in ten foot intervals. Water produced at each depth setting of the airline outlet was assumed to be representative of the groundwater in the adjacent rocks at that particular depth, because of the following conditions:
    a) The heavier drilling mud and the mud cake on the borehole wall prevent inflow from the aquifer below airline outlet;
    b) Higher pressures in the borehole due to expansion of air bubbles in the water/air blend above the airline outlet act to inhibit inflows to the well.

In practice, the second method yielded results that compared favorably with subsequent water sampling of the completed well.

Upon completion of construction, the elevation of the top of the casing of each exploratory well was established by a leveling survey referenced to National Geodetic Vertical Datum of 1929 (NGVD). Water level measurements from these reference points were used to provide information on the direction and quantity of groundwater flow. Aquifer parameters (transmissivity and coefficients of storage and leakance) were determined by the analysis of two constant-discharge pumping tests conducted at wells C-2011D and C-2012D. The tests yielded information that was used to predict aquifer response to changes in recharge and discharge.

RESULTS OF INVESTIGATION

Stratigraphy and Lithology

The shallow stratigraphy and lithology in the study area were determined from examination of drill cuttings, borehole geophysical logs, and on-site observations of drilling progress. Appendix 1 contains descriptions of the drill cuttings and comments on significant drilling changes; Appendix 2 shows suites of borehole geophysical logs; and Figure 5 illustrates a typical geologic column illustrating the major lithologic and stratigraphic units.

The upper 200 feet of sediments may be divided into three formations: the Pamlico Sand, the Tamiami Formation, and the Hawthorn Formation. These formations may be further divided into a total of seven lithologic units.

The youngest formation encountered in the area is the Pamlico Sand (Unit 1). It is a medium to fine-grained sand that varies from transparent to brown in color, depending on the organic content. The thickness of this formation ranges from zero at well C-2008D to 14 feet at well C-2006D and averages about 8 feet.

The Pamlico Sand is underlain by the Tamiami Formation which can be subdivided into at least two or three members and possibly five lithologic units. The uppermost member is referred to as the Ochopee Limestone (Missimer and Associates, Inc., 1980). This member has been identified as the top of the Tamiami Formation by the Center for Wetlands (1979). Lying below the Ochopee Limestone member is the Buckingham Limestone member and below that a third unnamed member consisting of coarse clastic quartz pebbles and quartz sand.

The Ochopee is composed predominantly of a mixture of sand and shell in a micrite matrix of variable hardness. It can be further subdivided into two, and in some areas three, lithologic units (Units 2, 3 and 4, Figure 5) on the basis of hardness and sand content, although the distinctions between units

System	Series	Formation	Lithology	Unit
Quat.	Holocene Pleistocene	Pamlico	Sand, Quartz, Medium, to Fine; Low to Moderate Permeability	1
TERTIARY (PART)	Pliocene	Tamiami Formation	Limestone, Hard, Gray, Sandy, Shelly, Cavernous In Places; Moderate to Very High Permeability — — — — — — — Limestone, Gray, Shelly, Coral, Minor Sand; High Permeability, Variable Near Top	2
			Limestone, Gray, Shelly, Sandy; Moderate Permeability, Decreasing Downward	3
	---?---			
	Miocene		Sandstone, Gray, Limey, Fine and Medium Sand Grains; Low Permeability, Except in Scattered Cavernous Zones	4
			Limestone, Gray, Shelly, Sandy, Moderate Permeability	5
			Sand, Quartz, Coarse to Very Course, Rounded, Consolidated in Places; Moderate Permeability	6
		Hawthorn Formation	Clay, Green-Gray, with Sand and Silt; Low to Very Low Permeability	7

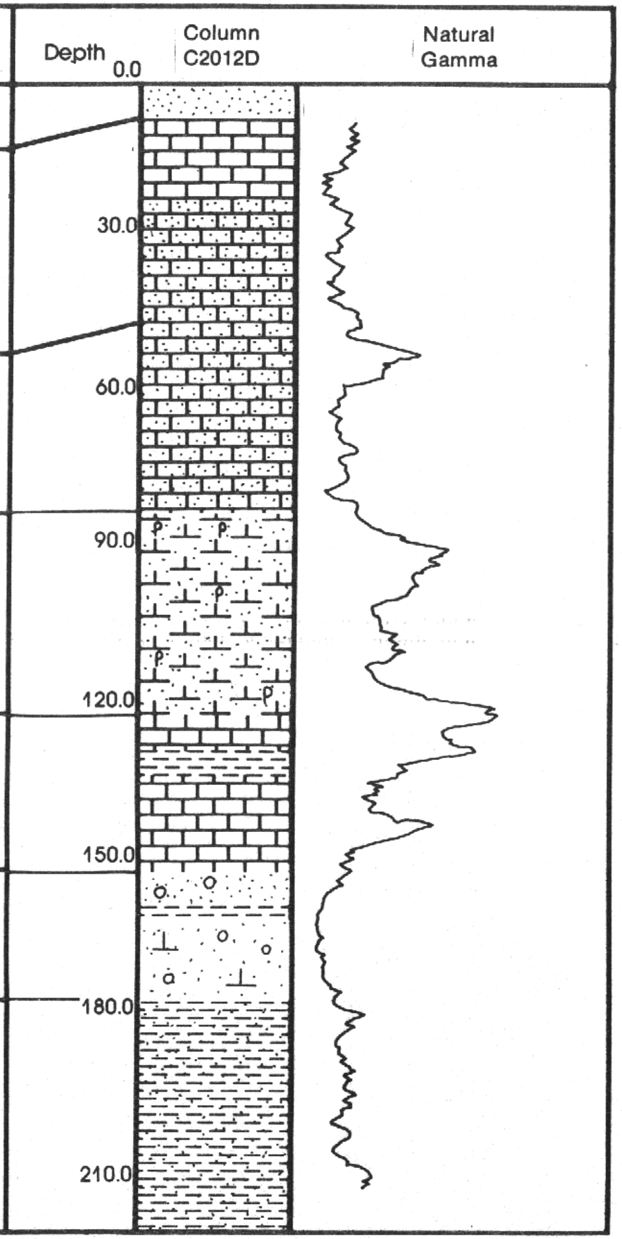


Figure 5 GEOLOGIC COLUMN SHOWING MAJOR LITHOLOGIC AND HYDROGEOLOGIC UNITS IN THE STUDY AREA

are often tenuous and difficult to define from well cuttings. The uppermost unit of the Ochopee Limestone member (Unit 2, Figure 5) is generally a hard to very hard, light gray to tan limestone containing variable amounts of sand and usually a substantial shell content. Large cavities are encountered in this unit, resulting in loss of drilling fluid during drilling operations. This unit contains a hard authigenic limestone locally referred to as "cap rock"; it is fractured, and lies in large blocks even when in situ beneath the surface. The unit ranges in thickness from 10 feet to 50 feet, averaging about 30 feet. The top 10 feet of this unit is often a soft calcareous clay or dolosilt (marl) as at well C-2003D, and contains fossil coral fragments in greater abundance than in other parts of the Ochopee Limestone sequence. The lower portion of the unit is a light gray and tan, relatively sand-free, shell-laden limestone.

The second unit of the Ochopee Member (Unit 3, Figure 5) is a predominantly light gray and tan, sandy and shelly limestone, with sand content increasing with depth until the unit grades rapidly to a calcareous sandstone. The sandstone unit (Unit 4, Figure 5) is the third and lowest unit of the Ochopee Limestone. It consists of fine to medium-sized quartz grains and shell fragments in a variably hard micrite matrix and ranges in color from gray to tan. The thickness of this unit averages about 52 feet, but varies from 15 to 90 feet.

Underlying the sandstone is a variably hard, gray, brownish, sandy and shelly limestone, corresponding to the Buckingham Limestone member. To the north of the study area, this member was described by Missimer and Associates, Inc. (1978) as a gray carbonate mud with shell and limestone stringers; it ranges in thickness from 4 feet to 38 feet and averages about 22 feet.

Underlying the limestone is a coarse to very coarse, generally unconsolidated quartz sand (Unit 6, Figure 5). The sand grains are characteristically well rounded to ellipsoidal and gray in color. The unit thickens unevenly towards the southeast, attaining a maximum thickness of 35 feet in the study area, with an average thickness observed in project wells of about 20 feet. A gravelly bed of similar character has been described by Klein et al. (1964) north of the study area in Glades and Hendry Counties. A well in Clewiston, located approximately 70 miles northeast of the study area, reportedly penetrated this bed between 91 feet and 127 feet below ground level. Bishop (1956) described similar sediments that extend to the south from Polk County, and attributes their origin to Miocene deltaic deposition. For the purpose of this report, this bed has been placed in the Tamiami Formation; however, its true stratigraphic position is still uncertain and it may also be considered part of the underlying Hawthorn Formation.

The lowest unit penetrated by the deeper project wells is a gray to green sandy and silty clay bed. This unit, (Unit 7, Figure 5) which is areally extensive in southwest Florida, marks the bottom of the shallow aquifer. At well C-2017D, this clay was found to be 82 feet thick. Beneath this clay unit, at approximately 290 feet below ground surface, are phosphatic limestones assigned to the Hawthorn Formation. The aquifer formed by these deeper limestones is artesian.

Stratigraphic Correlation Based on Geophysical Surveys

Borehole geophysical surveys were used to supplement data which were obtained from the exploratory drilling program and to correlate the stratigraphic and lithologic units. Correlations using borehole geophysical logs are based on identification of correlatable variations in the logs which can be assumed to be characteristic of the composition of the units. The logs which were most useful in this respect were the Natural Gamma and Caliper. The electric logs (16 inch and 64 inch Normal Resistivity, 6 foot Lateral Resistivity and Spontaneous Potential), although theoretically capable of detecting differences in lithology, proved to be less useful. This was due to water-quality variations (within the borehole and formation fluid) below a depth of about 60 feet which masked those variations expected to develop solely from lithologic changes within the borehole. It should be noted that above 50 feet, the resistivity logs are affected by inadequate cable shielding and are unreliable. The Neutron Porosity logs were affected by variations in borehole diameter, and in most cases were "mirror images" of the Caliper logs. This occurred because the enlarged portion of the borehole, which was filled with drilling mud or water, yielded a signal similar to that of porous rock.

For the purpose of stratigraphic and lithologic correlation, the Natural Gamma logs were found to be the most useful. These logs detected gamma radiation emitted from phosphorite and, to a lesser degree, clay minerals. Three profiles based on data derived from Natural Gamma logs and drill cuttings are shown on Figures 6, 7, and 8. Locations of the cross sections are shown on Figure 4. As illustrated, distinct marker beds are identifiable on the Gamma Ray logs. A relatively high gamma response, attributable to phosphatic sand in the matrix of the rocks, is traceable between depths of 30 feet and 60 feet below NGVD. A more persistent and higher gamma response is noted in the sandstone between approximately 80 feet and 160 feet below NGVD. The highest gamma ray peak generally occurs near the bottom of this interval in the southeastern wells, and towards the top of this interval in the northwestern wells.

Caliper logs can be used to correlate cavernous zones and poorly consolidated zones that are prone to washout during drilling. Both of these show up as hole enlargements on the logs. Cavernous zones, due to solution of the limestone, generally occur in the hard limestones and coincide with mud-loss zones (where drilling mud was lost during well construction). Caverns also occur in deeper sandstones and limestones, as shown by hole enlargements which coincide with mud-loss zones. Within the upper 50 feet of most boreholes, washouts occur in the soft limestone. These often coalesce with enlargements which are due to cavernous rock between depths of 8 to 20 feet below surface.

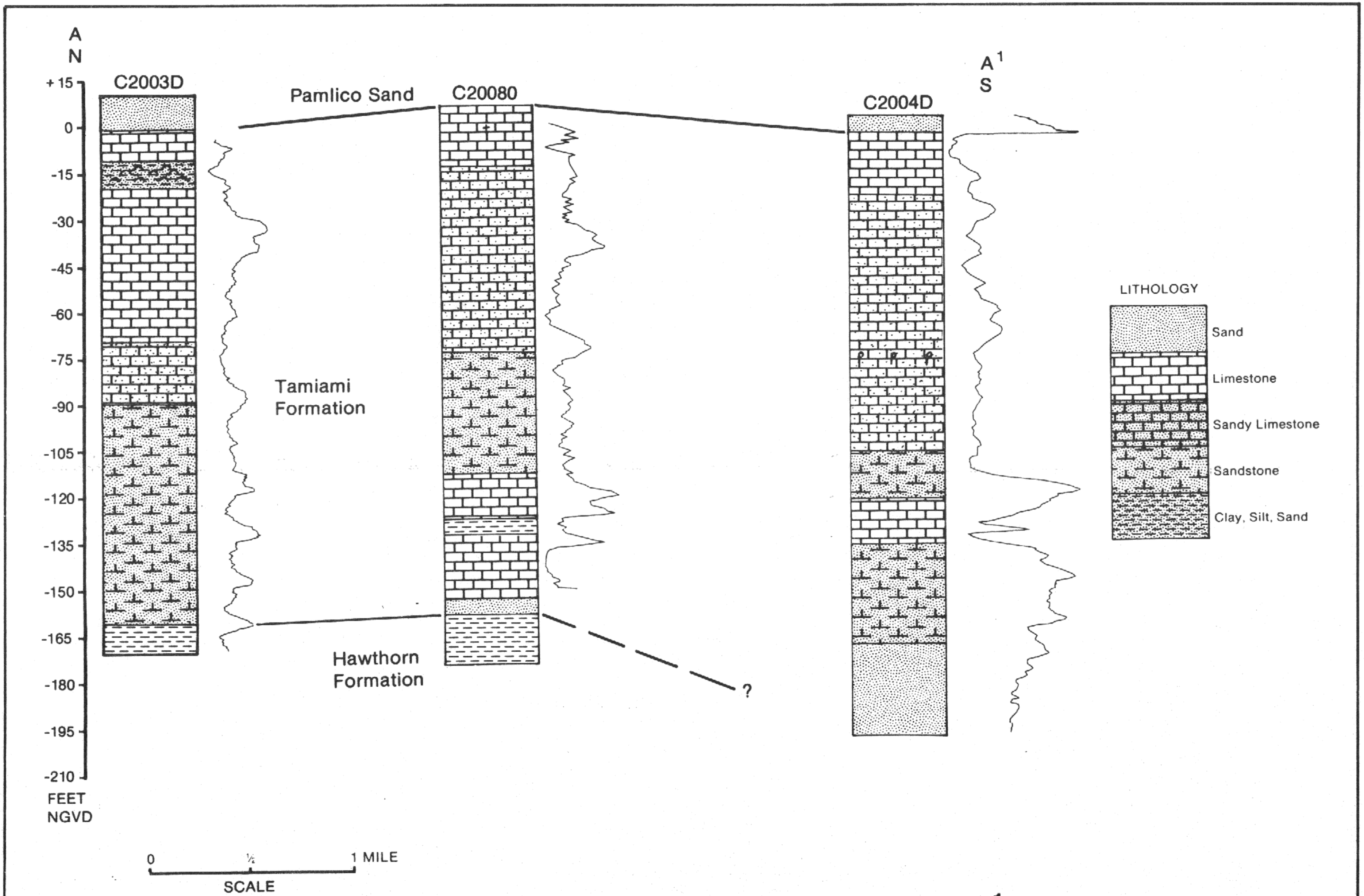


Figure 6 GEOLOGIC CROSS-SECTION A-A[1]

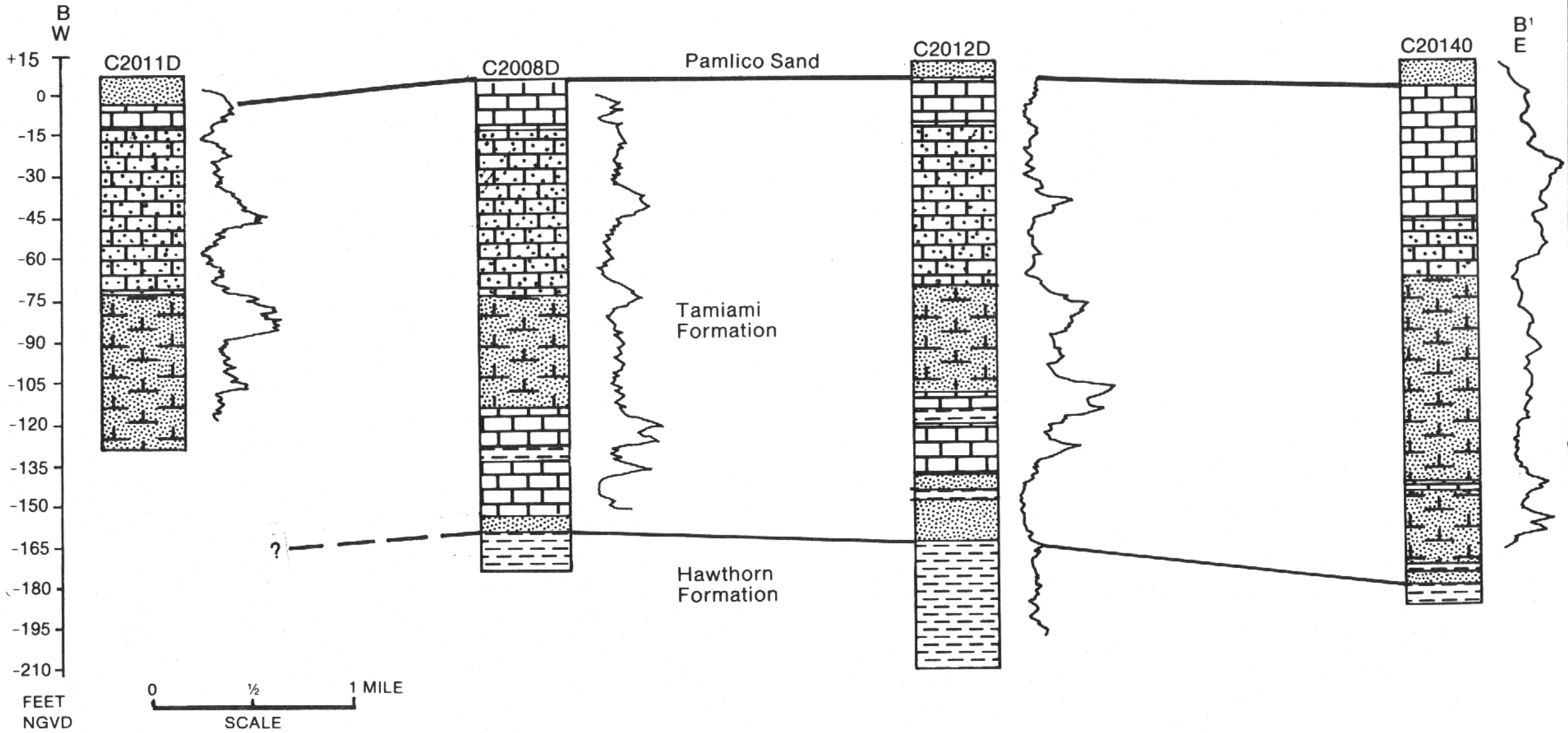


Figure 7 GEOLOGIC CROSS-SECTION B-B[1]

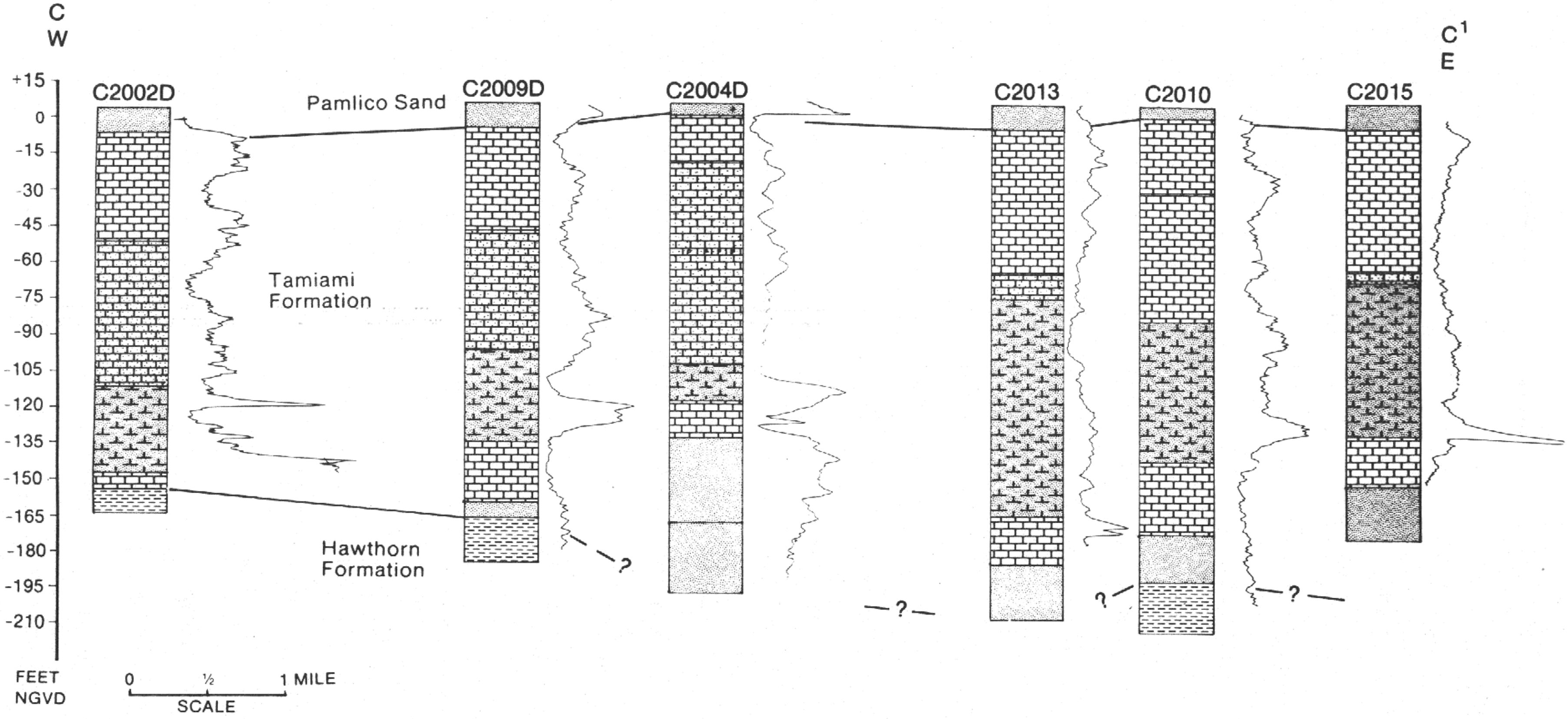


Figure 8 GEOLOGIC CROSS-SECTION C-C[1]

Sands and sandstone have variable washout resistance depending on the degree of consolidation and clay content. Both cavernous and washout zones are common in the study area, but no apparent trends are correlatable with the stratigraphy.

Well C-2003D, in the north-central part of the area, contains seven widely spaced cavernous mud-loss zones in contrast to the average of about one for other project boreholes. It is possible that this area represents an extension of the highly permeable reef deposits to the north, mentioned by Meeder (1979), although cuttings from well C-2003D were not significantly different from those obtained from other project wells.

Hydrostratigraphy

Examination of drill cuttings, borehole geophysical logs, and on-site observations of drilling changes yielded qualitative information on the water-bearing characteristics of the shallow aquifer. An identification of major water-producing zones was based on apparent intergranular porosity and permeability, grain size and sorting, relative degree of cementation, clay and silt content, and the degree of secondary permeability through the development of fractures, solution cavities, and moldic porosity. The hydrogeologic properties of the major lithologic units are discussed below, and depicted on Figure 9.

Unit 1, consisting of the surficial sands of the Pamlico Formation, is comprised of largely unsorted, medium to fine quartz grains and is considered to have a low to medium permeability (Figure 5).

Unit 2 contains the major producing zone in the shallow aquifer. In general the top 12 feet of this limestone sequence is very dense, sandy and shelly, and appears to have moderately high permeability due to the development of secondary porosity and solution features. Where large cavities were encountered, the permeability is considerably higher. The moderately indurated limestone between approximately 20 and 25 feet below ground contains

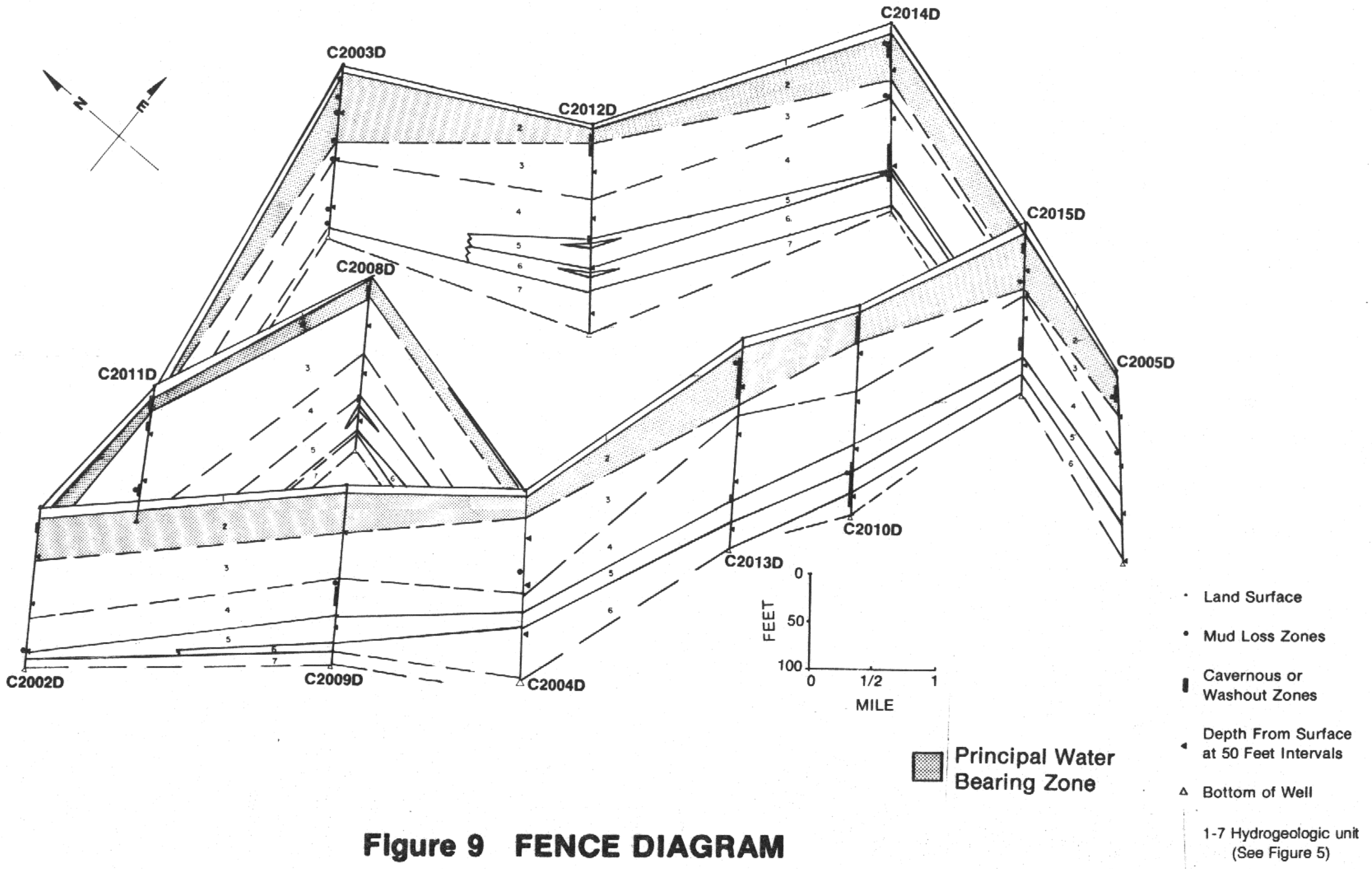


Figure 9 FENCE DIAGRAM

sufficient marl to retard the downward movement of recharge water. This zone is considered a semi-confining zone to the major producing zone. The soft limestone between 25 feet and 50 feet below ground (the major producing zone of the shallow aquifer) has a coarse matrix, well developed moldic porosity, minimal sand content, and contains numerous solution features.

Unit 3 is encountered below 50 feet. Permeability in this unit decreases rapidly from moderate to low because of an increase in fine sand content, inclusions of silt size dolomite fragments, and clay particles in the matrix of rock. Between approximately 90 and 142 feet below ground is a calcareous, fine to medium grained moderately indurated sandstone which comprises Unit 4. This unit appears to have low permeability, except in several more indurated zones that contain caverns, indicated in Figure 9. These cavernous zones are not traceable, given the areal density of the project wells. Units 5 and 6 consist of limestone and sand respectively, between 142 and 184 feet below ground. From a qualitative perspective Unit 5 would appear to have moderate permeability. The upper 22 feet of this interval consists of a shelly, sandy limestone. The sandy matrix usually contains silt size particles which may reduce the permeability of the unit. Unit 6 is a sand which contains coarse to very coarse, rounded quartz pebbles, and is consolidated in places; thus the permeability of this unit is likely to be moderate to high.

The green sandy clay that occurs at 184 feet below ground constitutes Unit 7 and marks the base of the shallow aquifer. This clay is low in permeability and acts as a confining bed to the limestone below the clay. This limestone contains brackish water under a static head of approximately 23 feet above land surface at wells C-2012D and C-2017D. Variations in the salinity of the water in the shallow aquifer above 184 feet suggest that the confining properties of Unit 7 vary areally, probably due to variations in thickness or clay content. Upward leakage of brackish water through the clay would occur more rapidly where the degree of confinement is least.

Geophysical logs including Fluid Resistivity, Temperature, and Flowmeter (Appendix 2) strengthen the hydrostratigraphic interpretations stated above. At about 60 feet, these logs indicated an increase in water salinity by a decrease in the fluid resistivity, and a temperature increase averaging about 1.6^{o}F. These trends suggest slower turnover of water below this depth due to low permeability. The most direct evidence supporting this conclusion was obtained from Flowmeter surveys made during pumping of wells C-2011D and C-2012D. These indicated that less than 5 percent of the flow from the wells was derived from the aquifer below 60 feet.

Aquifer Parameters

Two aquifer tests were conducted during the course of this study to quantify the aquifer parameters transmissivity (T), storage coefficient (S), and coefficient of leakance (L). Definition of these terms, as well as the theory and assumptions underlying aquifer tests are described by Walton (1970). The tests were conducted at wells C-2011D and C-2012D, by pumping water from the wells at a constant rate and observing the decline of water levels in nearby observation wells. Data relevant to the tests are presented in Appendix 3. Figure 10 illustrates a plan of the test sites. Details of the analyses are presented in Figures 11 to 13. The results of the test are summarized in Table 3.

The test at well C-2011D (Site A) was designed to estimate the transmissivity, storage coefficient, and the coefficient of leakance of the shallow aquifer. The lithologic log of the well (Appendix 1) indicates a 10 foot thickness of unsorted sand and sandstone at the surface. This is underlain by an increasingly sandy limestone that contains marly material from 15 to 20 feet. The major producing zone of the aquifer lies between 20 and 60 feet. The flowmeter log

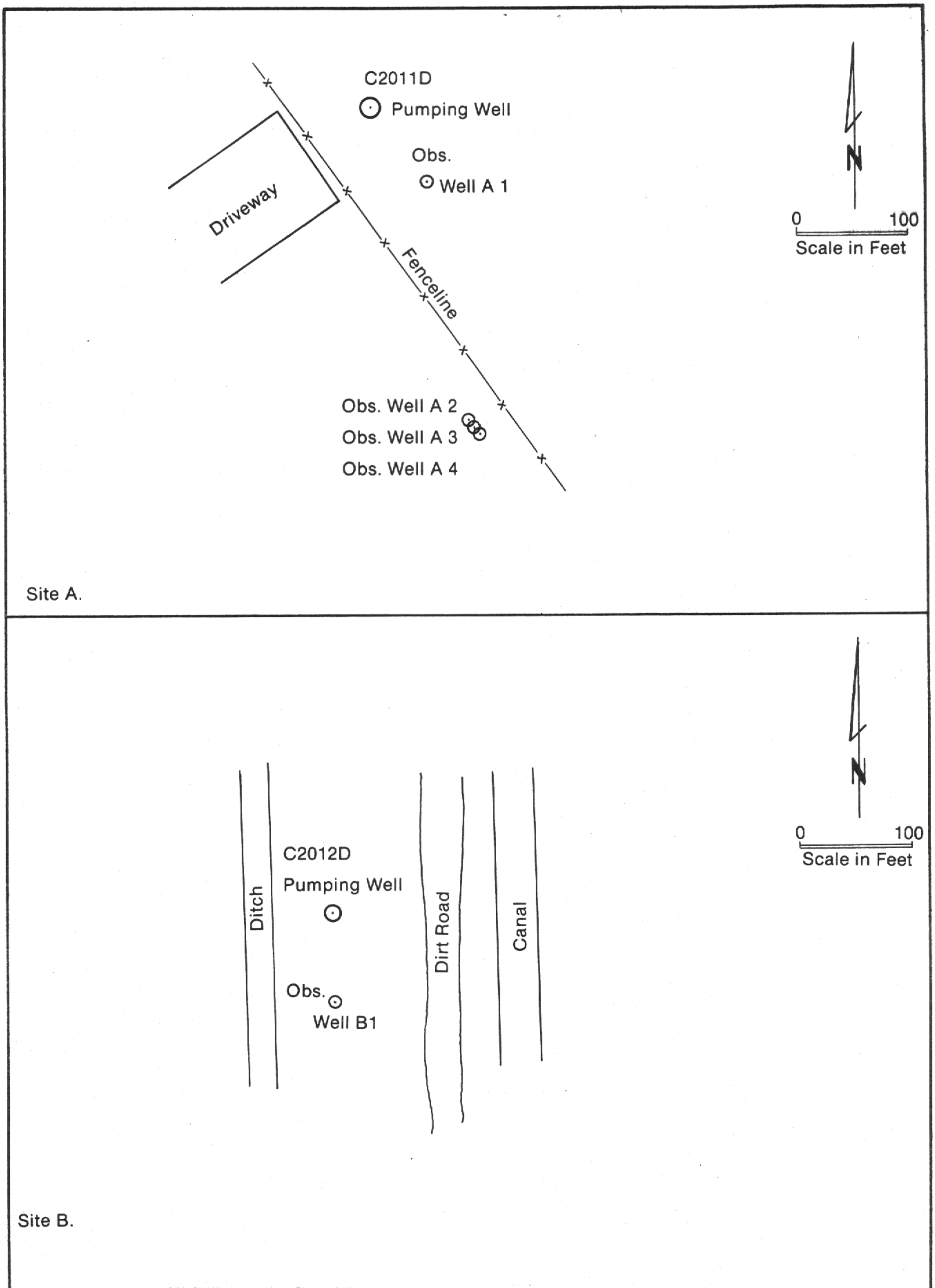
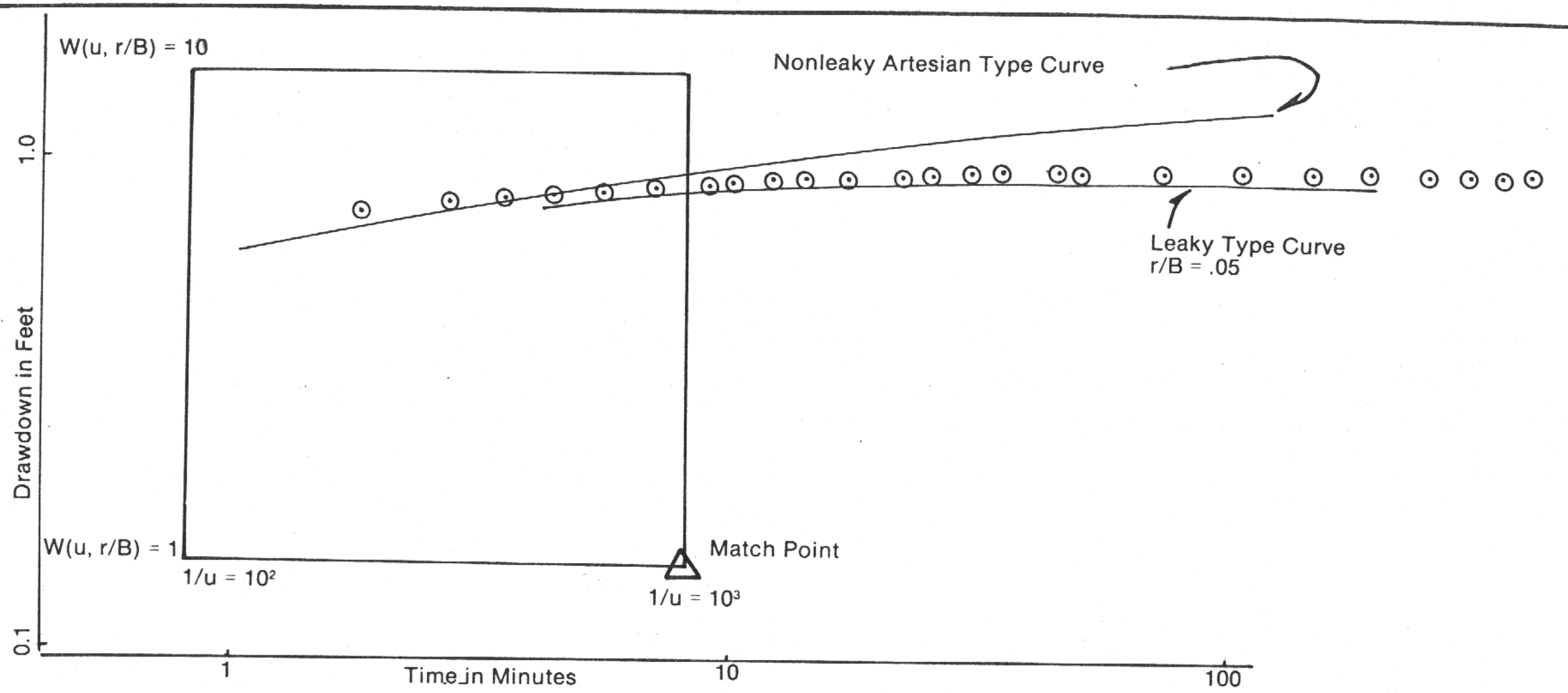


Figure 10 PLAN OF PUMPING TEST SITES



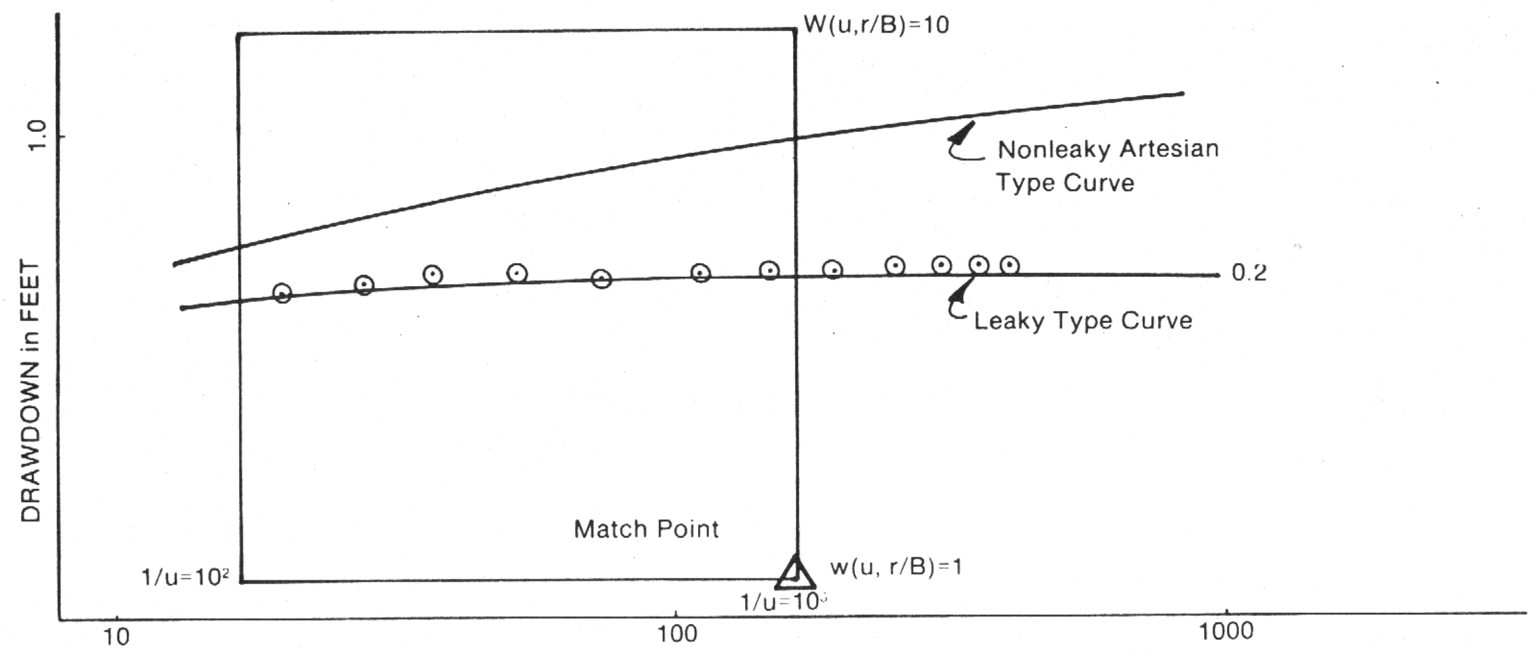
u = .001
W(u, r/B) = 1
t = 8 min. = .0055 days
s = 0.15 feet
Q = 382 gpm
r = 41 feet
r/B = .045

T = (114.6 Q W(u, r/B))/s
T = 291,848 gpd/ft.

S = Tut/1.87 r^2
S = .00052

Leakance = P^1/m^1
P^1 = vertical permeability of confining zone
m^1 = thickness of confining zone
$P^1/m^1 = (r.B)^2\ T/r^2 = 0.43$ gpd/ft³

Figure 11 ANALYSIS OF PUMPING TEST DATA FROM SITE A. OBSERVATION WELL A1



$u = .001$

$W(u, r/B) = 1$

$t = 165$ min. = .114 days

$s = 0.15$ feet

$Q = 382$ gpm

$r = 150$ feet

$r/B = 0.175$

Leakance = P^1/m^1

P^1 = Vertical Permeability of the Confining Zone

M^1 = Thickness of the Confining Zone

$P^1/M^1 = (r/B)^2 \ T/r^2 = 0.40$ gpd/ft^3

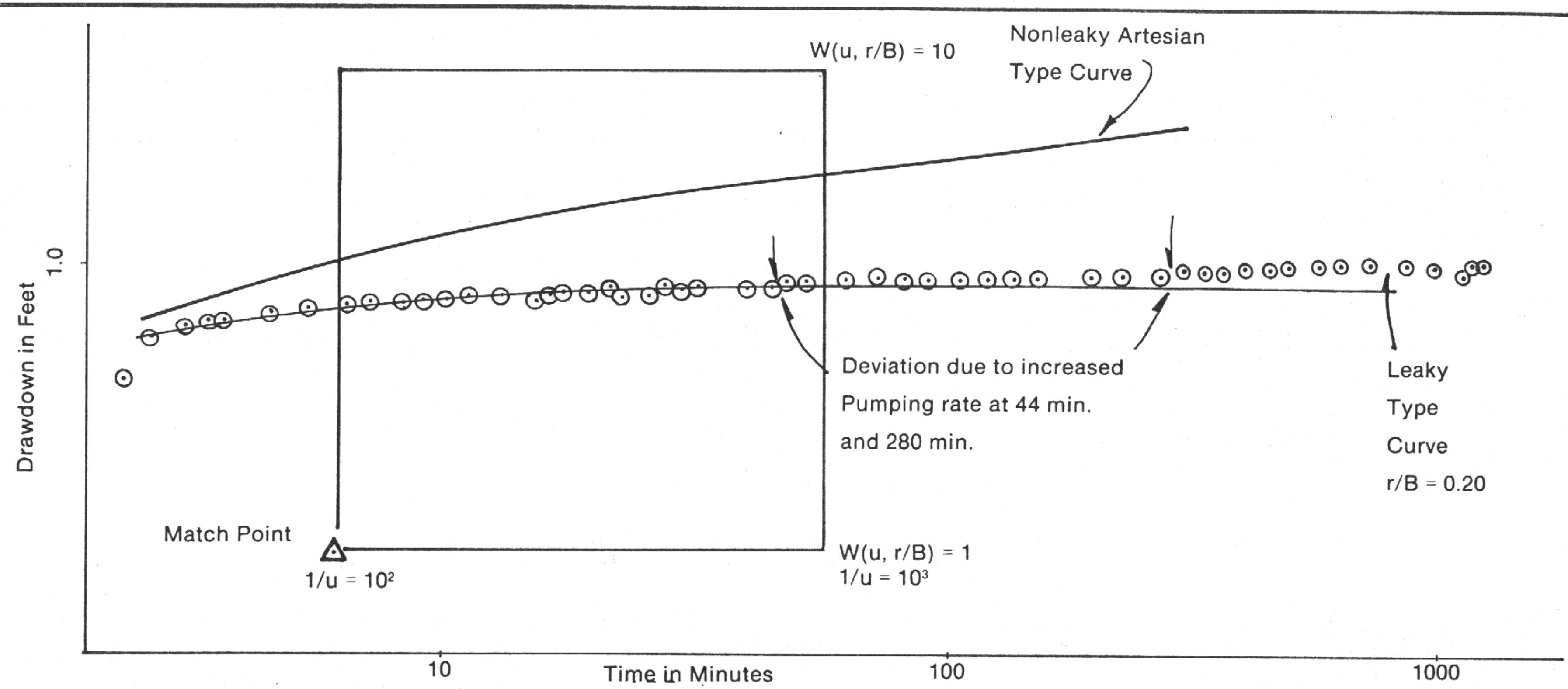
$T = (114.6\ Q\ W(u, r/B))/s$

$T =$ 291,848 gpd / ft.

$S = Tut/1.87r^2$

$S = .00079$

Figure 12 ANALYSIS OF PUMPING TEST DATA FROM SITE A. OBSERVATION WELL A 3



$T = (114.6\ Q\ W(u, r/B))/s$
T = 229,200 gpd/ft.
$S = Tut/1.87\ r^2$
S = .0029

Leakance = P^1/m^1
P^1 = vertical permeability of confining zone
m^1 = thickness of confining zone
$P^1/m^1 = (r/B)^2\ T/r^2$ = 5.73 gpd/ft.^{3}

u = .01
w(u,r/B) = 1
t = 5.5min. = .0038 days
s = 0.255 feet
Q = 510 gpm
r = 40 feet
r/B = 0.20

Figure 13 **ANALYSIS OF PUMPING TEST DATA FROM SITE B, OBSERVATION WELL B1**

TABLE 3. AQUIFER TEST RESULTS

PUMPED WELL NO.	OBSERVATION WELL NO.	TYPE OF ANALYSIS	TRANS-MISSIVITY (gpd/ft.)	COEFFICIENT OF STORAGE	COEFFICIENT OF LEAKANCE (gpd/ft3)
C-2011D	A1, A3, A4	Semi-Log Distance/ Drawdown	280,000	-	-
	A1	Log-Log Time/ Drawdown	290,000	.00052	.43
	A3	Log-Log Time/ Drawdown	290,000	.00079	.40
C-2012D	B1	Log-Log Time/ Drawdown	230,000	.0029	5.73

(Appendix 2), indicates that about 95 percent of the water yielded from the well during pumping was derived from this zone.

Prior to the beginning of pumping, the water level in Observation Well A2, which tapped the surficial sand, was 0.09 foot lower than those measured at Observation Well A3, and 0.05 foot lower than levels at Observation Well A4. Observation Wells A3 and A4 tap the main body of the aquifer. These data suggest that under non-pumping conditions, the main body of the aquifer leaked water upward through the marl and into the sand during the period before the test. This head relationship was probably due to drainage and evapotranspirative losses from the surficial sand.

Examination of the test data indicated that Observation Wells A1, A3, and A4, which tap the main body of the aquifer, show similar drawdown characteristics with respect to time. The time/drawdown data were fitted successfully to leaky-artesian type curves except for early drawdown data from Observation Well A1. This deviation from the type curve was probably due to an excessive pumping rate during the first 3-4 minutes of the test, before discharge could be adjusted to the long-term rate of about 382 gallons per minute (gpm). Observation Well A2, with a screen setting in the surficial sand, displayed much less drawdown than that observed in adjacent observation wells. These observations indicate that the main body of the aquifer is semi-confined. The marly limestone between a depth of 15 to 20 feet appears to retard downward movement of water from the surficial sand under pumping conditions.

Analysis of the data indicated a transmissivity value of approximately 290,000 gallons per day per foot (gpd/ft.), an average storage coefficient of 0.00065, and a coefficient of leakance of 0.40 to 0.43 gallons per day cubic foot (gpd/ft^3). The coefficient of leakance suggests that the source bed (the surficial sands) could become dewatered if extended pumping in the absence of recharge were to occur.

The second aquifer test was conducted with a single production-zone observation well at a distance of 40 feet from the pumped well. The lithologic log of the pumping well (C-2012D) indicates an unsorted sand to a depth of 6 feet below surface, underlain by limestone to 80 feet. The flowmeter log (Appendix 2) shows that, as at well C-2011D, over 95 percent of the water entering the well during pumping comes from depths above 60 feet. Again, a marly zone at a depth of about 20 feet may have retarded the downward movement of water from the surficial sand. Because of a pump-engine problem, a constant pumping rate was difficult to maintain; the test was aborted after 21 hours because of engine failure. These factors detract from the accuracy of the test results.

Analysis of the observation-well data yielded a transmissivity value of 230,000 gpd/ft., a storage coefficient of 0.0029, and a coefficient of leakance of 5.73 gpd/ft.^{3} The high coefficient of leakance suggests that there is little confinement between the surficial sands and the producing zone. Thus, the assumption of a water-table aquifer with delayed yield from storage (Boulton, 1963) and a storage coefficient of about 0.10 would be equally valid for predicting the effects of long-term pumpage.

Groundwater Levels

Water levels were measured on each project well at the end of the dry season (5/28/80) and midway into the wet season (8/22/80). The data were referenced to NGVD as determined by a leveling survey. These data are presented in Table 4 and contoured in Figures 14 and 15. The values are considered to be representative of nonpumping water levels in the producing zone of the aquifer.

Figures 14 and 15 indicate that the regional direction of groundwater flow is predominantly towards the Gulf of Mexico to the southwest. The position of the one foot contour line near the landward border of the mangrove

STATION NUMBER	APPROXIMATE GROUND ELEVATION (FT NGVD)	TOP OF CASING (FT NGVD)	5/28/80		6/18/80		8/22/80	
			DEPTH BELOW T.O.C.*	WATER LEVEL (FT NGVD)	DEPTH BELOW T.O.C.	WATER LEVEL (FT NGVD)	DEPTH BELOW T.O.C.	WATER LEVEL (FT NGVD)
C2002S	4.5	8.324	5.64	2.68	5.76	2.56	4.65	3.67
C2002D	4.5	8.314	5.66	2.66	5.79	2.52	4.60	3.71
C2003S	9.2	11.436	4.71	6.73	5.63	5.81	2.25	9.19
C2003D	9.2	11.446	4.84	6.61	5.75	5.70	2.26	9.19
C2004S	3.2	5.761	4.05	1.71	4.92	0.84	3.59	2.17
C2004D	3.2	6.181	4.77	1.41	5.66	0.52	4.28	1.90
C2005S	3.9	7.172	5.76	1.41	6.39	0.78	5.22	1.95
C2005D	3.9	7.172	6.09	1.08	6.71	0.46	5.49	1.68
C2006S	3.0	4.772	2.69	2.08	3.39	1.38	2.58	2.19
C2006D	3.0	4.882	2.81	2.07	3.51	1.37	(b)	-
C2007D	4.4	7.668	6.04	1.63	6.63	1.04	4.74	2.93
C2008S	7.0	7.226	5.22	2.01	5.80	1.43	2.88	4.35
C2008D	7.0	6.896	4.88	2.02	5.46	1.44	2.54	4.36
C2009D	5.9	5.944	3.70	2.24	4.59	1.35	(a)	-
C2010D	5.5	5.512	2.64	2.87	2.93	2.58	0.71	4.80
C2011D	6.4	6.478	2.57	3.91	3.21	3.27	0.35	6.13
C2012D	7.0	7.052	2.75	4.30	3.18	3.87	1.05	6.00
C2013D	5.5	6.178	3.90	2.28	4.38	1.80	0.92(c)	5.26(c)
C2014D	8.0	8.272	3.69	4.58	3.61	4.66	3.19	5.08
C2015D	6.0	6.292	3.71	2.58	3.73	2.56	1.85	4.44

*T.O.C. = top of casing
(a) well filled with gravel
(b) not measured
(c) T.O.C. moved, measurement approximate

TABLE 4. SUMMARY OF GROUNDWATER LEVEL DATA

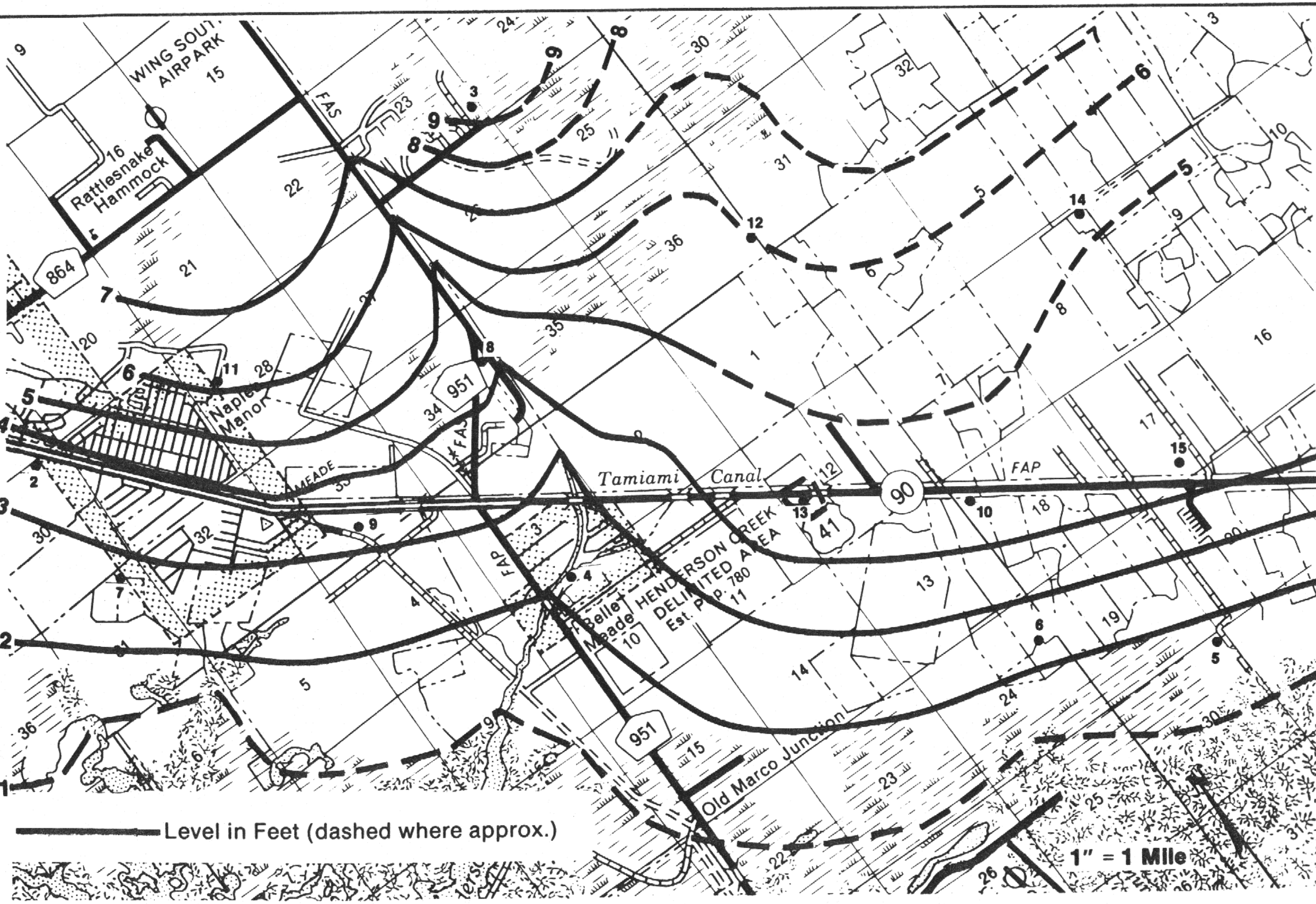


Figure 14 GROUND WATER LEVEL CONTOURS ON 8-22-80.

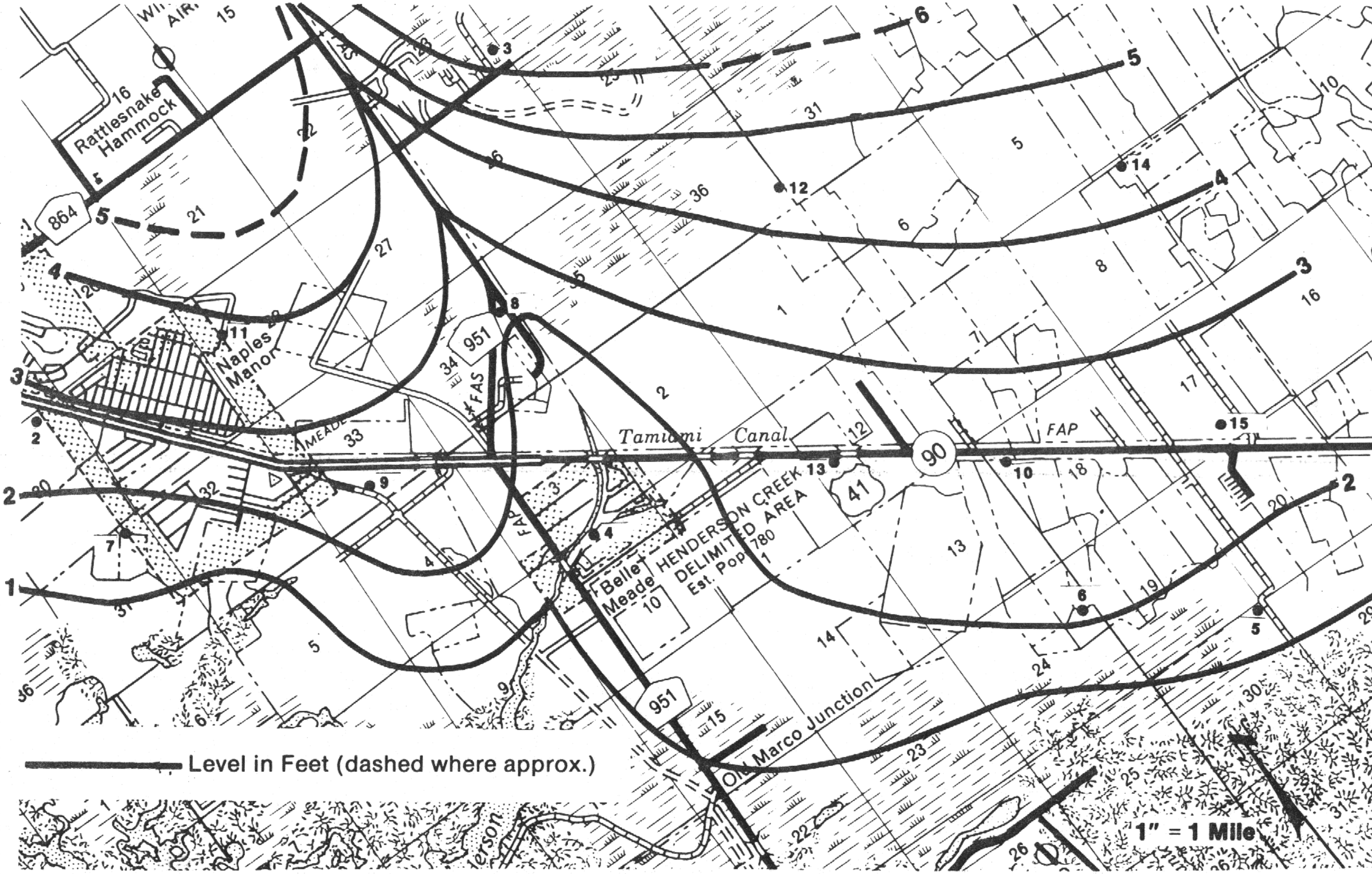


Figure 15 GROUND WATER LEVEL CONTOURS ON 5-28-80.

swamp is approximated, based upon vegetation distribution and the tidal level. Locally, surface drainage features exert a major influence on the direction of groundwater flow. A significant depression of groundwater levels is centered on Henderson Creek, indicating that this surface-water body diverts a large quantity of water from the aquifer. The Tamiami Canal, which traverses the area from east to west, also appears to have considerable effect on groundwater levels. There is a noticeably increased spacing of the contour lines in the vicinity of this canal indicating that the canal serves to both drain (from north) and recharge (to south) the aquifer.

The increase in groundwater levels from the dry to the rainy season ranged from a maximum of 2.98 feet at well C-2013D to a minimum of 0.09 foot at well C-2006D, and averaged 1.49 feet for all project wells. A shallow U. S. Geological Survey well (No. C-500) located about 0.3 mile south of County Route 846 on U. S. Route 41 (U. S. Geological Survey, 1980) had an average annual fluctuation of 3.83 feet during the water years 1976 to 1977. Wells at inland locations and wells located distant from drainage features tend to exhibit a greater annual range in groundwater levels.

Groundwater Quality

The quality of groundwater within the shallow aquifer varies considerably with depth and location and is dependent upon the geology, topography, and local hydrology. Because a determination of the availability of potable groundwater in the study area is largely a determination of the thickness of the freshwater lense that "floats" on more dense saline water, special attention was given to locating the saltwater/freshwater interface. Other physical and inorganic water-quality parameters were also examined during this study.

A number of methods were used to determine areal and vertical water-quality variations. These included collection and analysis of water samples from completed wells, sampling of wells during their construction, and interpretation of geophysical logs. A comparison of the resistivity logs (the 64-inch Long Normal and 6-foot Lateral) with water-quality analyses of samples taken at specific depths indicated that a resistivity value of 30 ohm-meters on the logs coincided with a chloride concentration of approximately 250 mg/l or a specific conductance of about 1500 umhos/cm.

Figure 16 illustrates equal-depth contours to groundwater having a chloride concentration of 250 mg/l. Water-quality data utilized on this figure were derived from the sampling and analysis of chlorides from project wells and inventoried private wells. In addition, borehole resistivity data from project wells were also included. Generally, private wells tap only the freshwater horizon and therefore determine a minimum depth to saline water and not the actual depth to the interface. All the project wells penetrated the saltwater/freshwater interface. However, well screens were not always set exactly at the interface, and in these cases the water-quality data (Table 5) were used to indicate a minimum or maximum depth to the interface.

In general, the data suggest that the depth to the interface increases in proportion to the fresh-water head above sea level as predicted by the Ghyben-Herzberg relationship (Walton, 1970, p. 194). Northeast of the U.S. Rt. 41, however, the depth to the interface clearly departs from this relationship. A variety of factors affecting the interface depth are discussed below.

From the time sediments of the shallow aquifer were deposited, sea water was entrained between the sand grains, shells, and within the matrix that binds them as rock. Subsequent to the deposition of the units, sea water flooding occurred repeatedly during the Pleistocene Epoch, and as recently as 25,000 years ago during the Sangamon interglacial stage. It was during the Sangamon stage that the surficial Pamlico Sand formation was deposited (Parker and

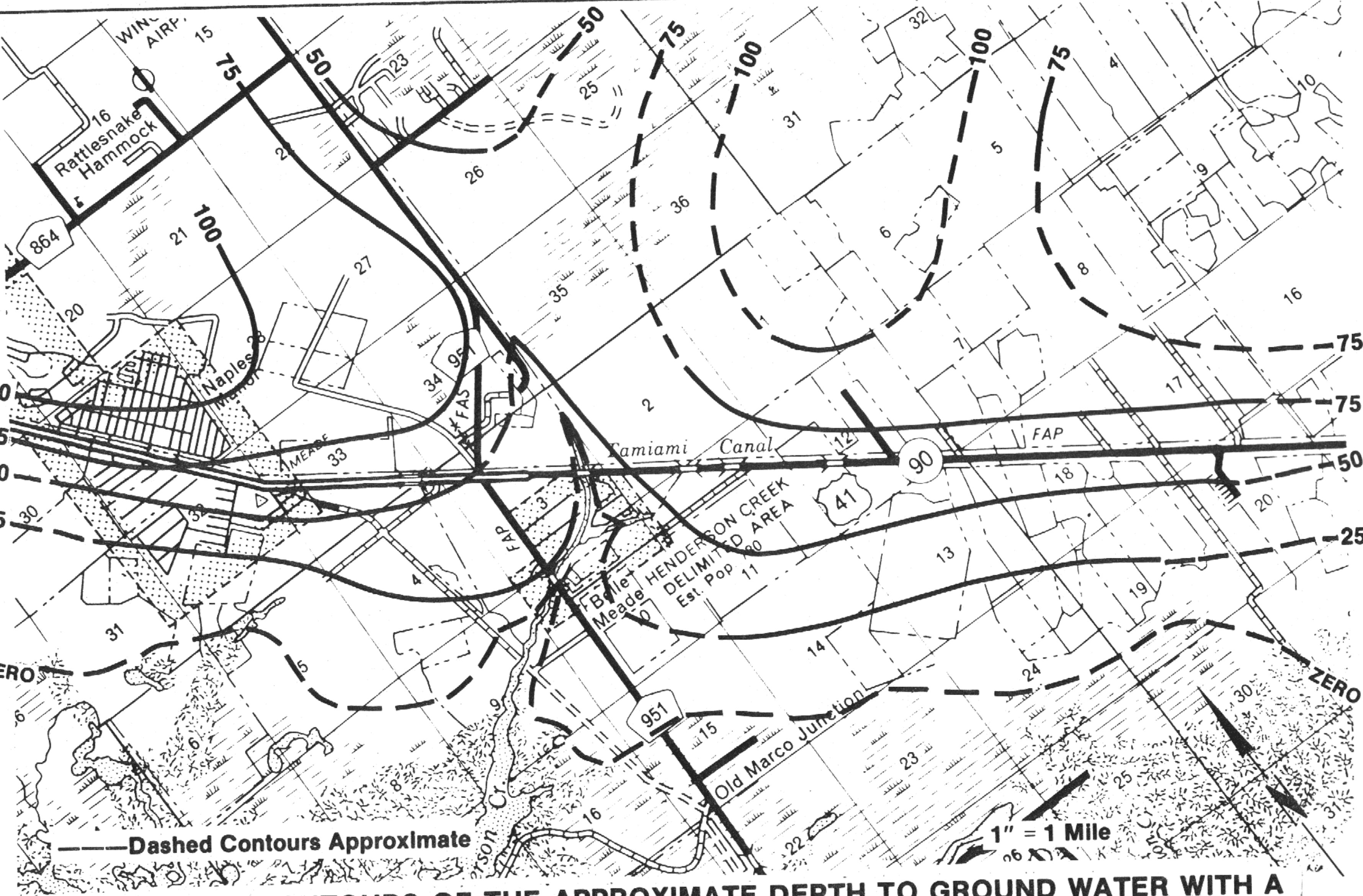


Figure 16 **CONTOURS OF THE APPROXIMATE DEPTH TO GROUND WATER WITH A CHLORIDE CONTENT OF 250 Mg/l OR SPECIFIC CONDUCTANCE OF 1500 umhos/cm.**

TABLE 5. CHEMICAL ANALYSES OF GROUNDWATER SAMPLES FROM PROJECT WELLS.

	SAMPLING DATE	SPECIFIC CONDUCTIVITY (umhos/cm)	pH	HARDNESS (mg/l)	ALKALINITY (mg/l)	Cl^- CHLORIDE (mg/l)	$SO_4^=$ SULFATE (mg/l)	Na^+ SODIUM (mg/l)	Ca^{++} CALCIUM (mg/l)	K^+ POTASSIUM (mg/l)	Mg^{++} MAGNESIUM (mg/l)	Fe^{+++} DISS.IRON (mg/l)	NON-CARBONATE HARDNESS (mg/l)	RATIO SULFATE TO CHLORIDE
C2002S SCREEN 30-35'	3/11/80	720.		304.4	229.0	95.1	43.3	40.10	103.91	1.85	10.91		75.4	0.45
	8/25/80	820.	7.92	292.6	252.0	100.3	29.5	48.88	104.49		7.70		40.6	0.29
C2002D SCREEN 68-73'	3/11/80	1100.		392.0	377.0	160.2	20.6	74.85	137.62	1.56	11.76		15.0	0.12
	8/25/80	1120.	7.30	401.2	347.0	146.6	12.8	78.80	139.30		12.96		54.2	0.08
C2003S SCREEN 40-45'	1/17/78	1550.	8.35	294.3	161.5	353.9	60.8	199.93	91.47	8.40	16.02		132.8	0.17
	8/25/80	1600.	7.47	360.5	246.5	322.0	29.5	166.72	115.62		17.44		114.0	0.09
C2003D SCREEN 138-143'	1/28/80	1900.		515.8		448.1	39.8	219.35	167.80	4.32	23.51			0.09
	8/25/80	1750.	7.30	345.5		366.1	90.6	170.10	105.88		19.72			0.24
C2004S SCREEN 18-23'	8/17/78	8430.	6.95	1361.2		2666.1		1418.70	324.38	19.20	133.91			
	8/25/80	4250.	7.21	882.5	286.0	1025.3	85.0	578.95	243.25		66.83			0.08
C2004D SCREEN 56-63'	8/17/78	28300.	7.07	4231.5		10071.7		5536.57	436.02	186.44	763.55			
	8/25/80	30000.	7.04	4196.7	216.0	9812.7	1778.7	5063.38	560.76		679.42			0.18
C2005S SCREEN 43-48'	9/07/78	52000.	7.85	7082.9	219.0	19334.6	2757.2	7008.51	525.06		1402.29			0.14
	8/25/80	50000.	6.94	7089.1	246.5	17193.9	2126.1	9397.95	621.41	343.08	1345.34			0.12
C2005D SCREEN 72-78'	9/07/78	59000.	7.89	7740.4	232.5	22408.5	3112.0	12051.54	551.27	414.64	1546.12			0.14
	1/22/79	50790.				24023.7	2930.2							0.12
C2006S SCREEN 5-10'	5/29/80	2900.		737.5				288.39	265.84	2.28	17.90			
	8/25/80	3600.	6.96	917.4	246.5	937.2	21.1	381.49	331.72		21.64			0.02
C2006D SCREEN 25-30'	10/5/78	7790.	6.85	1422.6	260.5	2498.4	305.3	1137.59	314.59	19.80	154.78			0.12
C2007D SCREEN 21-69'	10/23/78	7200.												
	8/25/80	4400.	6.86	983.3	319.5	1113.5	19.7	568.81	299.62		57.14			0.02

TABLE 5. (Continued)

	SAMPLING DATE	SPECIFIC CONDUCTIVITY (umhos/cm)	pH	HARDNESS (mg/1)	ALKALINITY (mg/1)	Cl^- CHLORIDE (mg/1)	$SO_4^=$ SULFATE (mg/1)	Na^+ SODIUM (mg/1)	Ca^{++} CALCIUM (mg/1)	K^+ POTASSIUM (mg/1)	Mg^{++} MAGNESIUM (mg/1)	Fe^{+++} DISS.IRON (mg/1)	NON-CARBONATE HARDNESS (mg/1)	RATIO SULFATE TO CHLORIDE
C2008DS														
SCREEN	5/28/80	1000.		405.0				58.21	136.77	2.33	15.43			
32-37'	8/25/80	960.	7.34	355.5	257.5	95.9	51.7	53.11	119.27		14.01		98.0	0.53
C2008DD	1/28/80	1380.		484.8		179.0	148.4	118.63	160.78	3.19	20.25			0.82
SCREEN	5/28/80	1420.		323.7	303.5	160.1	138.9	57.55	104.12	2.35	15.48		20.2	0.86
62-67'	8/25/80	1400.	7.01	512.0	319.5	175.2	131.0	104.16	168.02		22.47		192.5	0.75
C2009D														
SCREEN	1/28/80	1800.		538.8		358.6	85.5	160.39	178.25	4.30	22.77			0.24
57-62'	5/28/80	1900.		755.9	303.2	413.0	58.4	167.03	258.93	4.30	26.57			0.14
C2010D	5/28/80	1140.		413.6	258.0	164.7	27.8	77.99	143.34	2.17	13.52		155.6	0.16
SCREEN	8/25/80		7.01	350.2	341.5		68.4		126.81		8.16		8.7	
15-20'	1/09/81			459.8	321.0	208.4	25.9	93.19	159.78	1.86	14.79	2.67	138.8	0.12
C2011D	1/10/80	700.		327.2	286.0	38.9	20.0	34.02	123.38	0.40	4.64		41.2	0.51
OPEN	8/25/80	660.	7.00	298.7	308.0	23.2	15.6	19.97	111.96		4.64			0.67
20-140'	1/09/81			331.9	315.5	33.7	17.6	19.97	125.33	0.51	4.60	4.43	16.4	0.52
C2012D	1/09/80	820.		310.7	255.5	93.6	18.7	59.91	115.97	0.73	5.12		55.2	0.19
OPEN	6/23/80			333.9	245.5	104.0	22.6	54.44	124.13	1.39	5.81		88.4	0.21
8-220'	8/25/80	820.	7.24	297.7	257.5	102.5	18.3	51.92	109.70		5.78		40.2	0.18
	1/09/81			317.5		81.1	14.8	46.86	118.92	0.72	4.99	2.67		0.18
C2013D	7/24/80	1020.	6.93	339.9	269.5	153.4	54.1	83.18	116.44		11.93		70.4	0.35
OPEN	8/25/80	970.	7.19	317.5	257.5	133.4	15.6	71.20	109.70		10.58		60.0	0.11
25-72'	1/09/81			352.7	288.0	140.4	16.2	77.38	120.53	2.63	12.57	0.99	64.7	0.11
C2014D	1/28/80	1900.		483.6		425.7	97.0	212.77	154.44	6.01	23.81			0.23
SCREEN	5/28/80	1750.		466.3	303.5	385.6	86.1	283.45	151.46	4.37	21.41		162.8	0.22
69-74'	8/25/80	1700.	7.45	408.1	274.5		60.0		144.65		11.40		133.6	
	1/09/81			394.5	271.5	212.7	50.9	107.42	140.23	2.27	10.77	1.81	123.0	0.24
C2015D	5/29/80	1090.		429.7	315.0	192.0	8.4	105.69	151.46	2.31	12.51		114.7	0.04
SCREEN	8/25/80	700.	7.27	269.6	235.5	76.1	12.8	38.23	101.13		4.14		34.1	0.17
35-40'	1/09/81			266.1	248.0	76.8	9.3	38.47	100.98	0.62	3.40	3.55		0.12
C2017D														
SCREEN														
310-330'	11/5/80	7600.		958.0	158.0	2081.2	620.8	1284.21	152.43	39.68	140.28			0.30

Cooke, 1944). The sandstones and sandy limestones that generally lie at depths of 60 feet and greater may still contain remnants of this ancient sea water due to the low permeability of these units and the regionally low pressure gradients that drive water through them. The saline water in the bottom part of the shallow aquifer could thus be unflushed sea water as suggested by McCoy (1962).

Another factor that may explain the lack of flushing in the lower part of the shallow aquifer is the existence of a marly stratum, which in some areas occurs at the top of the limestone Unit 2. This low permeability stratum would prevent deep infiltration of rainfall and the freshening or flushing of the underlying strata. This marly layer has been detected in many areas of western Collier County, but it is not persistent. Thus the degree of flushing may depend on the areal extent of the marl. The limestone overlying the marl is often cavernous, suggesting more rapid movement of groundwater in this zone. This would be a factor in enhancing solution of the limestone and flushing relict saline water from the shallow part of the aquifer.

Another factor that may account for saline water in the bottom of the shallow aquifer is the existence of the underlying artesian aquifer. At Well C-2017D, this aquifer contains water having a chloride content of over 2000 mg/l under a hydrostatic pressure head of 23 feet above land surface. It is probable that the confining layer on top of the artesian aquifer allows slow seepage of the saline water into the bottom of the shallow aquifer; this is suggested by a comparison of sulfate and chloride-ion ratios found in water samples from the project wells. The sulfate to chloride ratio (Table 5) of the artesian water is 0.298 and that common in sea water is 0.142 (Hem, 1970). On this basis, groundwater having a sulfate to chloride ratio significantly greater than sea water (wells C-2008D, C-2011D, C-2012D, and C-2014D) can be considered partially derived from the underlying artesian aquifer. The sulfates in the artesian aquifer may have been derived from dissolution of evaporites and anhydrite, known to exist at considerably greater depths.

Recurring threats of salt-water contamination of fresh groundwater in the shallow aquifer can occur because of tidal inundations that may accompany major hurricanes. Figure 2 shows areas of inundation expected from cyclonic storms with up to a 100-year return frequency. Inundations having lower frequencies could conceivably spread sea water over all of western Collier County. Prudent development of municipal water supplies from the shallow aquifer would dictate inland or topographically high locations for supply wells.

In addition to the mechanisms discussed above for salt-water contamination of the shallow aquifer, the obvious coastal source of sea water presents a constant but manageable threat. In this area of low topographic elevations, and therefore low fresh-water pressure head, sea water can easily migrate inland in response to overpumping of fresh groundwater. Although historical data are lacking to trace the inland movement of the sea water front with time, a local land owner reported that several hundred acres of near coastal farm land had been abandoned because of overpumping and the depletion of fresh groundwater.

Salt-water intrusion can also occur in uncontrolled canals and ditches. At the end of the dry season of each year, the discharge of Henderson Creek is significantly reduced below its annual mean. This permits the upstream intrusion of sea water, especially during high tide. The relatively shallow depth to the interface observed at well C-2008D is probably due to this intrusion.

In addition to the salinity of the groundwater, other chemical characteristics pose limitations to groundwater use. Among the water quality parameters that appear in Table 5, the carbonate and non-carbonate hardness and dissolved iron concentrations are significant.

Groundwater hardness (total) in the shallow aquifer zone above the interface generally ranges between 300 and 500 mg/l (as $CaCO_3$). This is typical of south Florida's groundwater and is considered "very hard" (Hem, 1970). There is considerable variability in hardness within the study area and also within several of the wells throughout the year. The non-carbonate hardness (attributable to Ca^{++} and Mg^{++} in association with other ions such as $SO_4^{=}$) is also characteristically high. It ranges from about 10 to 200 mg/l and averages about 70 mg/l. Although non-carbonate hardness poses no problem to zeolite-type water softeners commonly used in the home, utility companies using such water may find it necessary to soften the water by a more expensive soda-ash treatment in addition to the application of lime.

Variability is also noted in the dissolved iron concentration. Analyses for iron indicate that the dissolved iron concentration in the shallow aquifer is above recommended limits for drinking water. The recommended maximum iron concentration in drinking water is 0.3 mg/l (EPA, 1978). For domestic use, iron removal is desirable.

GROUNDWATER AVAILABILITY

Hydrogeologic data obtained within the study area during this investigation were used to estimate groundwater availability; this estimate was based on average annual inflows to the shallow aquifer.

Inflows to the shallow aquifer are derived principally from two sources; direct infiltration of precipitation, and subsurface inflows from adjacent areas. Studies by the South Florida Water Management District (Burgess, personal communication) suggest that the annual average precipitation is 7 inches greater than the annual average evapotranspiration. Within the 65-square mile project area, approximately 20 square miles are located in or near the tidal marshes and therefore do not contribute to the availability of water. The net inflow from rainfall to the remaining 45 square miles was calculated to be 15 million gallons per day (mgd), on an average annual basis.

Subsurface inflow to the study area was calculated using flow net analysis that incorporated the transmissivities and groundwater gradients measured during this study; the subsurface inflow was calculated to be 7 mgd. Of the total inflow of 22 mgd; about 6 mgd is required to maintain the existing seaward gradient of fresh water for the prevention of salt-water intrusion. To maintain this gradient, no major groundwater withdrawals should be considered south of U. S. Route 41. The remaining 16 mgd may be augmented considerably as evapotranspiration is salvaged within the cones of depression of pumping wells. Site-specific evaluations of water availability, using guidelines suggested below, should be conducted for any significant proposed groundwater use.

GROUNDWATER DEVELOPMENT POTENTIAL

Development of groundwater in the study area is subject to a number of limiting factors; the most important of which is water quality. Saline water occurs at relatively shallow depths. In addition, the area borders the coast and saline intrusion could result from local overdevelopment of the aquifer. The coastal canals allow penetration of sea water inland, providing another potential source of saline contamination. Water quality considerations, therefore, limit the location of wells and their available yield and drawdown. As shown in the previous sections of this report, the shallow aquifer in some parts of the study area does, however, contain good quality water at shallow depths. This water can be safely developed by means of proper well construction and wellfield design. The major factors to be considered in well construction and wellfield design are:

(1) Wells should be sited away from the coastline and areas prone to wave inundation (see Figure 2).

(2) Wells should be sited, where possible, to induce recharge from surface-water bodies where these surface bodies contain good quality water.

(3) The screened or open-hole portion of a production well should be substantially above the saltwater/freshwater interface. Generally, wells should not tap the bottom one third of the freshwater portion of the aquifer (see Figure 16 for the depth to the interface).

(4) Withdrawals from individual wells should be limited so that drawdowns do not cause water quality deterioration by the lateral movement or upconing of saltwater. Generally, pumping levels (excluding frictional head losses near the well) should be above mean sea level. Deeper pumping levels may be considered in the area northeast of Route 41.

Shallow private wells used for lawn sprinkling are common in south Florida and are encouraged. Such wells can be developed safely and used in most of the study area. A suitable depth for these wells is 15-20 feet. The sometimes hard limestone that lies at about 8 feet below surface, however, may preclude well construction by driving sand points.

For larger groundwater developments, the area extending inland from about 1 mile northeast of Route 41 is suggested as most suitable. Wells C-2011D and C-2012D are good examples of wells that may be located in this area. These wells have specific capacities (pumping rate divided by drawdown) of about 100 gpm per foot. A pumping rate of 500 gpm at either site would produce a drawdown from the dry-season static water level (about four feet above mean sea level) to a level about one foot below sea level. On the basis of this demonstration, and the results of the aquifer test, a well in the suggested area should be capable of producing 400 to 500 gpm without adverse effects. Wells that are constructed on the same or adjacent properties whose cones of depression overlap will act to reduce the ultimate pumping capacities described above.

In those areas where significant pumping rates are proposed, monitoring of saline water is recommended. Monitoring wells in these circumstances should be placed to observe the effects of pumping at a horizon deeper than the depth of the pumping well to preclude upconing effects and, where appropriate, wells of similar depths should be installed to observe lateral movements of the freshwater/saltwater interface. Limiting conditions to a water use permit should require that, in the even some set chloride level is exceeded, pumpage be reduced such that this level is not violated.

Limiting conditions to a water use permit issued for agricultural or ranching purposes (improved pasture) should require best management practices (BMP) for agricultural irrigation; and in those areas where wells will flow under flowing artesian conditions, should require that adequate control valves be installed and maintained in good operating condition to preclude unnecessary waste of water. Further, these type wells should be shut down by use of the operating valves during periods of adequate rainfall.

All wells existing on a property where a water use permit is being considered (that are in a derelict or abandoned state) should be plugged using criteria and techniques approved by the Water Management District.

Based on the results of this study, the longterm sustained yield on an average annual basis is about 250,000 gallons per day per square mile. Significantly larger withdrawals may be appropriate on an areal basis if certain hydrogeologic conditions exist. Inflow (recharge) from canals is one example of such a situation. A second, less tangible circumstance can occur due to salvage of evapotranspirative losses within appropriate portions of the cone of depression created by the pumping. The quantities thus salvaged can be very substantial, particularly in areas that are heavily pumped and wherein regional water levels are lowered several feet.

By the same token, hydrologic and regional constraints can act to limit long term sustained yields described above. Proximity to saltwater reaches of canals having access to the Gulf of Mexico or higher capacity wells in areas south of Route 41 are two examples where such constraints are appropriate.

A further limitation to pumping can occur in those areas where heavy pumping can cause drainage of environmentally sensitive lands by the lowering of water levels. All of the conditions described above that may act to increase or decrease safe yields must be considered on a case-by-case basis.

SUMMARY AND CONCLUSIONS

(1) The shallow aquifer in the study area consists of a series of sand, sandstone, and limestone beds extending from ground surface to about 185 feet below ground. The base of the aquifer is a clay layer which confines groundwater in the underlying Hawthorn aquifer.

(2) The most permeable zone within the aquifer is the limestone sequence, generally encountered between 20 feet and 50 feet below ground surface. A semi-confining zone of marly limestone sometimes separates this main producing zone from the surficial sands. Transmissivities in the aquifer determined from two pumping tests range from 230,000 to 290,000 gpd/ft; the storage coefficient varies from 0.00052 to 0.0029; and the coefficient of leakance varies from 0.40 to 5.73 gpd/ft^3.

(3) The saltwater/freshwater interface (defined as the 250 mg/l isochlor) varies in depth from land surface to greater than 100 feet. Saline water at the bottom of the aquifer may be the result of direct intrusion from the Gulf of Mexico, relict sea water from wave inundations, or upward leakage of brackish water.

(4) The available quantity of groundwater in the study area is estimated to be 16 mgd. However, step-by-step development of this supply is recommended, with major withdrawals sited north of Route 41. Wells which tap the main body of the aquifer may produce up to 500 gallons per minute without adverse effects.

(5) Domestic wells or lawn-irrigation wells may be utilized throughout the area, with recommended depths of 15 to 20 feet.

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A P P E N D I X I

LITHOLOGIC LOGS

SFWMD Well No. C-2002D
Collier County
Latitude: 26°05'37"
Longitude: 81°44'19"
Sec. 30, T 50S, R 26E
Reference Datum: 4.5 ft. NGVD
Onwer:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Paul Jakob

DEPTH (FT.)	DESCRIPTION
0 - 5	Sand, quartz, medium to fine grained.
5 - 10	Sand, quartz, as above with brownish organic material.
10 - 24	Limestone, white and gray with shell and minor coral in micrite matrix; some quartz grains present; drilling easy.
24 - 46	Limestone, gray with shell fragments and minor coral in loose micrite; some hard limestone streaks; hard drilling at 24 feet, otherwise medium drilling.
46 - 54	Limestone, medium gray with shell fragments in loose to dense micrite; split spoon sample indicates limestone is tight at 51 feet.
54 - 79	Limestone, medium gray, with shell fragments some sand and minor coral in loose to hard micrite.
79 - 99	Limestone, light gray, sandy, shell fragments and quartz sand in micrite; medium to hard drilling; quartz content increases to about 20% at 99 feet.
99 - 114	Limestone, sandy; contains about 30% medium gray shell fragments and 20% quartz sand in dense micrite. Small phosphorite nodules between 104 feet and 114 feet.
114 - 149	Sandstone, brownish gray; medium to fine quartz sand and shell fragments in loose micrite; few dense streaks; some phosphorite nodules between 144 feet and 149 feet.
149 - 155	Limestone, brownish gray, hard micrite and some shell fragments; cuttings return poor, circulation lost at 149 feet; hard, dense limestone at about 152 feet to 155 feet.
155 - 167	Clay and silt, greenish gray; quartz in fine grains about 20%, some phosphorite (Note: no cuttings return, sample collected from drilling bit).

SFWMD Well No. C-2003D
Collier County
Latitude: 26°05'49"
Longitude: 81°40'21"
Sec. 23, T 50S, R 26E
Reference Datum: 9.2 ft. NGVD
Owner:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Paul Jakob

DEPTH (FT.)	DESCRIPTION
0 - 5	Quartz, sand; medium size, clear, subrounded.
5 - 14	Limestone, very hard, light gray micrite; minor shell inclusions.
14 - 20	Lost circulation at 14 feet, no cuttings.
20 - 29	Sandy marl, soft drilling, cuttings well suspended in drilling mud, sand is medium to fine quartz, marl light gray.
29 - 38	Limestone, rounded shell fragments loosely cemented in micrite, few streaks of dense limestone; some quartz sand; lost circulation at 34 feet, drilling soft.
38 - 44	Limestone, dense micrite, gray; some shell fragments, subrounded, drilling medium.
44 - 54	Limestone, loose micrite matrix, subrounded small shell fragments, 20% hard limestone streaks; medium drilling; trace of phosphorite. Lost circulation at 49 feet.
54 - 79	Limestone, micrite matrix, shell fragments subrounded; lesser amounts of dense limestone fragments, all gray to light gray; lost circulation at 79 feet, drilling medium.
79 - 99	Limestone, subrounded shell fragments in micrite; some dense limestone streaks; some phosphorite from 80 feet to 85 feet, lost circulation at 98 feet; medium drilling; increasing quartz content towards bottom; drilling soft from 95 feet.
99 - 138	Sandstone, quartz grains cemented loosely; some shell fragments, some dense limestone steaks; soft drilling; some phosphorite nodules.
138 - 142	Sandstone, less quartz than above, loose cementing; significant shell content; some phosphorite; drilling soft, hard streak at 138 feet to 129 feet.

SFWMD Well C-2003D (Continued)

DEPTH (FT.)	DESCRIPTION
142 - 171	Sandstone, poor cementation, mostly medium and fine quartz grains; shell content down to 5%, subrounded fragments; phosphorite present; hard limestone streaks 146 feet to 148 feet, lost circulation 153 feet to 155 feet and 166 feet to 168 feet.
171 - 179	Calcareous clay and silt, 20% fine quartz grains; minor phosphate mineral.

SFWMD Well No. C-2004D
Collier County
Latitude: 26°03'02"
Longitude: 81°41'40"
Sec. 10, T 51S, R 26E
Reference Datum: 3.2 ft. NGVD
Owner:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Paul Jakob

DEPTH (FT.)	DESCRIPTION
0 - 5	Sand, quartz, fine to medium, clear, subrounded.
5 - 10	Limestone, mostly dense micrite, some shell included, very hard.
10 - 19	Limestone, light gray shell in micrite, some quartz sand and coral; drilling medium hard from 10 feet to 17 feet, soft from 14 feet to 19 feet.
19 - 29	Limestone, light gray shell fragments in loose micrite; some coral and hard limestone stringers.
29 - 34	Limestone, light gray and buff; shell and quartz grains in micrite, loose cementation.
34 - 44	Limestone, light gray and buff, rounded shell fragments and minor sand in micrite; medium drilling.
44 - 109	Limestone, sandy, gray shell and quartz grains in micrite; few hard streaks of more dense limestone at 59 feet to 64 feet; some coral and phosphorite between 70 feet and 80 feet; medium to hard drilling; quartz content increasing with depth; lost circulation at 85 feet.
109 - 124	Sandstone, greenish gray, almost entirely fine quartz grains, loosely cemented; some rounded shell fragments.
124 - 141	Limestone, gray micrite matrix with shell fragments; minor quartz inclusions, increasing with depth; several stringers of dense limestone.
141 - 174	Sandstone, gray, very loosely cemented; medium quartz grains predominate; some shell fragments and phosphorite nodules; several streaks of hard, dense limestone between 149 feet and 157 feet.
174 - 194	Sand and sandstone, gray rounded quartz grains of variable size; more frequent streaks of hard gray limestone or dolomite; some phosphorite in larger grain sized; minor shell inclusions.

SFWMD Well No. C-2004D (Continued)

DEPTH (FT.)	DESCRIPTION
194 - 199	Sand and sandstone, gray loosely cemented quartz grains, subrounded, predominantly fine grained; some rounded quartz grains; minor phosphorite.

SFWMD Well No. C-2005D
Collier County
Latitude: 26°00'18"
Longitude: 81°38'22"
Sec. 30, T 51S, R 27E
Reference Datum: 3.9 NGVD
Owner:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Paul Jakob

DEPTH (FT.)	DESCRIPTION
0 - 5	Sand silica, medium, subrounded; moderate amount of organic material.
5 - 14	Limestone, hard dense micrite with some sand.
14 - 28	Limestone, white micrite with shell and some sand, some dense limestone stringers, circulation lost at 27 feet.
28 - 37	Limestone, rounded shell and fine to medium sand in micrite; sand decreasing to bottom of interval; drilling soft.
37 - 47	Limestone, rounded shell fragments loosely held in micrite; some dense limestone near bottom of interval.
47 - 88	Limestone, hard, dense, interspersed with loose micrite holding shell fragments; increasing sand from 62 feet to 70 feet; circulation lost at 83 feet.
88 - 133	Sandstone, limey, sand and some shell in loose micrite, some dense stringers, some phosphorite nodules, increasing at 98 feet, increasing occurrence of gray (phosphorite) shell in lower half of interval.
133 - 143	Limestone, white and gray, shell in micrite; sand content minor; phosphorite nodules present.
143 - 163	Limestone, gray and white, minor shell and sand in dense micrite, cuttings angular.
163 - 171	Sandstone, limey, large rounded quartz grains in micrite matrix; minor shell fragments; some gray limestone and quartz.
171 - 175	Limestone, hard; loss of drilling mud between 171 feet and 172 feet.
175 - 177	Clay and limestone stringers, no cuttings.
177 - 183	Sandstone, limey, white to gray quartz grains large and rounded, minor shell content, some phosphorite.

SFWMD Well No. C-2005D (Continued)

DEPTH (FT.)	DESCRIPTION
183 - 198	Sandstone, limey, 60% quartz grains, large, rounded, frosted and gray (minor amounts) in sparse micrite; quartz grains increase to 90% at 188 feet and below, little evidence of cementation; clay streak at 187 feet.

SFWMD Well No. C-2006D
Collier County
Latitude: 26°00'55"
Longitude: 81°39'22"
Sec. 24, T 51S, R 26E
Reference Datum: 3.0 ft. NGVD
Owner:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Paul Jakob

DEPTH (FT.)	DESCRIPTION
0 - 9	Sand, fine to medium clear, upper 5 feet contains moderate amount of organics.
9 - 14	Sandstone, fine to medium grains, loose micrite cement.
14 - 29	Limestone, sand and shell fragments in loose micrite with streaks of dense micrite.
29 - 70	Limestone, micrite holding minor sand and major portion of shell fragments, with some streaks of dense micrite; shell decreases with depth between 34 feet and 54 feet while dense limestone increases to 90%.

SFWMD Well No. C-2007D
Collier County
Latitude: 26°04'47"
Longitude: 81°44'25"
Sec. 31, T 50S, R 26E
Reference Datum: 44 ft. NGVD
Onwer:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Paul Jakob

DEPTH (FT.)	DESCRIPTION
0 - 9	Sand, quartz, fine to medium; contains moderate amount of organics between 4 feet and 9 feet.
9 - 19	Limestone, hard and dense, micrite, some brownish in color, circulation lost between 11 feet and 19 feet.
19 - 34	Limestone, brown to gray, mostly dense micrite, some loose micrite with shell and minor quartz grains; shell content increases below 29 feet.
34 - 69	Limestone, light gray, micrite matrix with shell and some quartz; minor coral, less dense hard micrite than above.

SFWMD Well No. C-2008D
Collier County
Latitude: 26°04'35"
Longitude: 81°41'17"
Sec. 34, T 50S, R 26E
Reference Datum: 7.0 ft. NGVD
Owner:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Paul Jakob

DEPTH (FT.)	DESCRIPTION
0 - 10	Limestone, sandy, brown, gray or white, fossiliferous, some iron staining, vuggy, shell imprints.
10 - 20	Limestone, marly, light gray, shell in micrite, vuggy, minor quartz sand, trace of phosphorite.
20 - 40	Limestone, light gray, sand and shell in micrite, vuggy, some coral, minute trace of phosphorite.
40 - 50	Same as above, with more coral and shell.
50 - 80	Limestone, abundant shell, light gray, minor quartz sand, some oolite present, minor coral, trace of phosphorite.
80 - 100	Sandstone, limey, light gray to light greenish gray, fine to medium grained quartz, some shell, trace of phosphorite.
100 - 110	Sandstone, limey, light gray, some shell, trace of phosphorite, minor coral.
110 - 120	Sandstone, limey, light gray, friable, some shell, trace of phosphorite.
120 - 133	Limestone, sandy, light gray with shell, trace phosphorite and some coral.
133 - 138	Clay.
138 - 150	Limestone, sandy, light brown, abundant shell, minor coral.
150 - 158	Same as above with brown and gray limestone, and some coarse, well rounded quartz grains.
158 - 160	Sand, coarse quartz, rounded to subrounded, elongated, frosted, weak micrite matrix, trace of phosphorite.

SFWMD Well No. C-2008D (Continued)

DEPTH (FT.)	DESCRIPTION
160 - 170	Clay with fine to medium quartz sand, grayish green color, a few well rounded elongated coarse quartz sand grains.
170 - 180	Clay and fine sand, grayish green color, minor well-rounded coarse quartz sand.

SFWMD Well No. C-2009D
Collier County
Latitude: 26°04'04"
Longitude: 81°42'44"
Sec. 33, T 50S, R 26E
Reference Datum: 5.9 ft. NGVD
Owner:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Paul Jakob

DEPTH (FT.)	DESCRIPTION
0 - 10	Silt and fine sand, well sorted, brownish gray to black, angular to subangular, minor phosphorite.
10 - 20	Limestone, marly, light gray, shell and minor quartz sand in micrite, minor coral, vuggy, trace of phosphorite.
20 - 40	Same as above with more shell and coral.
40 - 50	Same as above with oolites.
50 - 60	Limestone, light gray shell and sand in micrite; trace of phosphorite.
60 - 70	Limestone, sandy, with shells, light gray, trace of phosphorite, minor coral.
70 - 100	Same as above, with greenish tinge.
100 - 140	Sandstone, limey, fine to medium grained sand, some shell gray to greenish gray, streaks of dense, hard micrite, some shell, trace of phosphorite; lost circulation between 104 feet and 106 feet.
140 - 160	As above, with streaks of hard limestone.
160 - 165	Limestone, streaks of dense micrite with layered sandstones.
165 - 171	Coarse to very coarse, gray quartz, rounded to subrounded quartz, frosted, clay steaks, phosphorite trace.
171 - 175	Sand, loose or no matrix, fine to medium grained, gray to greenish gray, trace of phosphorite.
175 - 190	Clay, silt and fine to coarse quartz sand, rounded to subrounded, frosted, grayish green, trace of phosphorite.

SFWMD Well No. C-2010D
Collier County
Latitude: 26°01'57"
Longitude: 81°39'12"
Sec. 18, T 51S, R 27E
Reference Datum: 5.5 ft. NGVD
Owner:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Paul Jakob

DEPTH (FT.)	DESCRIPTION
0 - 5	Sand, medium, silica.
5 - 10	Limestone, hard, light micrite, softer between 10 feet and 12 feet.
10 - 20	Limestone, marly, gray/white micrite with shale fragments and minor quartz sand, vuggy, medium drilling.
20 - 37	Limestone, hard with shell fragments.
37 - 60	Limestone, gray/white, vuggy, shell fragments in micrite; minor quartz sand increasing towards bottom. Streak of iron stained limestone, at 50 feet.
60 - 80	Limestone, shell fragments in micrite, and rounded quartz sand.
80 - 90	Limestone, sandy, white to gray micrite with shell fragments, large phosphorite grains.
90 - 100	Sandstone, limey, with shell fragments, large phosphorite grains.
100 - 120	Sandstone, limey, white to gray with shell fragments; trace of phosphorite.
120 - 133	Sandstone, limey, gray to dark gray with shell fragments, trace of phosphorite.
133 - 135	Sandstone, limey, very hard; with shell fragments and phosphorite.
135 - 140	Sandstone, limey, gray to white; phosphorite grains; shell and wood fragments.
140 - 145	Sandstone, gray to dark gray; with shell fragments, phosphorite.
145 - 174	Limestone, sandy, grayish brown, cherty, vuggy; shell fragments and molds; trace of phosphorite, gray between 150 and 160 feet.

SFWMD Well No. C-2010D (Continued)

DEPTH (FT.)	DESCRIPTION
(@174)	Sand, coarse, rounded, quartz.
175 - 180	No samples, lost circulation, cavernous (bit dropped).
180 - 195	Sand, quartz, rounded, fine; trace of phosphorite grains.
195 - 220	Clay.

SFWMD Well No. C-2011D
Collier County
Latitude: 26°05'27"
Longitude: 81°43'02"
Sec. 28, T 50S, R 26E
Reference Datum: 6.4 ft. NGVD
Owner:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Paul Jakob

DEPTH (FT.)	DESCRIPTION
0 - 10	Sandstone and sand, fine to medium, light micrite cement, iron staining, trace phosphorite grains, clay streaks near bottom.
10 - 20	Limestone, cherty and vuggy with abundant shells, marly from 15 feet to 20 feet, phosphorite and minor coral from 18 feet to 20 feet.
20 - 40	Limestone, white to gray micrite with shell and some sand.
40 - 52	Limestone, mostly coral fragments and shell, some sand.
52 - 57	Limestone, abundant shell in grayish micrite, some coral and sand.
57 - 60	Limestone, sandy, white to gray, minor coral.
60 - 70	Limestone, sandy, with rounded shell fragments.
70 - 80	Limestone, sandy, white to gray with shell, some coral fragments and minor phosphorite grains.
80 - 110	Sandstone, limey, white to gray, with shells, coral and minor phosphorite.
110 - 140	Rapid softening, lost circulation, bit dropped to 113 feet, could not regain circulation or add pipe; no cuttings.

SFWMD Well No. C-2012D
Collier County
Latitude: 26°04'10"
Longitude: 81°39'20"
Sec. 36, T 50S, R 26E
Reference Datum: 7.0 NGVD
Owner:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Paul Jakob

DEPTH (FT.)	DESCRIPTION
0 - 6	Sand, quartz, unsorted fine to medium.
6 - 10	Limestone, brownish-gray, hard, vuggy, shells, some sand, trace of phosphorite.
10 - 20	Limestone, vuggy, white to light gray, micrite with shells, very minor quartz sand.
20 - 50	Limestone, shell in micrite, some sand, trace of phosphorite.
50 - 60	Same as above, with some coral present.
60 - 80	Limestone, shell in micrite, increasing fine sand, trace of phosphorite.
80 - 100	Sandstone, limey, with shell, trace of phosphorite, minor coral.
100 - 119	Sandstone, limey, white to light gray, some shell, trace of phosphorite.
119 - 126	Limestone, dark gray, phosphorite shell in micrite.
126 - 128	Clay streak.
128 - 134	Limestone, brownish gray, shell in micrite with sand.
134 - 146	Limestone, gray to beige, with shell in dense micrite, vuggy, minor coral.
146 - 152	Limestone, very hard, dark gray shell (phosphatic) in dense micrite.
152 - 157	Sand, large rounded quartz grain, frosted.
157 - 158	Limestone.
158 - 160	Clay.
160 - 176	Sandstone, quartz grains, rounded, large in loose cement; with streaks of hard limestone and some clay.

SFWMD Well No. C-2012D (Continued)

DEPTH (FT.)	DESCRIPTION
176 - 220	Silt and fine sand, sorted, greenish gray.

SFWMD Well No. C-2013D
Collier County
Latitude: 26°02'35"
Longitude: 81°40'07"
Sec. 12, T 51S, R 26E
Reference Datum: 5.5 ft. NGVD
Owner:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Paul Jakob

DEPTH (FT.)	DESCRIPTION
0 - 9	Sand, quartz, fine to medium, clear; organics.
9 - 20	Sandstone, limey to limestone, light gray mostly in micrite matrix, some sparry calcite; shell, hard streak at 15 feet.
20 - 30	Limestone, light gray, hard, micrite with fine quartz sand; some shell, some sparite; 2-3 feet cavity at 25 feet.
30 - 50	Limestone, gray, shell hash in micrite; some coral, some shell.
50 - 60	Limestone, gray dense micrite; some shell.
60 - 70	As above, with pellets or rounded shell fragments.
70 - 80	Limestone, light gray micrite, pellets or rounded shell fragments and some medium quartz grains; trace phosphorite.
80 - 110	Sandstone, limey, gray with buff tinge from 80 feet to 90 feet, medium quartz grains and shell fragments in micrite; some coral, trace phosphorite, quartz content increases with depth.
110 - 130	Sandstone, limey, light gray medium quartz sand in micrite; some shell, some phosphorite.
130 - 160	Sandstone, limey, grayish, fine and medium quartz sand in micrite; some shell and phosphorite nodules; brown streak at 147 feet; green streak at 157 feet.
160 - 170	Sandstone, limey, gray and clear quartz sand in micrite, some larger quartz grains; some shell and coral, phosphorite (<1%); green clay streak at 165 feet.
170 - 180	Limestone, hash of shell and some quartz sand in micrite; some large dark limestone fragments, phosphorite; hard streak at 175 feet.

SFWMD Well No. C-2013D (Continued)

DEPTH (FT.)	DESCRIPTION
180 - 185	Limestone, hash of brown to light gray shell and quartz sand in dense micrite; 20% limestone fragments are gray (phosphatic?), some large phosphorite nodules.
185 - 192	Limestone, gray; large quartz grains, rounded, and shell, in gray micrite; hard drill.
192 - 200	Sand, gray, medium to large frosted and rounded quartz grains in very light micrite matrix; some phosphorite grains.
200 - 220	As above; grains larger, up to ¼ inch.

SFWMD Well No. C-2014D
Collier County
Latitude: 26°02'58"
Longitude: 81°37'20"
Sec. 08, T 51S, R 27E
Reference Datum: 8.0 ft. NGVD
Owner:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Paul Jakob

DEPTH (FT.)	DESCRIPTION
0 - 5	Sand, fine quartz.
5 - 10	Sandstone, limey, hard fine quartz in micrite matrix; iron stain and root material.
10 - 20	Limestone, white, very hard micritic, with fine quartz, some shell; drilling easier at 15 feet, circulation lost at 20 feet.
20 - 50	Limestone, white, soft, micrite matrix with abundant small shell fragments, harder at 38 feet, trace phosphorite at 40 feet to 50 feet.
50 - 60	Limestone, soft, white, micrite with abundant shell fragments; trace of phosphorite, minor coral.
60 - 75	Limestone, sandy, light gray, abundant shell, trace phosphorite; harder drilling between 70 feet and 75 feet.
75 - 80	Cavity, lost circulation, convert to air drilling.
80 - 100	Sandstone, limey, soft, medium quartz grains in white micrite matrix; abundant shell fragments, trace phosphorite.
100 - 130	Sandstone, limey, light gray, medium hard, fine quartz in micrite matrix; shell and trace phosphorite.
130 - 150	Sandstone, limey, tan, fine quartz in micrite matrix; abundant shell, trace phosphorite.
150 - 160	Sandstone, limey, gray medium sized quartz grains in micrite matrix; abundant shell, trace phosphorite; hard streak limestone between 154 feet and 157 feet.
160 - 170	Sandstone, limey, hard drill, medium sized quartz, gray, tan to green micrite matrix; abundant shell, some gray.

SFWMD Well No. C-2014D (Continued)

DEPTH (FT.)	DESCRIPTION
170 - 183	Sandstone, limey, hard drill, medium to large gray quartz grains in micrite, some tan matrix; shell; some sparry calcite; clay streak at 178 feet.
183 - 185	Green clay, carbonate, with fine sand.
185 - 190	Sand, clean frosted quartz grains, rounded, medium to coarse.
190 - 198	Sand, medium with silt and clay stringers; shell fragments at base of interval.

SFWMD Well No. C-2015D
Collier County
Latitude: 26°01'20"
Longitude: 81°38'00"
Sec. 17, T 51S, R 27E
Reference Datum: 6.0 ft. NGVD
Onwer:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Paul Jakob

DEPTH (FT.)	DESCRIPTION
0 - 10	Sandy, yellow-brown, subangular, quartz, dirty; with micritic and sparry matrix.
10 - 20	Limestone, light gray micritic; with some shell.
20 - 50	Limestone, light gray micrite; with some shell; quartz, and coral; brownish from 30 feet to 40 feet.
50 - 75	Limestone, light gray micrite matrix; with shell, coral, trace of phosphorite; lost circulation from 60 to 70 feet; sandy below 70 feet.
75 - 90	Sandstone, gray, with buff tinge quartz, subrounded, fine grain, in micrite matrix; with some shell pellets and trace of phosphorite.
90 - 100	Sandstone, limey, light gray, fine grain quartz, with shell, pellets and trace of phosphorite.
100 - 110	Sandstone, limey, light gray, fine grained quartz, abundant shell and some pellets.
110 - 120	As above, much less shell.
120 - 130	Sandstone, limey, greenish gray, fine quartz grains in micrite matrix; little shell and minor phosphorite content.
130 - 140	Sandstone, limey, greenish gray, medium quartz grains and abundant shell fragments; phosphoritic shell, some pellets.
140 - 160	Limestone, sandy, medium gray, hard medium rounded quartz grains in micrite matrix, quartz gray to clear; shell, some clay; trace phosphorite nodules.
160 - 180	Sand, unconsolidated to loosely consolidated, quartz grains rounded and up to ¼ inch diameter, gray to clear, some micrite, some large phosphorite nodules.

SFWMD Well No. C-2017D
Collier County
Latitude: 26°04'15"
Longitude: 81°39'23"
Sec. 36, T 50S, R 26E
Reference Datum:
Owner:
Drilled by: SFWMD
Cuttings Collected by: Driller
Cuttings Described by: Mike Knapp

DEPTH (FT.)	DESCRIPTION
0 - 6	Clayey sand, grayish orange, intergranular porosity (32%), mode fine, range very fine to medium, unconsolidated, 2% clay, 1% heavies.
6 - 20	Limestone, white, coarse grained, intergranular and intragranular porosity (16%), grain types skeletal, crystalline and biogenic; poorly indurated with micrite and spar cements; fossils include corals and mollusks.
20 - 90	Limestone, white, medium grained, intergranular and intragranular porosity (16%), grain types biogenic, micrite and crystalline; moderately indurated with micrite and spar cements; fossils include mollusks and corals.
90 - 120	Limestone, pale orange, micro-crystalline, intergranular porosity (12%), grain types micrite, crystalline and intraclast; moderately indurated with micrite and spar cement; accessory mineral is sand (12%) and fossils include bryozoans, mollusks and corals.
120 - 130	Dolomite, pale green, very fine grained, intergranular porosity (13%), moderately altered euhedral crystals; poorly indurated, spar and clay also as cements, accessories present are clay (12%), quartz (25%), and phosphorite (2%).
130 - 140	Sandstone, grayish green, medium grained, intergranular porosity (18%), poorly indurated with dolomite cement; accessories include dolomite (20%), clay (12%) and phosphorite (2%).
140 - 150	Sandstone, light gray, medium grained, intergranular and intragranular porosity (10%), well indurated with dolomite cement (35%).

SFWMD Well No. C-2017D (Continued)

DEPTH (FT.)	DESCRIPTION
150 - 190	Sand, light gray, coarse grained, intergranular porosity (32%), unconsolidated, with dolomite (65%) and micrite (5%) as accessories.
190 - 220	Clayey sand, grayish green, medium grained, intergranular porosity (18%) very poorly indurated with dolomite (20%) and clay (10%) cements; phosphorite (4%) present; frequent caving.
220 - 230	Clay, dusky green, intergranular porosity (13%), very poorly indurated with clay, dolomite, and spar cements; accessories include sand (12%), dolomite (12%) and phosphorite (4%).
230 - 240	Limestone, white, coarse grained, intergranular porosity (12%), grain types biogenic, crystalline, and intraclast; moderately indurated with micrite and spar cements; accessory sand (3%); fossils present corals, bryozoans, and mollusks.
240 - 290	Clayey sand, grayish green, intergranular porosity (14%), medium grained, poorly indurated with clay, dolomite, and spar cements; accessories include dolomite (30%), spar (9%), clay (12%), and phosphorite (12%).
290 - 340	Limestone, white, very fine grained, intergranular and moldic porosity (12%), grain types micrite crystal and intraclast; moderately indurated with dolomite, spar, and micrite cements; accessories include dolomite (20%), phosphorite (6%), and sand (8%). Fossils include mollusks corals and bryozoans.

A P P E N D I X II

GEOPHYSICAL LOGS

A P P E N D I X   III

PUMPING TEST DATA

APPENDIX III-1. Aquifer Test Data, Site A

A. Summary of Well Specifications

	PUMPED WELL C-2011D	OBSERVATION WELL A1	OBSERVATION WELL A2	OBSERVATION WELL A3	OBSERVATION WELL A4
DEPTH (FT.)	117	55	8	24	55
CASED TO (FT.)	19	50	5	20	50
CASING DIAMETER (IN.)	6	2	2	2	2
SCREENED INTERVAL (FT.)	(open hole)	50-55	5-8	20-24	50-55
SCREEN DIAMETER (IN.)	(5 5/8" open hole)	2	2	2	2
DISTANCE FROM PUMPED WELL (FT.)	-	41	148	150	152
DISCHARGE PIPE DIAMETER (IN.)	4	-	-	-	-
ORIFICE DIAMETER (IN.)	3	-	-	-	-

APPENDIX III-1. Aquifer Test Data, Site A (Continued)

B. Data From Pumped Well C-2011D

TIME	ELAPSED TIME (MIN.)	PUMPED WELL DRAWDOWN (FT.)	MANOMETER READINGS ELAPSED TIME	MANOMETER READINGS INCHES	DISCHARGE (GPM)
1015	-	-	1.8	>100	?
1029	-	-	2.7	90	382
	-	-	7	90	382
	8	3.6	-	-	-
	10	3.57	-	-	-
	13	3.49	-	-	-
	15	3.50	15	90	382
	23	3.59	-	-	-
	-	-	25	90	382
	26	3.65	-	-	-
	33	3.55	-	-	-
	-	-	35	90	382
	-	-	50	90	382
	-	-	73	90	382
	74	3.59	-	-	-
	-	-	75	89	380
	-	-	76	90	382
	108	3.62	-	-	-
	147	3.57	147	90	382
	192	3.51	192	90	382
	252	3.70	252	90	382
	301	3.66	301	90	382
	352	3.66	352	90	382
	402	3.65	402	90	382

APPENDIX III-1. Aquifer Test Data, Site A (Continued)

C. Drawdown Data From Observation Wells

WELL A1		WELL A2		WELL A3		WELL A4	
ELAPSED TIME (MIN.)	DRAW-DOWN (FT.)	ELAPSED TIME (MIN.)	DRAW-DOWN (FT.)	ELAPSED TIME (MIN.)	DRAW-DOWN (FT.)	ELAPSED TIME (MIN.)	DRAW-DOWN (FT.)
1.8	.78	19	.09	20	.50	20	.48
2.7	.81	27	.11	28	.52	28	.49
3.5	.83	36	.11	37	.54	38	.50
4.4	.85	40	.12	53	.54	54	.50
5.5	.86	52	.12	75	.53	75	.53
7	.87	75	.13	111	.54	76	.50
9	.88	110	.14	150	.55	111	.52
10	.90	150	.15	194	.55	151	.51
11	.91	191	.17	254	.45	195	.51
14	.92	194	.16	300	.56	255	.52
17	.92	254	.17	354	.56	300	.52
22	.93	303	.19	404	.56	354	.52
25	.94	354	.19			405	.53
30	.95	404	.19				
35	.95						
45	.95						
50	.95						
73	.95						
106	.96						
250	.96						
300	.96						
350	.96						
400	.97						

APPENDIX III-1. Aquifer Test Data, Site A (Continued)

D. Recovery Data From Observation Wells

WELL A1		WELL A2		WELL A3		WELL A4	
ELAPSED TIME (MIN.)	DRAW-DOWN (FT.)	ELAPSED TIME (MIN.)	DRAW-DOWN (FT.)	ELAPSED TIME (MIN.)	DRAW-DOWN (FT.)	ELAPSED TIME (MIN.)	DRAW-DOWN (FT.)
0.6	.38	4.5	.17	4.9	.17	5.3	.12
0.9	.31	6.1	.15	6.4	.14	6.7	.10
1.2	.29	12	.12	12	.09	12	.06
1.4	.26	35	.08	35	.04	35	.02
1.8	.23						
2.1	.21						
2.5	.20						
3.0	.17						
3.5	.17						
7.7	.09						
9	.09						
10	.09						
14	.05						
33	.05						

APPENDIX III-2. Aquifer Test Data, Site B

A. Summary of Well Specifications

	Pumped Well C-2012D	Observation Well B1
Depth (ft.)	130*	60
Cased To (ft.)	8	50
Casing Diameter (in.)	6	2
Open Hole Interval (ft.)	8-130	50-60
Open Hole Diameter (Nominal, in.)	5 5/8	2
Distance From Pumped Well (ft.)	-	40
Discharge Pipe Diameter (in.)	6	-
Orifice Diameter (in.)	4	-

*Hole collapsed below 130 feet. Original drilled depth was 220 feet.

APPENDIX III-2. Aquifer Test Data, Site B (Continued)

B. Data From Pumped Well C-2012D*

PUMPED WELL

TIME	ELAPSED TIME (MIN.)	DRAWDOWN (FT.)
0930	0.0	0.00
	0.2	0.28
	2.0	2.56
	5.8	4.79
	6.5	4.81
	7.5	4.81
	8.3	4.86
	10.2	4.91
	15	4.93
	19	4.89
	24	4.91
	30	4.88
	38	4.88
	46	5.08
	50	5.13
	61	5.09
	90	5.15
	135	5.11
	180	5.13
	225	5.12
	270	5.12
	300	5.13
	330	5.15
	420	5.10
	480	5.15
	510	5.16
	570	5.15
	630	5.15
	664	5.17
	721	5.20
	776	5.20
	870	5.10
	990	4.91
	1110	4.70
	1170	5.12
	1236	5.00

MANOMETER READINGS

ELAPSED TIME	INCHES	DISCHARGE GPM
0.0	0.00	
0.2	16.75	262
4.2	16.75	262
6.5	16.75	262
9.2	16.75	262
10.2	17.00	264
11	17.00	264
19	17.00	264
38	17.00	264
46	18.00	271
61	18.00	271
80	18.00	271
90	18.00	271
150	18.00	271
195	18.00	271
210	18.00	271
270	18.00	271
300	18.00	271
330	18.25	273
360	18.25	273
450	18.25	273
510	18.15	272
540	18.00	271
630	18.00	271
664	18.50	275
721	18.50	275
776	18.50	275
870	18.00	271
990	17.50	268
1100	17.75	270
1170	17.25	266
1236	16.50	261

*No recovery data available.

APPENDIX III-2. Aquifer Test Data, Site B (Continued)

C. Drawdown Data From Observation Well*

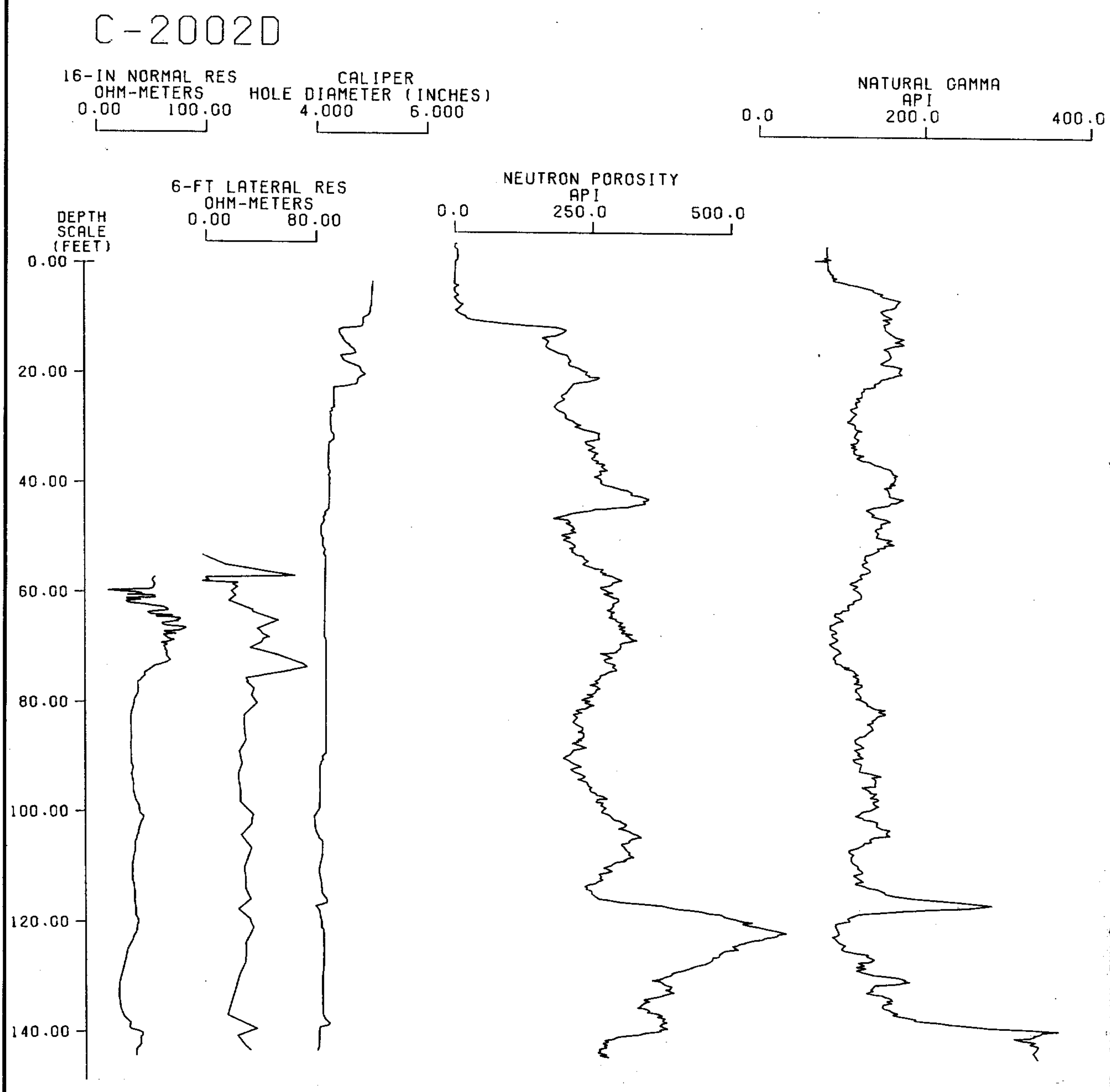
OBSERVATION WELL B1

ELAPSED TIME (MIN)	DRAWDOWN (FT.)
0.0	0.0
0.2	0.28
0.5	.10
1.1	.31
2.0	.59
2.3	.71
2.7	.75
3.0	.77
3.2	.77
4.0	.80
4.8	.82
5.8	.84
6.5	.84
7.5	.84
8.3	.85
9.2	.86
10.2	.87
12	.87
14	.85
15	.87
16	.88
18	.88
20	.90
21	.86
24	.87
26	.91
28	.89
30	.90
50	.93
61	.94
70	.94
80	.94
90	.94
105	.94
120	.94

OBSERVATION WELL B1

ELAPSED TIME (MIN)	DRAWDOWN (FT.)
150	.94
180	.95
225	.96
270	.96
300	.98
330	.98
360	.98
420	1.00
450	1.00
570	1.01
630	1.01
721	1.02
870	1.02
990	1.00
1100	.96
1170	1.02
1236	1.02

*No recovery data available.



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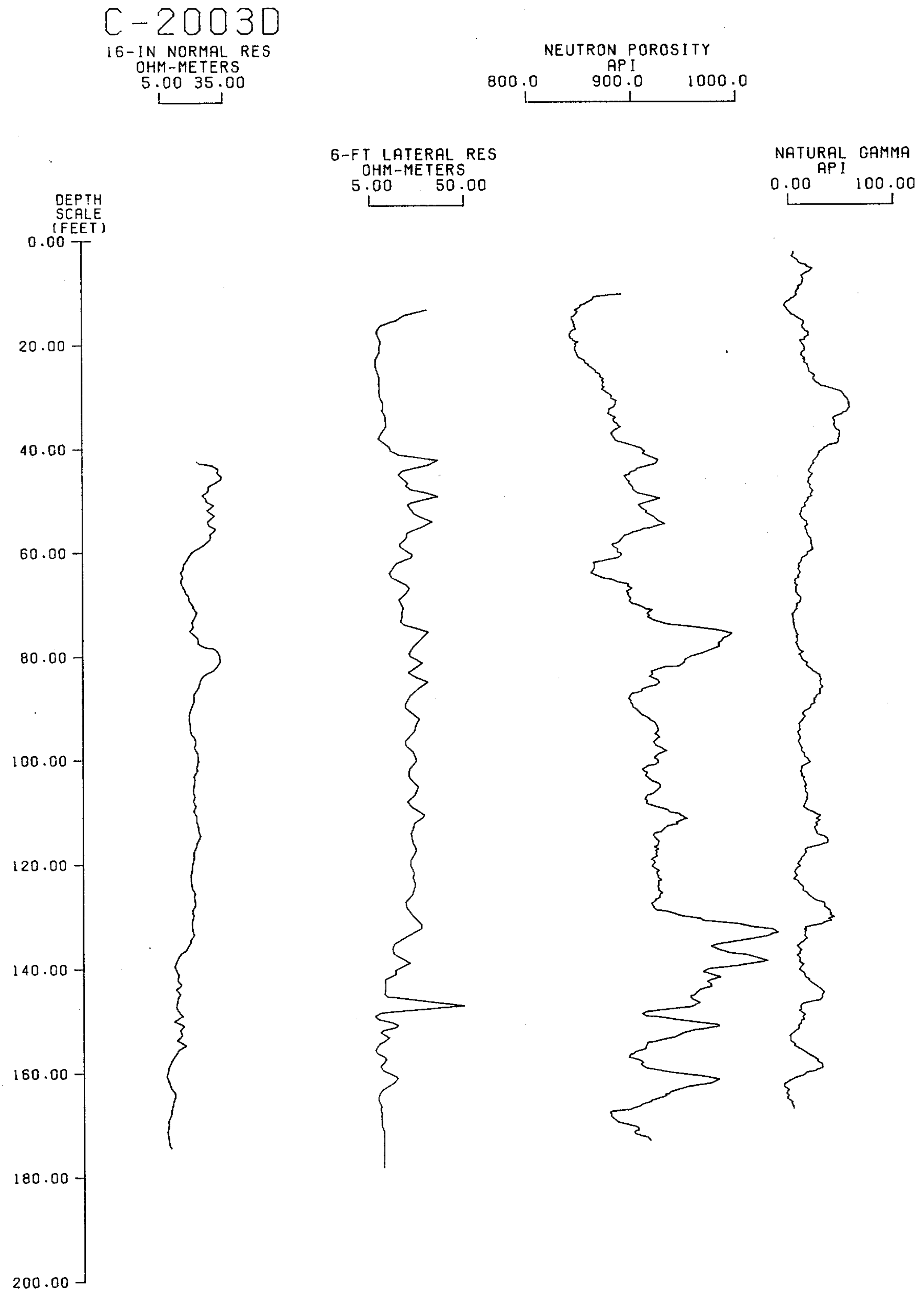

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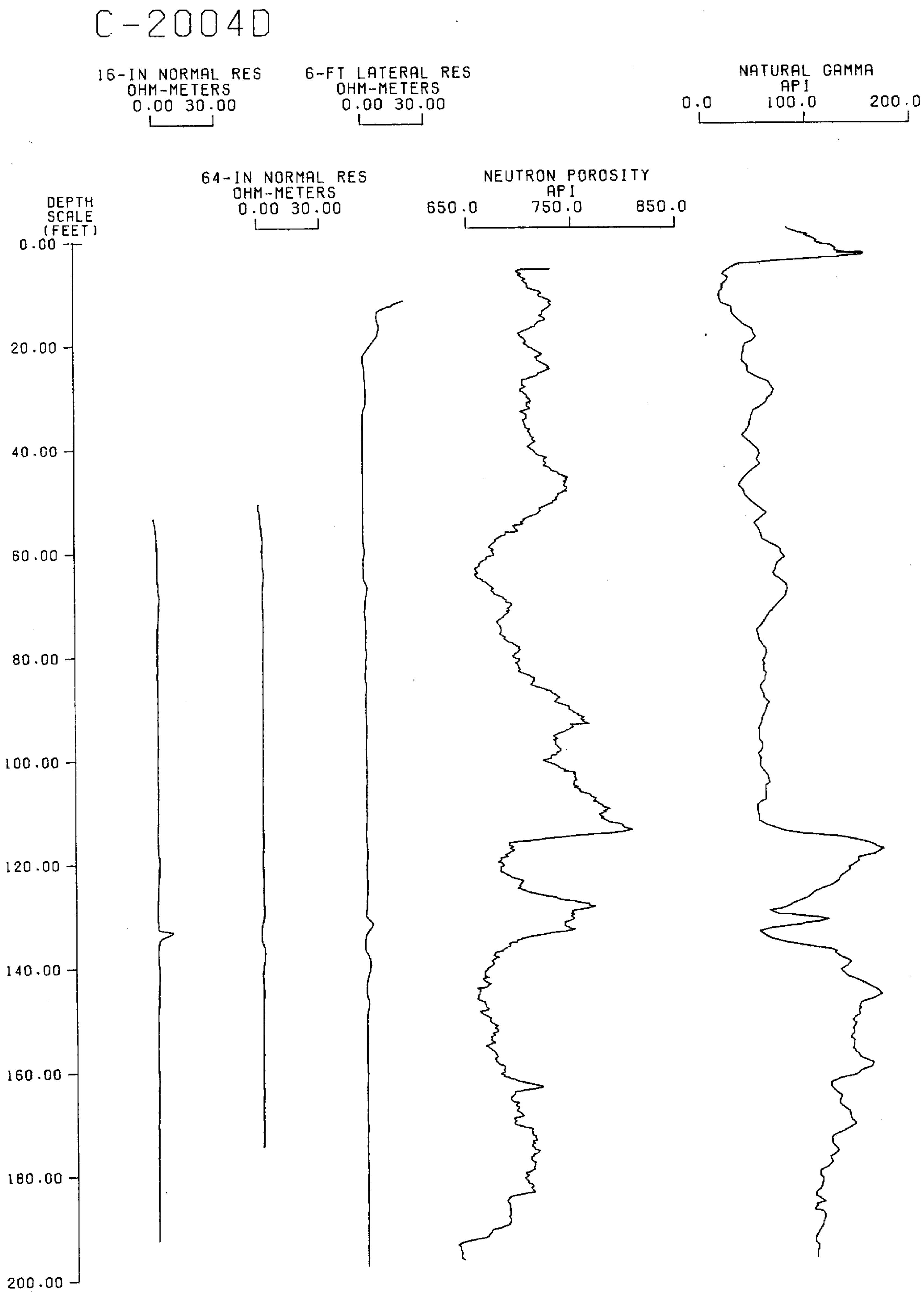

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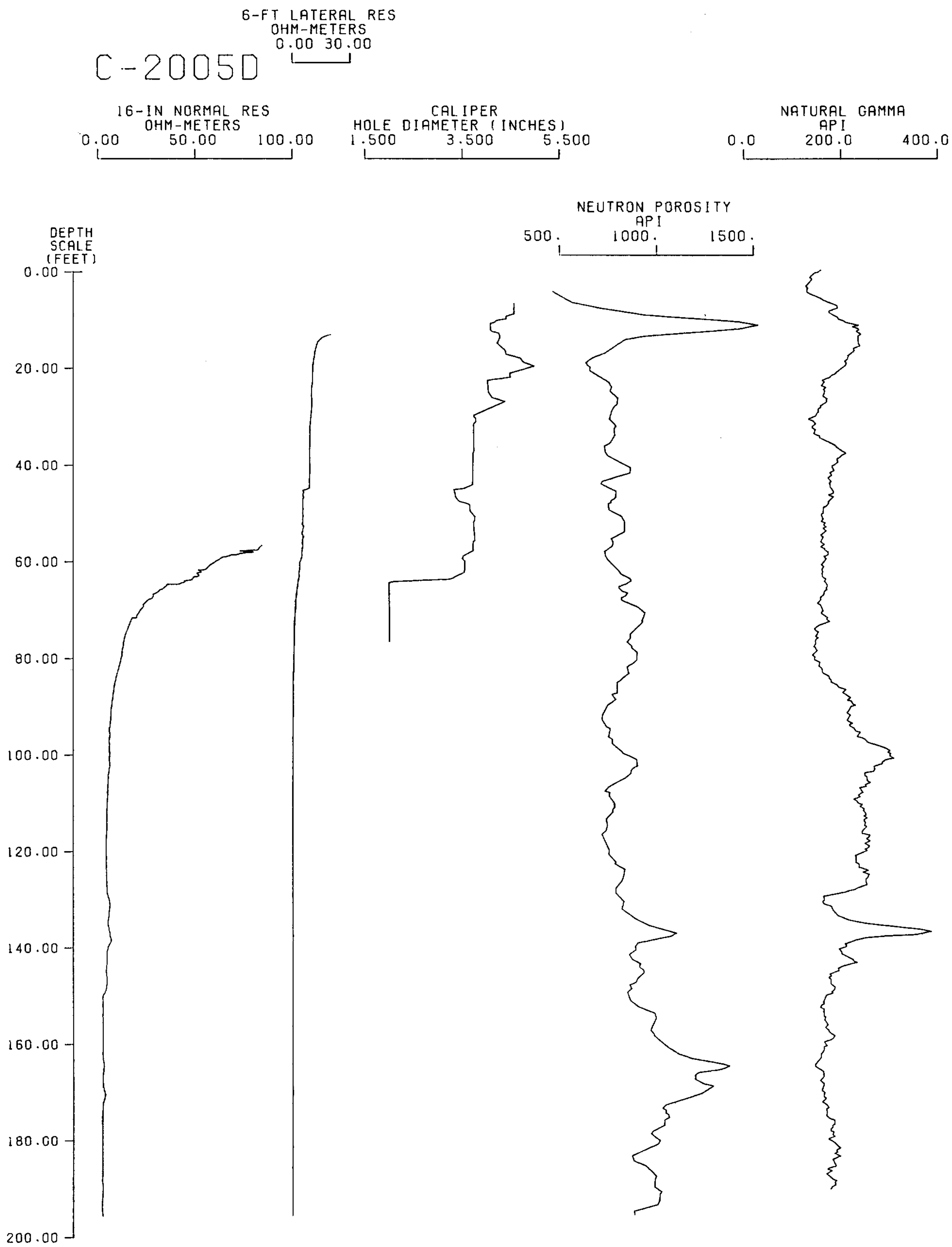
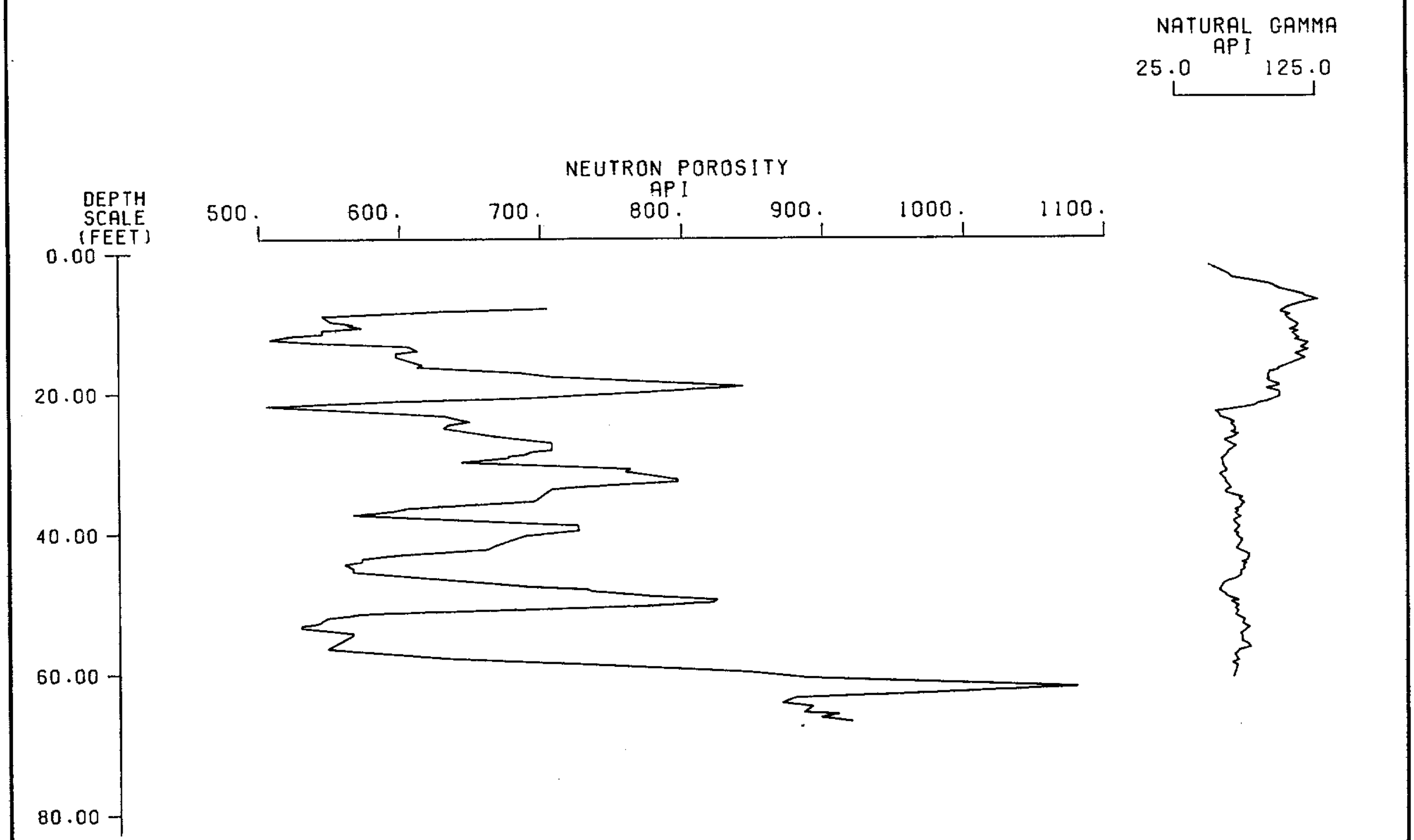


GEOPHYSICAL LOGS

C-2006D



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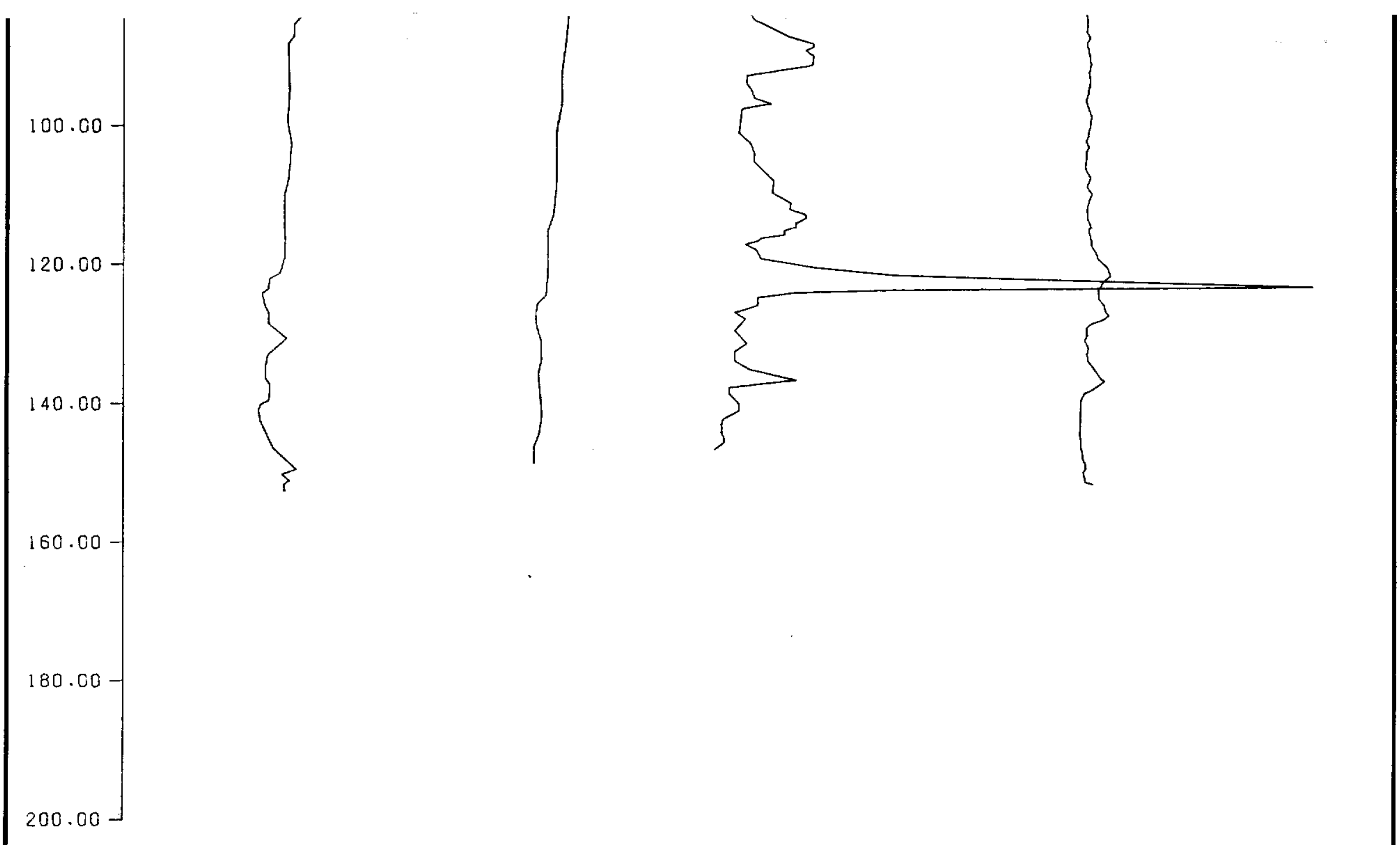

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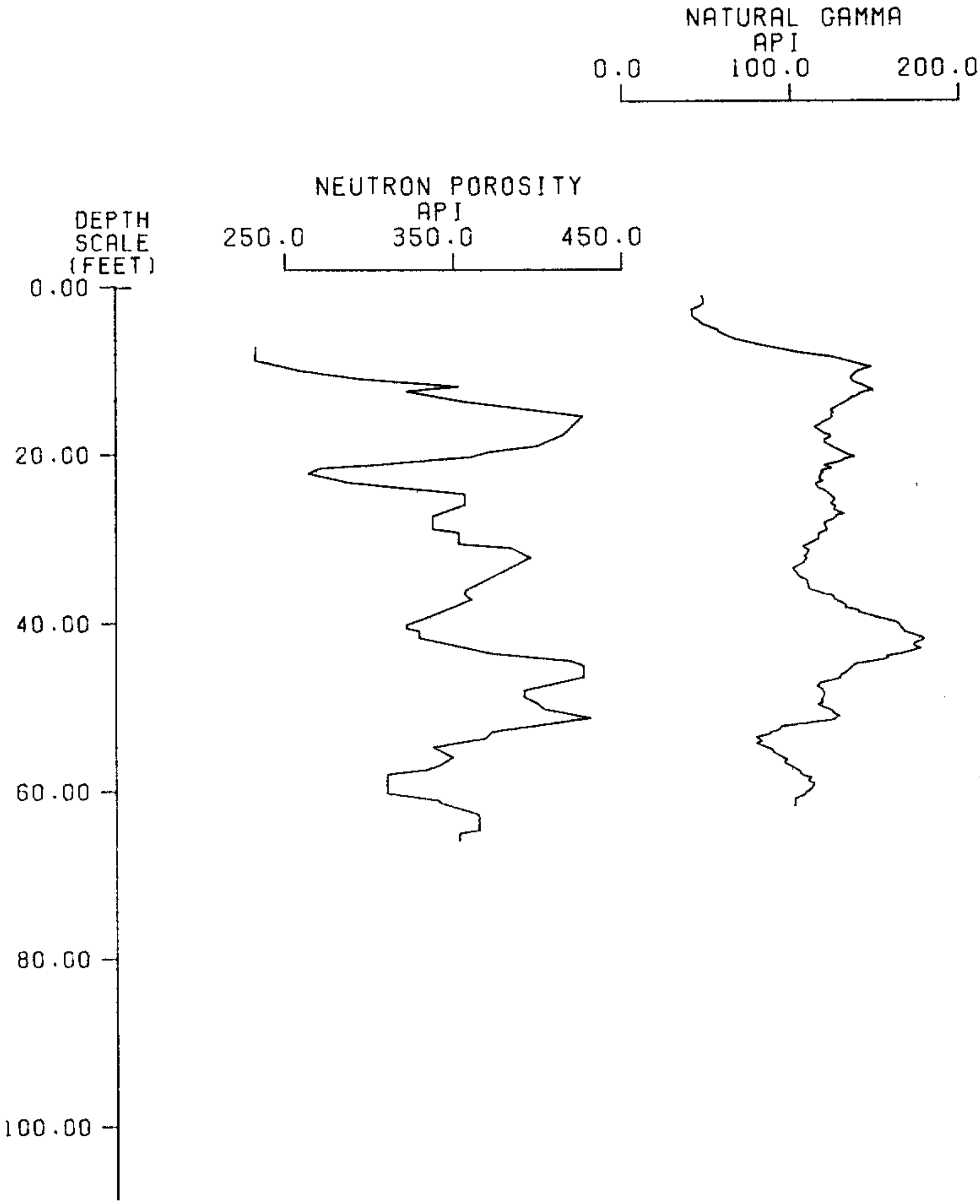
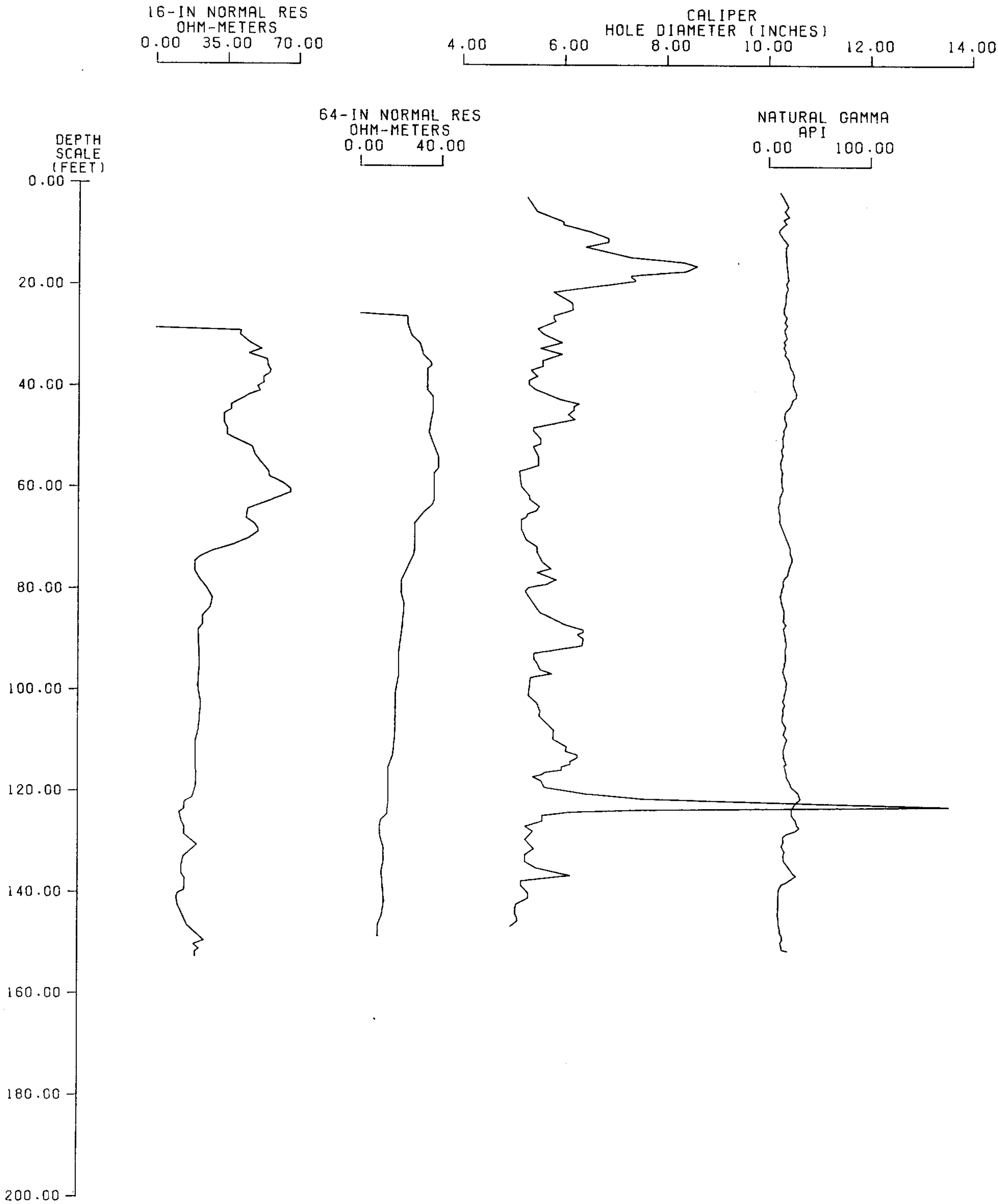
C-2007D



GEOPHYSICAL LOGS

C-2008D



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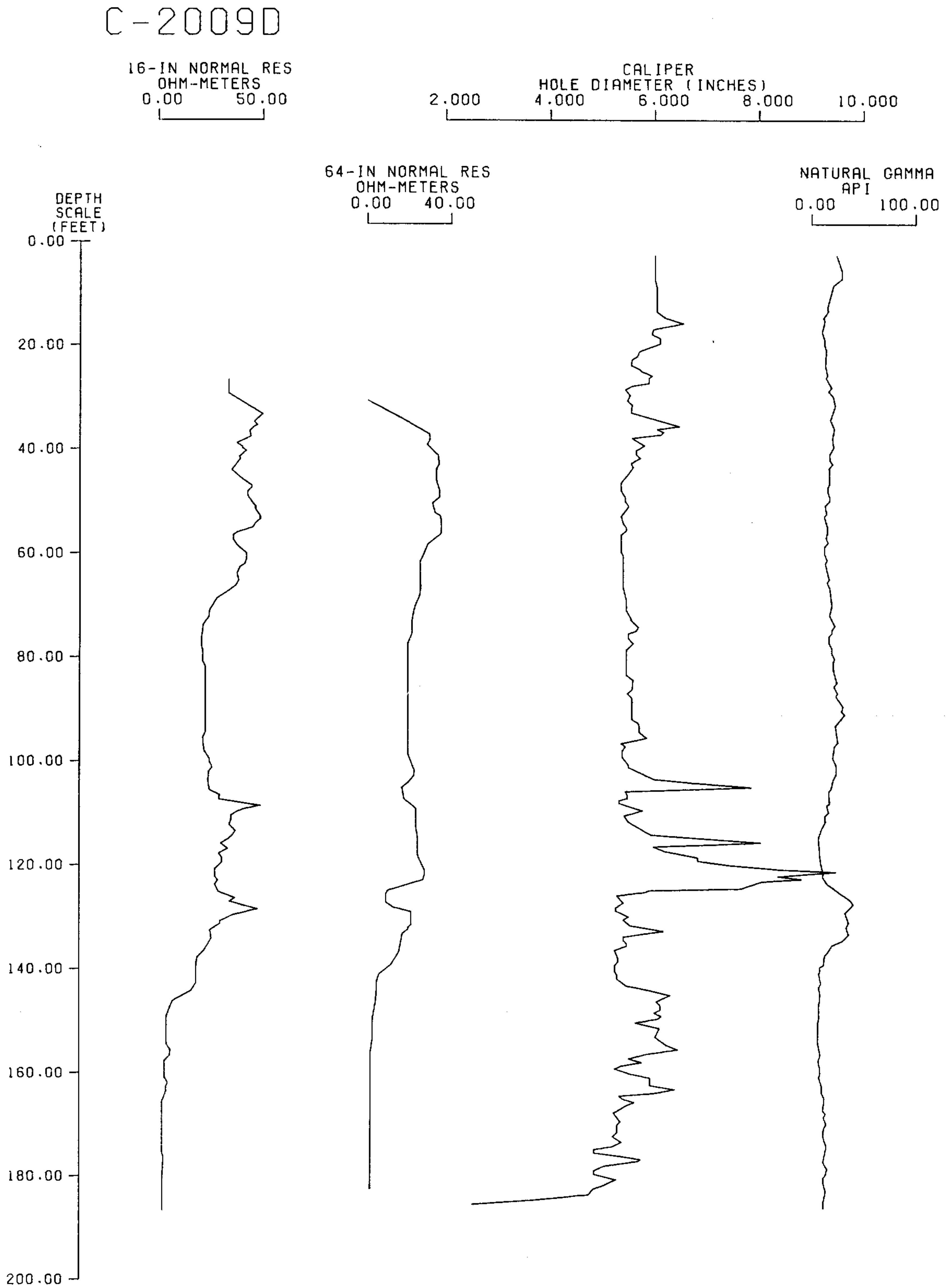

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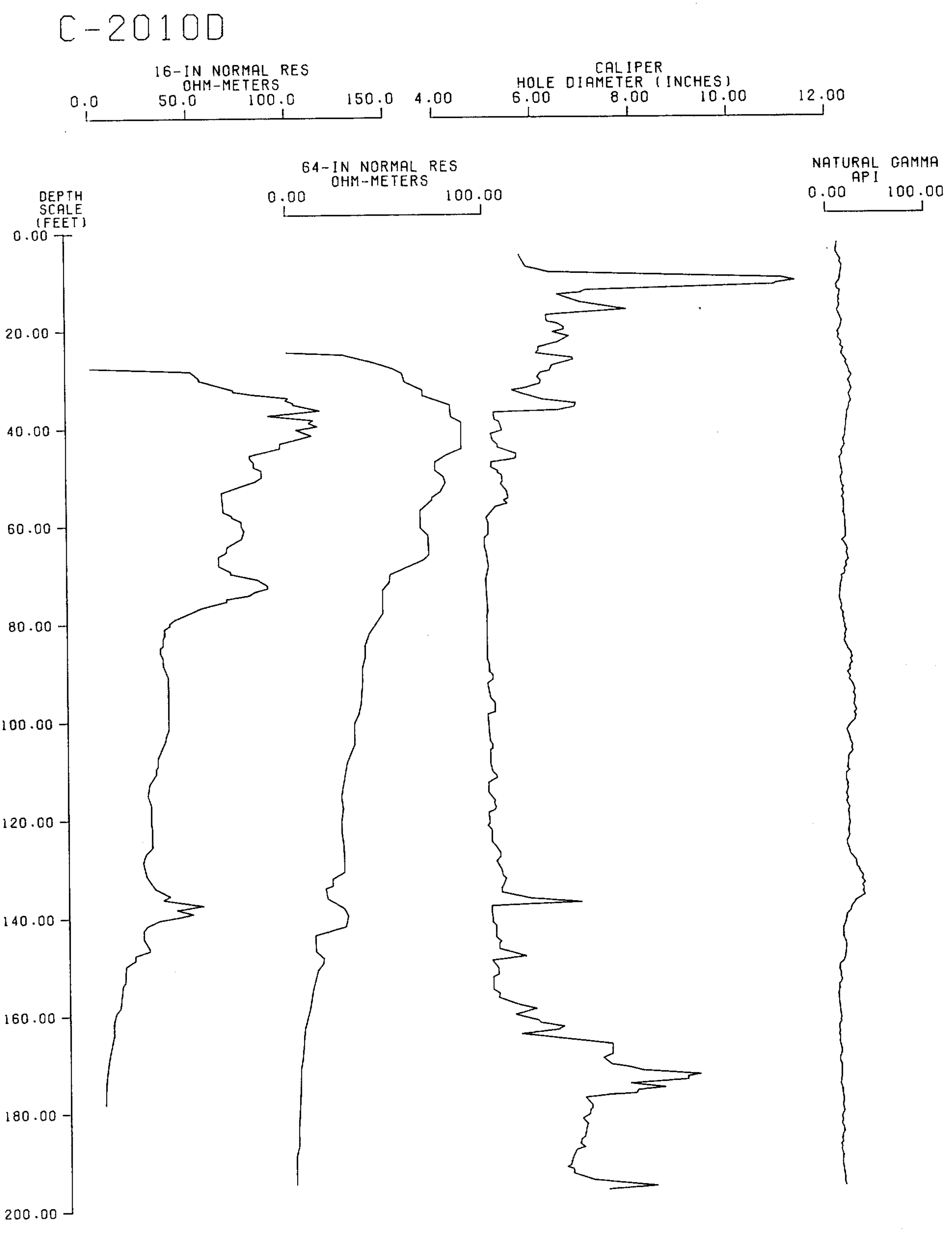

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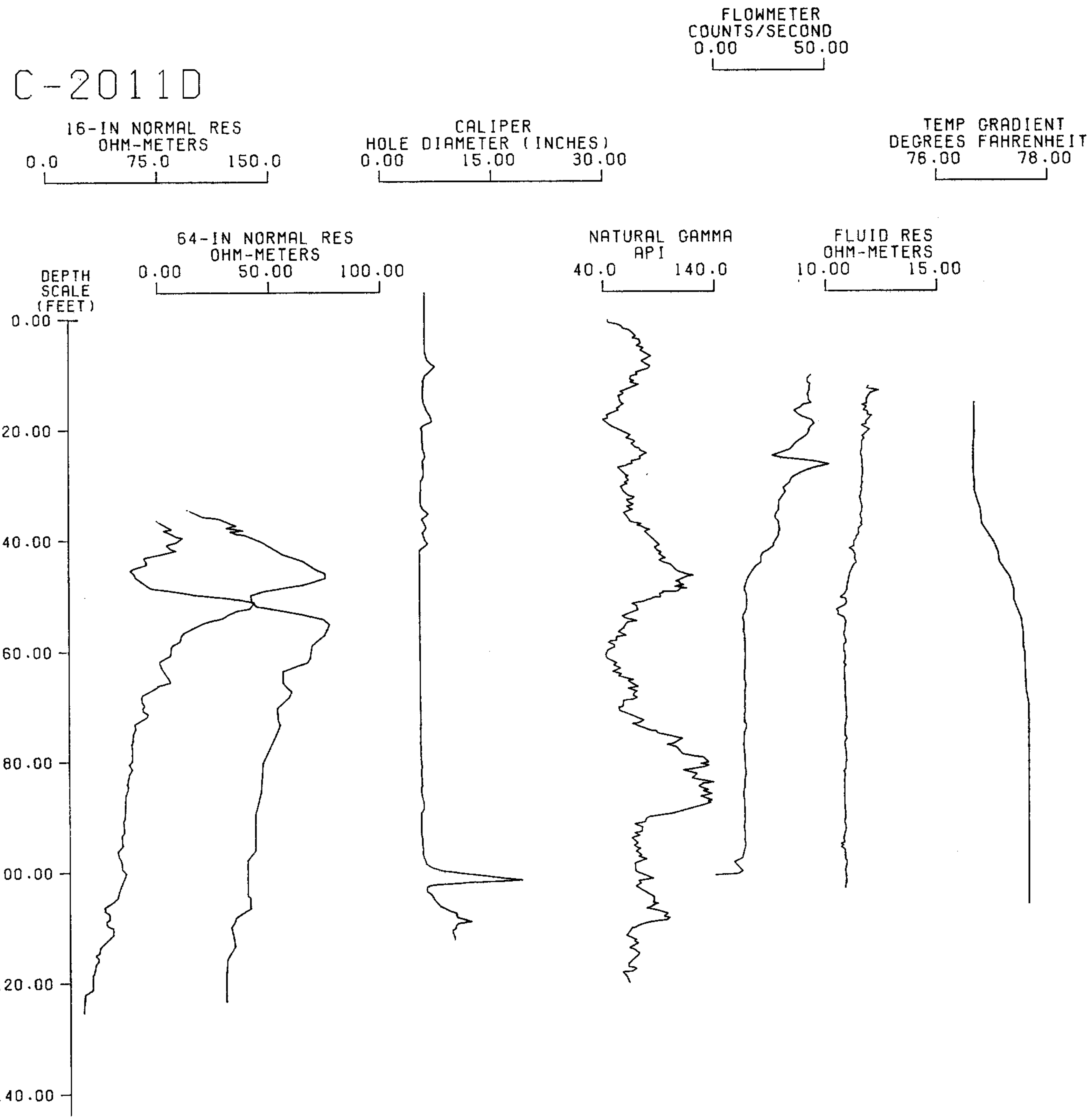

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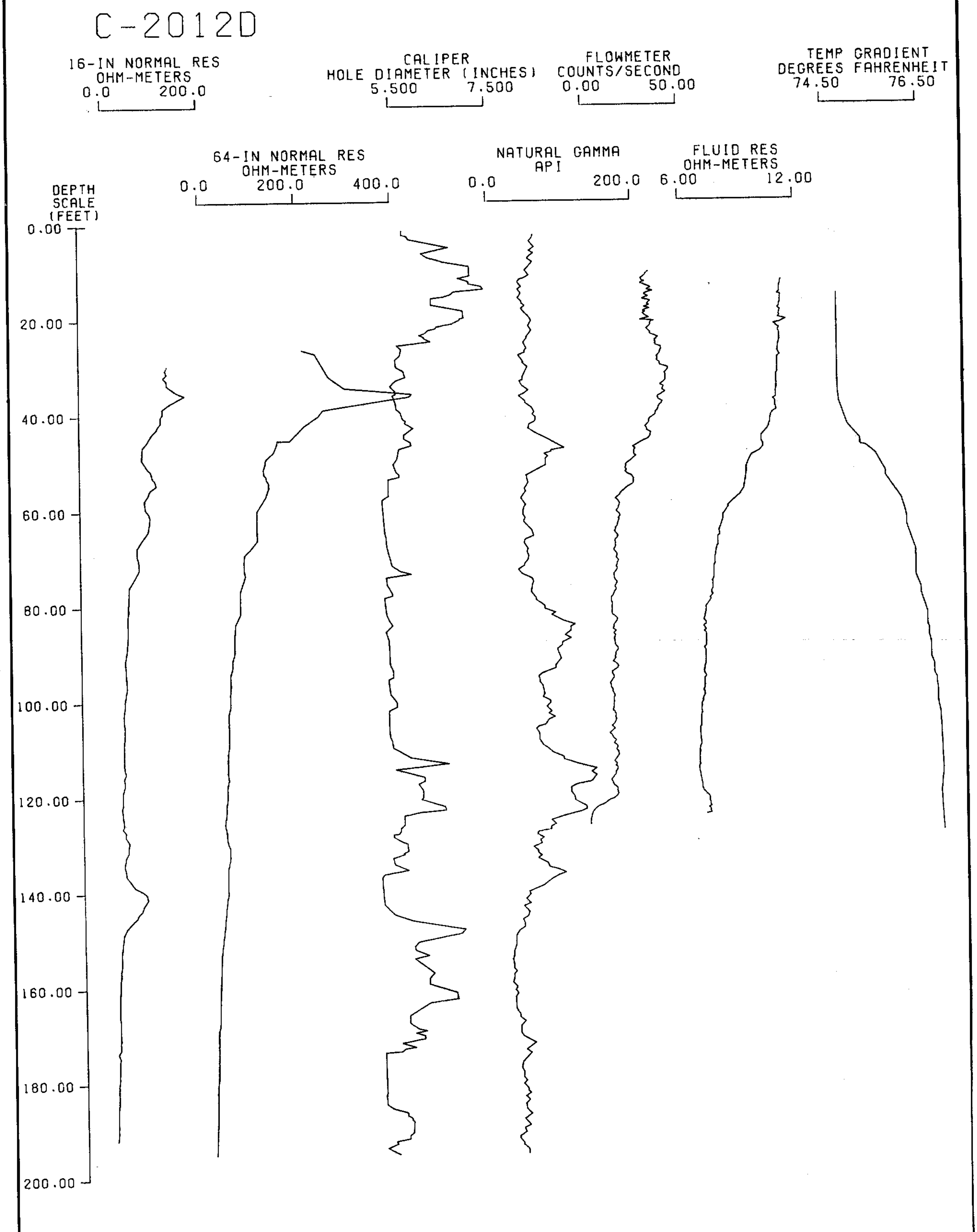

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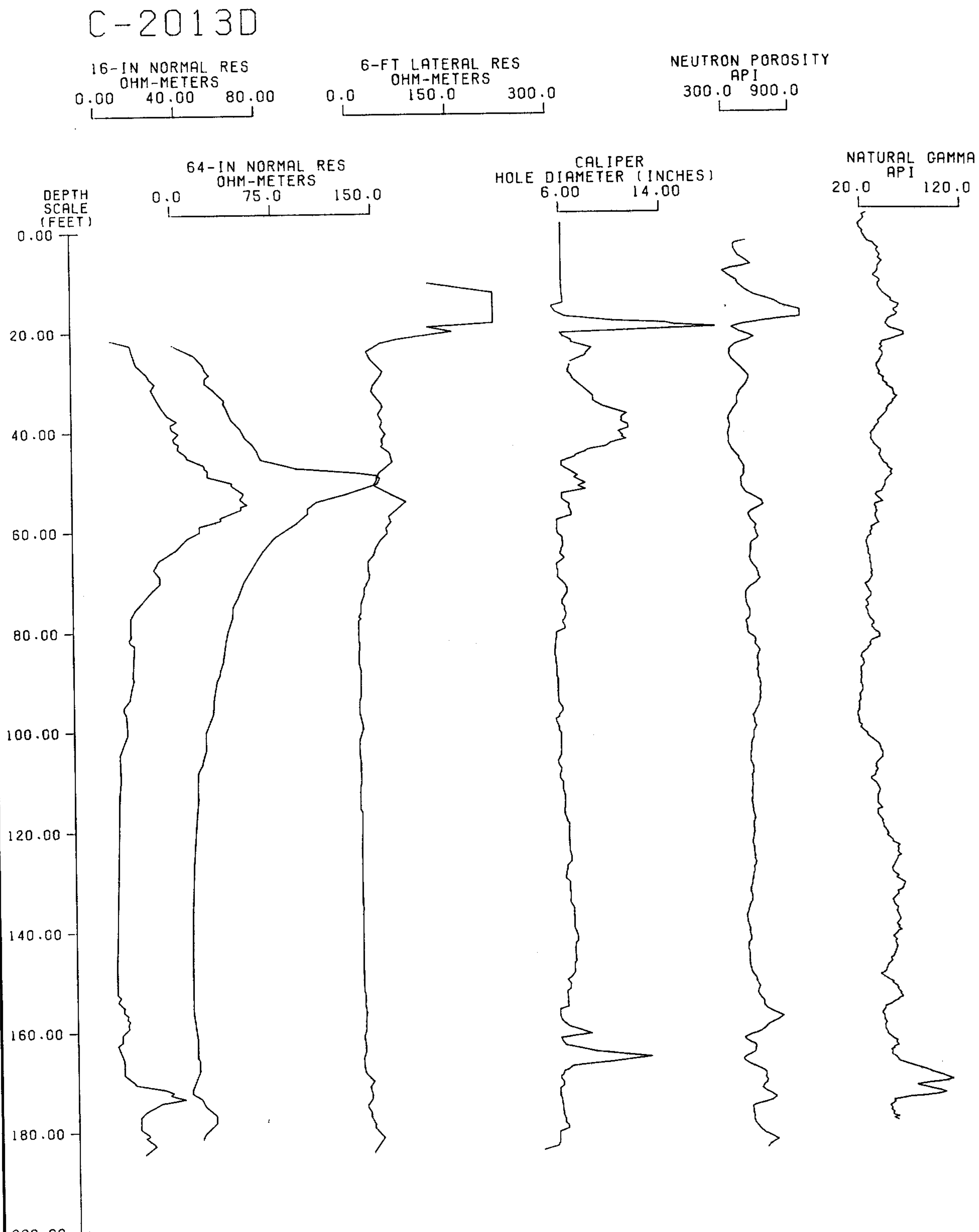

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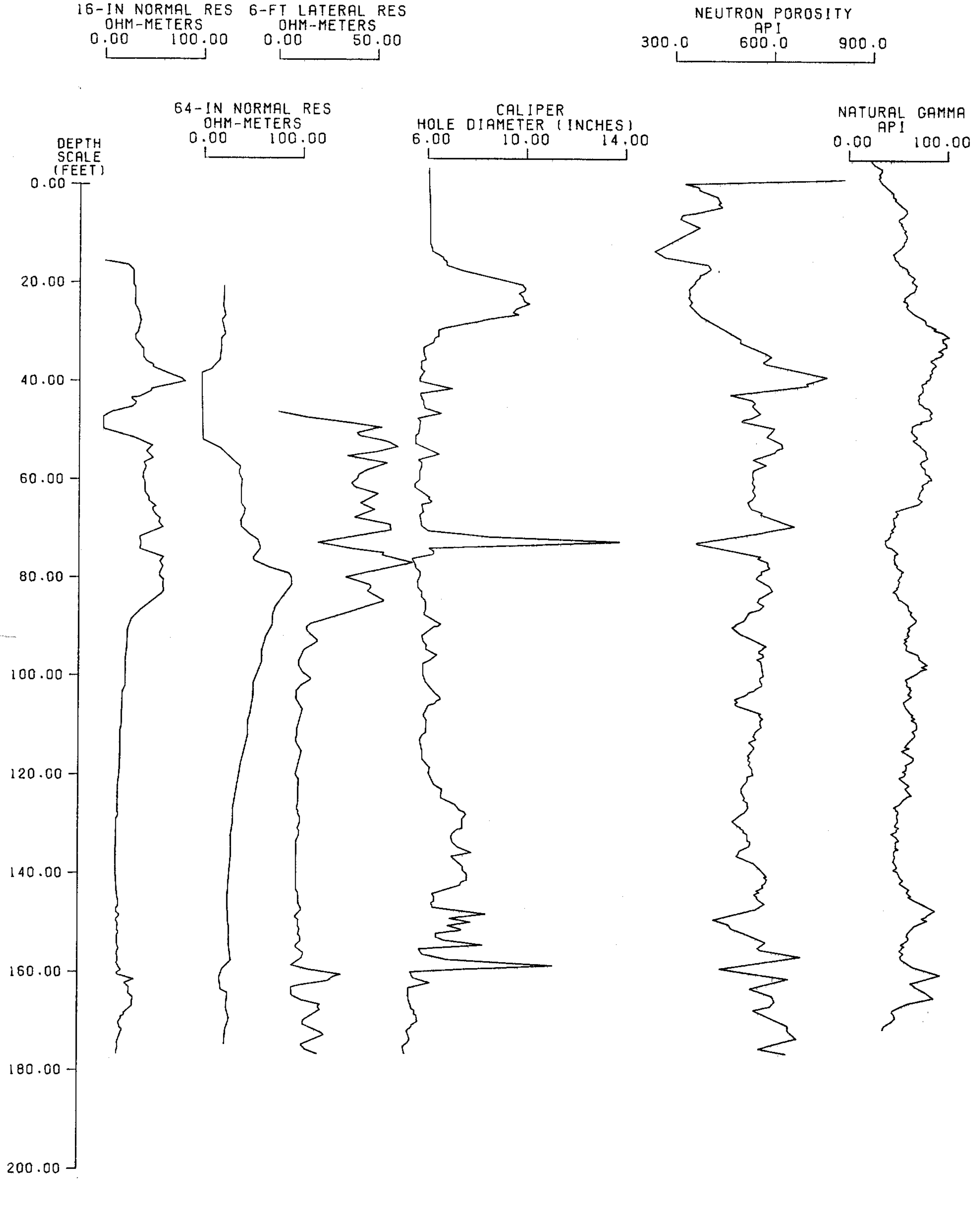
C-2014D



GEOPHYSICAL LOGS